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Electrophysiological correlates of implicit valenced self-processing in high vs. low self-esteem individuals

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We provide the first high-temporal resolution account of the self-esteem implicit association test (IAT; Greenwald & Farnham, 2000) to highlight important similarities and differences between the cognitive processes corresponding to implicit valenced self-processing in high vs. low self-esteem individuals. We divided individuals into high and low self-esteem groups based on the Rosenberg self-esteem scale (Rosenberg, 1965) and administered the self-esteem IAT while recording electroencephalographic data. We show that the P2 captured group (high vs. low self-esteem) differences, the N250 and the late parietal positivity (LPP) captured differences corresponding to category pairing (self/positive vs. self/negative pairing), and the N1, P2, and P300–400 components captured interactions between self-esteem groups and whether the self was paired with positive or negative categories in the IAT. Overall, both high and low self-esteem groups were sensitive to the distinction between positive and negative information in relation to the self (me/negative generally displayed larger event-related potential amplitudes than me/positive), but for high self-esteem individuals, this difference was generally larger, earlier, and most pronounced over left-hemisphere electrodes. These electrophysiological differences may reflect differences in attentional resources devoted to teasing apart these two oppositely valenced associations. High self-esteem individuals appear to devote more automatic (early) attentional resources to strengthen the distinction between positively or negatively valenced information in relation to the self.

Keywords: Self-esteem IAT; N1; P2; N250; P3/LPP complex.

Self-esteem is one of the oldest and most widely studied constructs in psychology (James, 1890; Marsh, Scalas, & Nagengast, 2010). High self-esteem has been associated with subjective well-being (Campbell, 1981; DeNeve & Cooper, 1998; Wilson, 1967), academic success (Liu, Kaplan, & Risser, 1992), and the ability to buffer negative feedback (Brown, 2010; Brown, Dutton, & Cook, 2001; Dutton & Brown, 1997; Fitch, 1970). A fruitful approach to studying self-esteem has been to use the implicit association test (IAT; Greenwald, McGhee, & Schwartz, 1998). The self-esteem IAT is a response time task that assesses the strength of association between self-representation categories and other categories that have a positive or negative valence. The task involves rapid categorization of a series of words that can be sorted according to whether they refer to self (or not), or whether they refer to the positively (or negatively) valenced categories. The critical manipulation is that the responses are paired, so that words that refer to self require the same response as words that refer to either negative or positive categories. Those with higher self-esteem are slower to categorize items when self is paired with negative words than when self is paired with positive words due to differences in the strength of associations between items of positive and negative valence in relation to the self (i.e., the self-esteem IAT effect; Greenwald & Farnham, 2000).

Behavioral studies using the IAT have provided important insight into the cognitive processes involved in high and low self-esteem individuals.

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For example, Brown and Brown (2011) used the Rosenberg self-esteem scale (RSES) (Rosenberg, 1965) to divide individuals into high and low self-esteem. They then showed that self-evaluative reflection enhanced the self-esteem IAT effect for high self-esteem individuals, but reduced the IAT effect for low self-esteem individuals. These behavioral observations suggest that self-evaluative reflection produces different effects in high and low self-esteem individuals, possibly leading to more positive feelings about the self in high, but more negative feelings about the self in low self-esteem individuals. Our goal in this study was to examine event-related potential (ERP) components as neural correlates of the self-esteem IAT effect that might help to interpret the behavioral responses and reveal the time course of brain processes that distinguish between high and low self-esteem groups on the self-esteem IAT.

Only a small number of studies have examined the electrophysiological correlates of high vs. low self-esteem individuals. Although none of these have directly looked at the strength of associations between items of positive or negative valence in relation to the self, as is examined in the self-esteem IAT, they have identified potentially relevant temporal components.

The P2 is a positive deflection occurring approximately 200 ms after stimulus onset; P2 amplitude differences are associated with negative emotionality (Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Mercado, Carretié, Tapia, & Gómez-Jarabo, 2006) and intensity of perceptual processing during attention (Yang, Guan, Dedovic, Qi, & Zhang, 2012). Recent work has associated the P2 with processes relevant to high vs. low self-esteem (Li, Zeigler-Hill, Luo, Yang, & Zhang, 2012; Yang, Dedovic, & Zhang, 2010; Yang, Guan, et al., 2012; Yang, Zhao, Zhang, & Pruessner, 2012), but the direction of these effects remains controversial. For instance, compared to high self-esteem, the amplitude of the P2 was larger for low self-esteem individuals while doing math (Yang, Zhao, et al., 2012), but smaller for low self-esteem individuals making decisions in a blackjack task (Yang et al., 2010). This discrepancy might be explained by the observation that the tasks differ with respect to evaluations of self-competency. In the math task, participants were required to indicate whether or not the product of two numbers was less than or greater than 10. Performance was highly dependent on individual competency in math, possibly leading to a reflection of the self. In contrast, the blackjack task involved making decisions based on randomly dealt cards, emphasizing the contribution of chance, and possibly minimizing focus on self-evaluative processes. If the P2 does provide a measure of self-esteem processing differences related to self-evaluation, then this component may be diagnostic in revealing processing differences between high and low self-esteem groups performing the self-esteem IAT, as this test directly assesses associations of positive and negative valence in relation to the self.

The anterior N1 and the N250 ERP components may also be relevant indices of processes that differ across level of self-esteem. Larger (i.e., more negative) N250 amplitudes are associated with more personal familiarity (Fan et al., 2011; Zhao, Wu, Zimmer, & Fu, 2011; Zhao et al., 2009). For example, the amplitude of the N250 is larger for an individual's own name than for another familiar or unfamiliar name (Zhao et al., 2011). Similarly, the N250 is larger for an individual's own flag vs. a familiar or unfamiliar flag (Fan et al., 2011). This same study showed early anterior N1 latency differences related to self-referential processing; longer latencies reflected enhanced attention allocation to personally familiar items (Fan et al., 2011). Given the sensitivity of the N1 and N250 components to self-relevant stimuli, they may be informative in identifying processes relevant to self-esteem.

It may also be useful to examine components sensitive to emotional stimuli. The self-esteem IAT requires categorization of words that have positive or negative valence, and the response to these emotional words may be enhanced by pairing these words with the self-relevant category. The P3/late parietal positivity (LPP) complex is sensitive to emotional stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000); larger responses are also often observed for negative compared to neutral and positive stimuli (Hajcak, Dunning, & Foti, 2009; Hajcak, Moser, & Simons, 2006; Hajcak & Nieuwenhuis, 2006; Zilber, Goldstein, & Mikulincer, 2007). Although both the P3 and LPP components are sensitive to emotional valence and arousal, a key distinction between the two components is their temporal course; the P3 is earlier and reflects a more automatic increase in attention allocation, whereas the LPP reflects more controlled cognitive processes (Hajcak et al., 2009). It is possible that the P3/LPP complex will reveal differences in the way in which high and low self-esteem individuals respond to the emotional valence of the categorization.

The studies mentioned above provide insight into the cognitive processes that might be expected during self-evaluation for high vs. low self-esteem individuals, but none have examined this directly. Following Brown and Brown (2011), we used the RSES to classify participants as high or low self-esteem and administered the self-esteem IAT.

Importantly, we also recorded electrophysiological activity to look at the time course of processing that might reveal differences between the groups. We focused our analyses on four ERP components based on the components sensitive to self-reference and emotion outlined above: N1, P2, N250, and P3/LPP complex. To identify any additional relevant components, we used an unbiased whole-brain statistical approach called partial least squares (PLS; Lobaugh, West, & Mcintosh, 2001; McIntosh, Bookstein, Haxby, & Grady, 1996), which provides an estimate for which ERP components (temporal and spatial) are correlated with the experimental conditions.

METHODS

Participants

Thirty undergraduate participants (mean age = 19 years old, all female)[1] from McMaster University completed the experiment for course credit. All procedures complied with the Tri-Council Policy and were approved by the McMaster Research Ethics Board.

Materials and apparatus

Participants were seated in a dimly lit room; a chin rest maintained a 90-cm distance from the 19-inch color cathode ray tube display (resolution of 1600 × 1200, frame refresh rate = 75 Hz). A Pentium 4 computer running Windows XP operating system and Presentation experimental software (Version 15.0, www.neuro-bs.com) was used to present stimuli and record responses. Stimuli were presented on a black background; text stimuli were presented in 20-point Helvetica font, with a vertical visual angle of 0.45° (horizontal visual angle varied with the length of the word). Category labels for the IAT were presented in the upper left and right (counterbalanced) sides of the screen, 2.86° horizontally and 1.43° vertically from the center of the screen, while the stimulus words to be categorized were presented in the center of the screen.

Target words for the self-esteem IAT

Thirteen positive (e.g., worthy and competent) and thirteen negative (e.g., inferior and inadequate) self-relevant target words were chosen based on the finding that using self-relevant words in the self-esteem IAT leads to positive correlations with explicit self-esteem (Oakes, Brown, & Cai, 2008). The *Me* target words consisted of demographic information produced by the participants at the beginning of the experiment (e.g., first name, last name, ethnicity, and hometown). The *Not Me* target words consisted of demographic information that did not describe the participants. Participants reviewed this list prior to the experiment and removed any *Not Me* items that were demographically related to themselves. We used the first 13 noneliminated words from the resulting list.

The implicit association test (IAT)

The self-esteem IAT consisted of five blocks; there were three practice blocks with 52 trials each and two experimental blocks with 104 trials each. The category labels (e.g., *Me/Not Me* or *Positive/Negative*) remained on the screen for the duration of the block. On each trial, a stimulus word was presented in the center of the screen; the task was to categorize the word by pressing a left or right key to indicate membership in the categories indicated on the left vs. right side of the screen. Stimulus words remained on the screen until response and the intertrial interval was varied between 500–900 ms. To facilitate categorization and to avoid any possible ambiguity (see Nosek, Greenwald, & Banaji, 2007), the stimulus words and the corresponding category labels were presented in white or green on a black background. For example, the *Me/Not Me* category labels and their corresponding demographic words were presented in green, and the *Positive/Negative* category labels and their corresponding attribute words were presented in white (counterbalanced across participants).

Blocks 1 and 2 were practice blocks that presented either a demographic (*Me/Not Me*) or attribute (*Positive/Negative*) category set. In one practice block, *Me* words required a left (or right) key response and *Not Me* words required a right (or left) key response (key assignment counterbalanced across participants), and in the other practice block, *Positive*

[1]Only female participants were used in the present study due to accessibility, but there is reason to believe that the findings presented herein generalize to male participants as well. Despite popular belief, there is very little difference in self-esteem between males and females (Hyde, 2014, 2005; Kling, Hyde, Showers, & Buswell, 1999). For example, large meta-analyses have shown small (d = 0.21, Kling et al., 1999, Analysis 1) or negligible (d = 0.04–0.16, Kling et al., 1999, Analysis 2; d = 0.14, Major, Barr, Zubek, & Babey, 1999) differences between the two genders. A recent Annual Review of Psychology article (Hyde, 2014) concluded that amongst several meta-analyses, the self-esteem literature supports the gender similarities hypothesis (Hyde, 2005).

words required a left (or right) key response and *Negative* words required a right (or left) key response (key assignment counterbalanced across participants).

In the third and fifth blocks, the categories from the target and attribute sets were paired so that left and right responses corresponded with one category from the target set and one category from the attribute set (counterbalanced across blocks 3 and 5). For example, in one block, *Me* and *Positive* words required a left key response while *Not Me* and *Negative* words required a right key response (key assignment counterbalanced across participants). In the other block, *Me* and *Negative* words required a left key response while *Not Me* and *Positive* words required a right key response (key assignment counterbalanced across participants). These paired-category blocks are the critical blocks, from which accuracy, reaction time (RT), and electrophysiological data were collected. The self-esteem IAT effect was measured as the difference in average response times between critical blocks 3 and 5.

Note that the fifth block reverses the pairing presented in the third block. For example, participants who encountered *Me* paired with *Positive* in block 3 encountered *Me* paired with *Negative* in block 5. To practice the new response mapping for the reversed category set (counterbalanced), practice block 4 presented that category set alone (similar to practice blocks 1 and 2) with the new left/right stimulus/response mapping.

Procedure

After signing consent, participants completed the RSES and provided demographic information to be used in the self-esteem IAT. We emphasized anonymity of responses beyond that of typical studies, because we have recently shown that this is a strong moderator for an improved relationship between implicit and explicit self-esteem (Grundy & Shedden, 2014). The self-esteem IAT was then administered, during which electroencephalographic (EEG) data were recorded.

Participants were categorized as having high or low self-esteem based on the RSES. The median score (20) on this scale was used as the partition, whereby those who scored in the top 50% of the scores were classified as having high self-esteem, and those who scored in the bottom 50% of the scores were classified as having low self-esteem. This led to mean scores of 15.9 (standard deviation: 2.6) for the low self-esteem group (N = 15) and 26.3 (standard deviation: 3.2) for the high self-esteem group (N = 15). The mean scores that resulted from our median split are similar to the mean scores for the high and low self-esteem groups reported in previous studies (Brown, 2010; Brown & Brown, 2011; Brown & Dutton, 1995; Brown et al., 2001).

Electroencephalography

The ActiveTwo Biosemi system (Amsterdam, Netherlands; www.biosemi.com) was used to record continuous EEG activity from 128 Ag/AgCl scalp electrodes plus four additional electrodes placed at the outer canthi and just below each eye for recording of horizontal and vertical eye movements. Two additional electrodes, common mode sense active electrode and driven right leg passive electrode, replace the “ground” electrodes used in conventional systems (www.biosemi.com/faq/cms&drl.htm). The continuous signal was acquired with an open passband from DC to 150 Hz and digitized at 512 Hz. The signal was band-pass filtered off-line at 0.3–30 Hz and rereferenced to left and right mastoids. Off-line signal processing and averaging were done using EEProbe (Enschede, Netherlands; www.ant-neuro.com). Eye blinks and movement artifacts were automatically identified and manually verified. All eye blinks and movement artifacts were removed from the analyses.

Partial least square analysis

Because of the vast number of possible ERP locations and components across time and space, we employed a whole-brain data-driven statistical approach called PLS analysis (Lobaugh et al., 2001; McIntosh et al., 1996) to reduce the search space. PLS uses singular value decomposition to extract information from the data set, similar to a principle components analysis (PCA); however, the analysis is constrained to variance explained by experimental conditions. An estimate of obtaining a singular value by chance (similar to a p-value) was computed from 1000 permutations. A set of latent variables (LVs; similar to eigenvalues in PCA) were produced, which represent particular contrasts that account for cross-block covariance in amplitudes explained by the experimental conditions. Each singular value explains how much of the covariance was explained by a particular LV. The reliability (standard error) of electrode saliences at each time point was assessed by performing 200 bootstrap resamplings (with replacement). The ratio of the salience to the standard error is approximately equal to a z-score; data points where the ratio was more than 1.7

($p < .05$) were considered reliable. Düzel et al. (2003) provide an example of applying PLS to EEG data.

We performed two separate PLS analyses. A PLS analysis of amplitudes was employed to assess the most reliable differences in ERP amplitudes, constrained to the experimental conditions (me/positive vs. me/negative) and groups (high vs. low). The electrode saliences (represented in Figure 2) represent the relation between the experimental design contrasts (as represented by the LV) and the spatiotemporal pattern of ERP amplitude changes. A second PLS analysis of amplitudes and behavior was performed to assess which ERP components were related to the behavioral RT differences between groups and conditions. The electrode saliences (represented in Figure 3) represent the most reliable spatiotemporal points relating amplitude changes to corresponding behavioral RTs.

Electrode clusters and componential analyses

Componential analyses were performed on electrode clusters that represent regions of interest consistent with the PLS salience maps and visual inspection of the grand averages. The PLS analysis of amplitudes identified time points of interest between 190–900 ms at a left parietal cluster of electrodes (PO7) (see below and Figure 2). The PLS analysis of amplitudes and behavior identified left parietal (PO7), left central (C1), as well as mid-line parietal (Pz), and mid-line central (Cz) electrode sites as being most reliable in predicting behavioral responses between 200 and 400 ms after stimulus onset (see below and Figure 3). Subsequent componential analyses were based on these analyses; we selected a cluster of electrodes in the left-hemisphere (PO7), an analog cluster in the right-hemisphere (PO8) to assess laterality effects, and a mid-line cluster (Pz). Mean amplitudes were extracted from time windows 300–400 ms, 400–600 ms, and 600–900 ms after stimulus onset to examine the P3/LPP complex. Peak amplitudes were used to examine P2 and N250 as these provided more stable measures than mean amplitudes, possibly due to the temporal proximity of these two components. The P2 amplitude at 200 ms was measured as the maximum peak between 150 and 250 ms after stimulus onset. The N250 amplitude at 250 ms was measured as the minimum peak between 225 and 275 ms after stimulus onset. Each of these components was examined separately by a 3 (location: left, mid-line, and right) × 2 (group: high self-esteem vs. low self-esteem) × 2 (category pairing: me/negative vs. me/positive) mixed-measures ANOVA.

Although our PLS analysis did not identify amplitude differences at the N1, the latency of the N1 was of interest due to sensitivity to self-esteem reported by Fan et al. (2011). N1 latency was examined using a 2 (group: high self-esteem vs. low self-esteem) × 2 (category pairing: me/negative vs. me/positive) mixed-measures ANOVA on latency to peak amplitude between 50 and 150 ms. We used a cluster corresponding to AF4, FZ, AFZ, FPZ, and AF3 from the extended 10/20 system for this purpose.

RESULTS

Behavioral results

A positive relationship between the self-esteem IAT and the RSES (Pearson $r = 0.42$, $p = .011$) supported the division of participants into high and low self-esteem groups for further analyses.

Following previous IAT studies (e.g., Kawakami, Steele, Cifa, Phills, & Dovidio, 2008), all RTs that were above 2000 ms or below 300 ms were classified as outliers and were removed from further analyses (this accounted for less than 7% of the data). A 2 (group: high self-esteem vs. low self-esteem) by 2 (category pairing: me/positive vs. me/negative) mixed-measures ANOVA was conducted and revealed a significant effect of category pairing, such that participants were faster at responding to words in the me/positive than in the me/negative category pairing, $F(1,28) = 97.07$, $p < .001$, $\eta^2 = 0.776$ (Figure 1). A significant interaction between group (high vs. low self-esteem) and category pairing (me/positive vs.

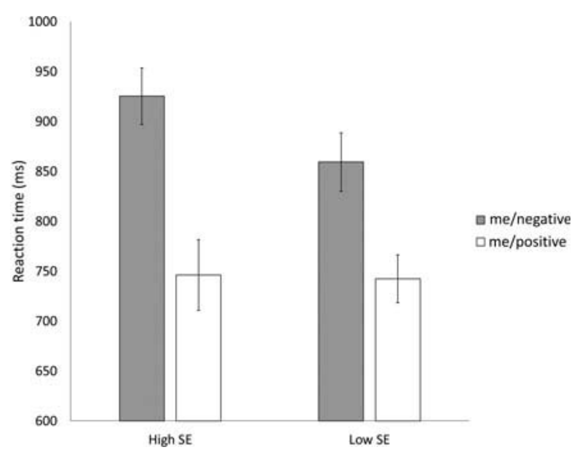

Figure 1. Reaction times. A significant interaction was found between group type (high versus low self-esteem) and IAT category pairing (me/positive versus me/negative). This interaction was driven by a larger IAT effect within the high self-esteem group.

me/negative) was also revealed, $F(1,28) = 4.27$, $p = .048$, $\eta^2 = 0.132$. This interaction was driven by a larger significant IAT effect (me/negative RTs—me/positive RTs) within the high self-esteem compared to the low self-esteem group, $t(28) = 2.067$, $p = .048$. No other effects reached significance.

Partial least squares: Waveforms differences

The PLS analysis revealed one significant LV demonstrating that the me/positive category pairing differed from the me/negative category pairing and that this difference was larger for high self-esteem individuals (see Figure 2). This LV accounted for 73.82% of the variance ($p < .007$). The bootstrap analysis of electrode salience, which provides confidence intervals for salience across time points and electrodes, revealed that this LV was most reliable in a left lateralized cluster of electrodes (corresponding to PO7 of the extended 10/20 system) at points between 190 and 900 ms after stimulus onset (see Figure 2).

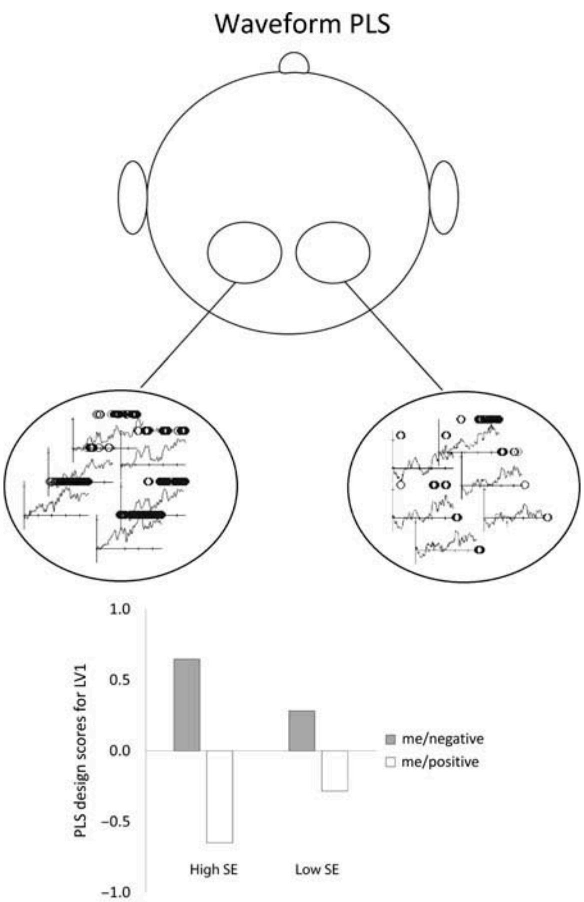

Figure 2. Waveform PLS. A PLS electrode saliency map showing the reliability of a LV representing a greater difference for high self-esteem individuals (compared to low self-esteem) between the me/positive category pairing and the me/negative category pairing. This LV accounted for 74% of the variance ($p < .007$) and was most reliable in a left lateralized cluster of electrodes (corresponding to PO7 of the extended 10/20 system) at points between 190 and 900 ms after stimulus onset. The *x*-axis represents time in milliseconds (−100–900) and the *y*-axis represents electrode salience (i.e., reliability of the LV).

Partial least squares: Behavioral predictors

One LV (accounting for 47.68% of the variance) was identified and showed that ERPs reflected RTs during the me/negative block for high ($r = 0.6$), but not low ($r = 0.06$) self-esteem individuals; as amplitudes increased, RTs decreased. As shown in the electrode salience map (Figure 3), this LV was most reliable between 200 and 400 ms after stimulus onset, at left parietal (PO7), left central (C1), as well as mid-line parietal (Pz), and mid-line central (Cz) electrode sites. These time windows and locations appear to fit best with the broad P300–400 component identified above. Indeed, when we examine simple Pearson *r* correlation coefficients between behavior and amplitude for all of the aforementioned components, only one component predicted a significant amount of the behavioral RTs. High (but not low) self-esteem individuals showed a strong negative relationship between P300–400 amplitude and RTs during the me/negative block ($r = -0.45$, $p < .05$).

Componential analyses based on PLS and a priori predictions

N1 latencies

A significant interaction between category pairing and group was revealed for N1 latency, $F(1,28) = 5.98$, $p = .021$, $\eta^2 = 0.176$ (see Figure 4). This is explained by shorter latencies for the me/positive than the me/negative pairing for low self-esteem, $t(14) = 2.84$, $p = .013$, but not for high self-esteem individuals, $t(14) = -1.31$, $p = .212$. There were no amplitude differences (all *Fs* less than 2.9, $p > .1$).

P2 amplitudes

The 3 × 2 × 2 ANOVA for this analysis revealed a significant main effect of group, $F(1,28) = 10.61$, $p = .003$, $\eta^2 = 0.275$, and a significant main effect of

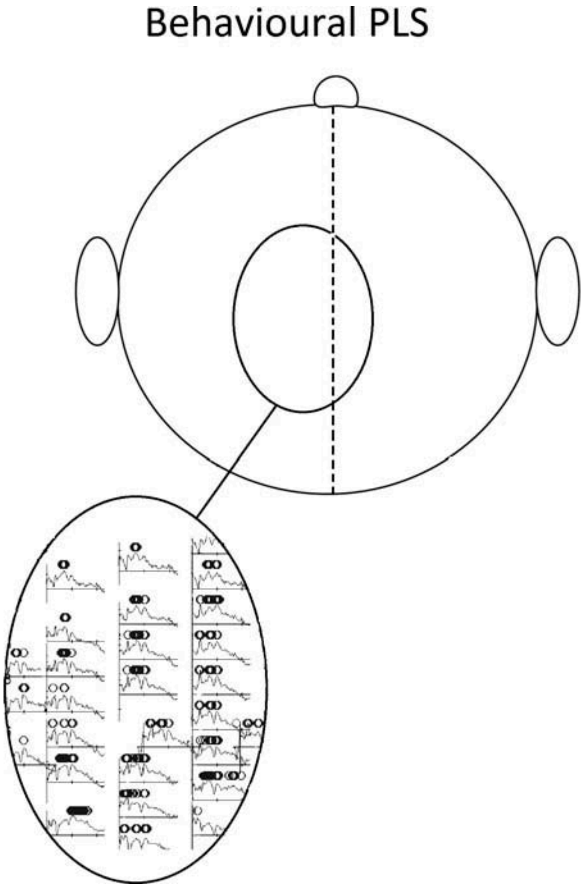

Figure 3. Behavioral PLS. A PLS electrode saliency map demonstrating the reliability of a LV that relates amplitude changes to behavioral performance. This LV was most reliable between 200 and 400 ms after stimulus onset, at left parietal (PO7), left central (C1), as well as mid-line parietal (Pz) and mid-line central (Cz) electrode sites and accounted for 48% of the variance. ERPs predicted RTs during the me/negative block for high (r = 0.6), but not low (r = 0.06) self-esteem individuals; as amplitudes increased, RTs decreased. The x-axis represents time in milliseconds (−100–900) and the y-axis represents electrode salience (i.e., reliability of the LV).

location, $F(2,56) = 8.66$, $p = .001$, $\eta^2 = 0.236$. The effect of group is explained by the finding that low self-esteem individuals had larger P2 amplitudes than high self-esteem individuals (see Figures 5 and 6). The effect of location is explained by the finding that larger amplitudes were observed for left and mid-line electrode sites compared to right-hemisphere electrode sites (both $p < .01$).

The effect of group is further qualified by a significant interaction between group and category pairing, $F(1,28) = 4.38$, $p = .046$, $\eta^2 = 0.135$, whereby high self-esteem individuals showed larger amplitudes for me/negative than for me/positive ($p = .018$), but that low self-esteem showed no category pairing effect ($p = .50$). The main effect of location is further

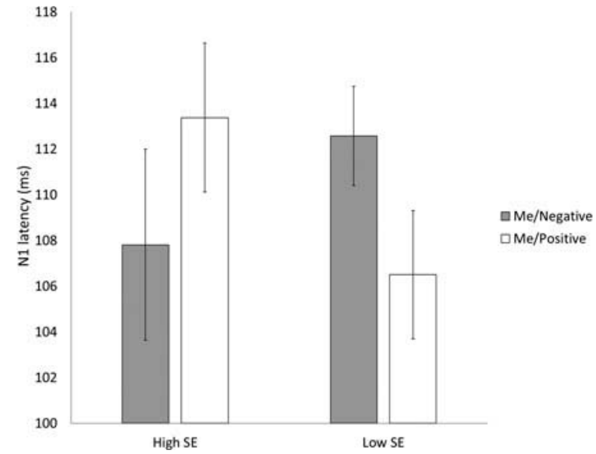

Figure 4. N1 latency. Latency to peak for the anterior N1 component at a frontal electrode cluster (AF4, FZ, AFZ, FPZ, and AF3). A shorter latency for the me/positive category pairing was observed for the low self-esteem but not the high self-esteem group.

qualified by an interaction between location and category pairing, $F(2,56) = 3.76$, $p = .029$, $\eta^2 = 0.118$, whereby a category pairing effect (me/negative > me/positive) was only observed over left-hemisphere electrode sites ($p = .05$). No other effects reached significance (all $p > .05$).

N250 amplitudes

The analysis revealed a main effect of category pairing, $F(1,28) = 6.58$, $p = .016$, $\eta^2 = 0.190$, whereby the N250 was larger for me/negative pairings than for me/positive pairings. No other effects reached significance (all $p > .05$).

Amplitudes within 300–400 ms

The 3 × 2 × 2 ANOVA revealed a significant interaction between group and category pairing, $F(1,28) = 5.70$, $p = .024$, $\eta^2 = 0.169$. This was driven by larger amplitudes for the me/negative pairing than the me/positive pairing within the high self-esteem group, $t(14) = 2.94$, $p = .011$, but not within the low self-esteem group, $t(14) = -0.616$, $p = .548$. No other effects reached significance (all $p > .05$).

Amplitudes within 400–600 ms

A significant interaction between location and category pairing was revealed, $F(2,56) = 8.96$, $p < .001$, $\eta^2 = 0.242$. This is explained by the finding that amplitudes for the *me/negative* category pairing were larger over *left*-hemisphere (PO7) than over right-hemisphere

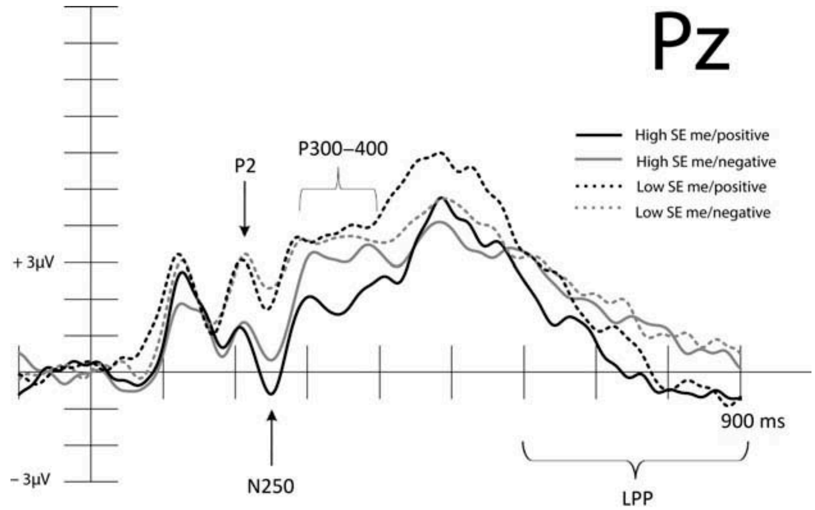

Figure 5. A representative mid-line electrode (Pz) from the parietal cluster illustrating the significant effects at P2, N250, P300–400, and LPP.

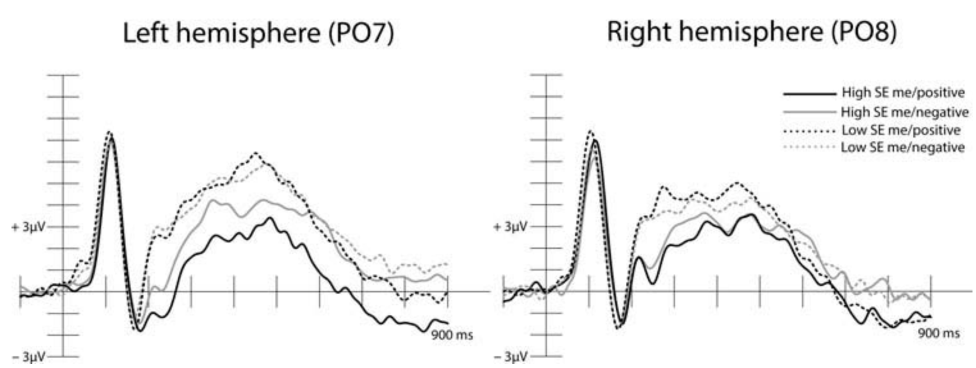

Figure 6. Two representative electrodes from the left (PO7) and right (PO8) parietal clusters illustrating laterality effects in self-esteem processing. High self-esteem individuals (compared to low self-esteem individuals) more strongly distinguished between positive and negative information in relation to the self and this distinction happened earlier; these effects were most pronounced over left-hemisphere electrodes.

(PO8) electrodes ($p < .01$), and that amplitudes for the *me/positive* category pairing were larger over *mid-line* (Pz) than over right-hemisphere electrodes ($p = .02$). No other effects reached significance (all $p > .05$).

LPP (600–900 ms) amplitudes

A significant effect of category pairing was revealed, $F(1,28) = 13.29$, $p = .001$ $\eta^2 = 0.322$, where LPP amplitude for the me/negative pairing was larger than for the me/positive pairing. A significant effect of location, $F(2,56) = 4.76$, $p = .012$, $\eta^2 = 0.145$, showed larger overall amplitudes for mid-line than right-hemisphere electrodes ($p = .004$). No other effects reached significance (all $p > .05$).

DISCUSSION

We provide the first high-temporal resolution account of the self-esteem IAT (Greenwald & Farnham, 2000) to highlight important similarities and differences between the cognitive processes corresponding to self-relevant processing in high vs. low self-esteem individuals. We highlight differences corresponding to groups (high vs. low) at the P2, differences corresponding to category pairing (me/positive vs. me/negative pairing) at the N250 and the LPP, and interactions between these factors at the N1, P2, and P300–400. These findings provide important insight into the electrophysiological time course of underlying cognitive processes involved in a task designed to measure self-esteem.

When processing positive or negative information in relation to the self, two ERP components in particular appeared to be relevant for all participants: the N250 and the LPP. The N250 is believed to index matching of input to stored representations, particularly in relation to personal familiarity (Fan et al., 2011; Zhao et al., 2009, 2011). Because a larger N250 response indexes more personal familiarity, the finding that all individuals in the present study showed a larger N250 for associations between the self and positive attributes suggests that thinking of oneself in a positive light is more familiar. Consistent with this finding, it is possible that the N250 reflects processes relevant to the self-positivity bias reported in behavioral studies; the self-positivity bias is the finding that on average, we tend to think of ourselves as above average (Hoorens, 1995; Mezulis, Abramson, Hyde, & Hankin, 2004). On the other hand, the LPP showed greater positive amplitudes when the self was paired with a negative category compared to when the self was paired with a positive category. Larger LPP amplitudes have been shown for positively and negatively valenced stimuli relative to neutral stimuli (Cuthbert et al., 2000), with largest effects for negative stimuli (Hajcak et al., 2006; Hajcak & Nieuwenhuis, 2006; Zilber et al., 2007). In the context of the present study, greater LPP amplitudes for the self-paired with negative vs. positive categories might be indicative of greater conscious attention allocation to negative pairings with the self. Because of their motivational significance, emotional stimuli elicit sustained attentional resources, and this conscious attention allocation is indexed by the LPP (Lang, Bradley, & Cuthbert, 1997); the LPP here might index enhanced conscious attention allocation to the emotional context created by pairing the self with negativity.

When looking at group (high vs. low self-esteem) differences, the parietal P2 was of particular interest. Greater P2 amplitude has been implicated in intensity of perceptual processing (Yang, Guan, et al., 2012), as well as higher levels of anxiety (Von Leupoldt, Chan, Bradley, Lang, & Davenport, 2011) and negative emotional processing (Carretié et al., 2001). Here, we show that low self-esteem individuals demonstrate larger P2 responses during the self-esteem IAT, which could suggest that low self-esteem individuals are processing thoughts about oneself as more threatening and anxiety-provoking. This interpretation is consistent with the finding that P2 responses are larger for low (vs. high) self-esteem individuals during a difficult math task (Yang, Zhao, et al., 2012). Greater P2 amplitudes were also observed for negative pairings with the self-compared to positive pairings with the self for high self-esteem individuals, but the same was not true of low self-esteem individuals. Because high self-esteem people have more positive views about the self, they might find negative pairings with the self more anxiety-provoking and/or intense, and this leads to an increase in processing at the P2 component.

Interestingly, we showed an interaction effect between group and category pairing at the anterior N1, identifying differences corresponding to low, but not high, self-esteem individuals. Low self-esteem individuals displayed shorter latencies for positive (vs. negative) attribute pairings with the self. Because shorter anterior N1 latencies have been shown to index a reduction in the amount of automatic attention allocation (Callaway & Halliday, 1982; Fan et al., 2011), it is possible that low self-esteem individuals are allocating fewer early attentional resources to positive associations with the self. Fan and colleagues showed that compared to self-national flags, familiar and unfamiliar national flags elicited shorter N1 latencies, presumably because these stimuli do not elicit as much automatic attention allocation as does self-relevant information. For low self-esteem individuals, less early attentional allocation to positive information in relation to the self might detract from later consolidation of positive associations with the self. An alternative but related interpretation has to do with processing effort; increases in N1 latency are associated with increases in processing effort (Fort, Besle, Giard, & Pernier, 2005). This is consistent with the present study in the sense that the early processing effort for high self-esteem individuals is equivalent for positive and negative information in relation to the self. However, the low self-esteem individuals do not show this effect for positive associations with the self. The lack of processing effort for positive associations with the self might detract from distinctions between positive and negative information later in processing.

The effect that we observed at the P300–400 might reflect such an instance. High self-esteem individuals displayed amplitude differences at the P300–400 component between positive vs. negative attribute pairings with the self, but low self-esteem individuals did not. Furthermore, the P300–400 component reliably predicted a significant amount of the behavioral RT variance for high self-esteem, but not for low self-esteem individuals. More precisely, the P300–400 component predicted RTs for high self-esteem individuals when the self was paired with negative, but not when the self was paired with positive. High and low self-esteem individuals produced slower responses in the me/negative (vs. me/positive) block, but this slowing was much greater for high self-esteem individuals; the

P300–400 component might reflect processes corresponding to this additional slowing. Our working hypothesis is that the P300–400 reflects a process that acts as an automatic buffer against associative pairings of negativity and the self. This is consistent with a hypothesis that the main difference between high and low self-esteem is not simply that people with high self-esteem feel better about themselves, but that they possess a skill set that allows them to respond to failure in a way that maintains their positive self-esteem over time (Brown, 2010; Brown et al., 2001; Dutton & Brown, 1997; Fitch, 1970).

The P300–400 component is also consistent in time course and topography with the P3b ERP component, which is associated with attentional capture to novelty or incongruence and activates or promotes subsequent memory processes (Polich, 2007). We suggest that the P300–400 component reported in the current study supports the hypothesis that high self-esteem individuals may be more likely than low self-esteem individual to find the associative pairing of self and negative incongruent, eliciting a larger P3. As previously mentioned, both the P3 and the LPP are sensitive to incongruence and emotional valence, with the former reflecting more automatic processing, and the latter reflecting more controlled conscious processing. High self-esteem individuals may have a buffer against automatic associations between negativity and the self (reflected by P300–400), whereas both high and low self-esteem individuals consciously perceive this pairing as emotionally salient during later stages of processing (reflected by LPP). Consistent with this hypothesis, high self-esteem individuals show larger ERP deflections for the me/negative (vs. me/positive) pairing at both the earlier P300–400 component and the later LPP component, whereas low self-esteem individuals only show larger ERP deflections for the me/negative (vs. me/positive) pairing at the later LPP component.

Finally, we provide electrophysiological evidence for a laterality effect in self-esteem processing. Using an unbiased whole-brain statistical approach (PLS; Lobaugh et al., 2001; McIntosh et al., 1996), we demonstrated that the main processing differences between high and low self-esteem individuals took place over left-hemisphere parietal electrodes. A second PLS analysis revealed that the P300–400 most reliably predicted RTs for high self-esteem individuals over *left* and *mid-line* parietal/central sites. To our knowledge, only one study has examined the hemispheric lateralization of self-esteem (McKay, Arciuli, Atkinson, Bennett, & Pheils, 2010); they used an auditory adaptation of the self-esteem IAT to show that self-esteem processing was left lateralized; larger IAT effects were found when presented to the right ear (left-hemisphere processing) than when presented to the left ear (right-hemisphere processing). These findings are important in that they provide support for an approach-withdrawal model of self-esteem. There is evidence to suggest that positive emotions (e.g., happiness and amusement) elicit approach behaviors and are left-hemisphere lateralized, whereas negative emotions (e.g., fear and disgust) elicit avoidance behaviors and are right-hemisphere lateralized (Davidson, 1995; De Raedt, Franck, Fannes, & Verstraeten, 2008; Harmon-Jones & Allen, 1998). McKay et al. (2010) interpreted their findings as support for the idea that high self-esteem is associated with approach behaviors, whereas low self-esteem is associated with withdrawal behaviors. We also found that the IAT effect was left lateralized for high self-esteem individuals. However, when we examined RTs separately for the me/negative vs. the me/positive pairings, we found that the lateralized effect for high self-esteem was specifically associated with RTs for pairings of the self with *negative*, but not for pairings of the self with positive. This observation is not as easily folded into the approach-avoidance model of self-esteem. We suggest that the left lateralization of self-esteem reflects a process by which high self-esteem individuals are able to automatically buffer against *negative* associations with the self.

The findings presented here provide us with a stepping stone onto which we can build future experiments examining the underlying cognitive mechanisms that distinguish levels of self-esteem. We are cautious about making strong conclusions regarding the meaning of individual ERP components at this stage; hopefully ongoing studies will provide converging evidence using a variety of measures. The IAT is generally thought to reflect associations between concepts that can help to determine individual differences in implicit cognition (Greenwald et al., 1998); however, we are still working to understand the factors that produce the IAT effect (see De Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009, for a review). There are potential ambiguities in interpretation of IAT results; for example, the difference in response times across the categorization tasks may be due to asymmetries in similarity across the paired categories (De Houwer, Geldof, & De Bruycker, 2005; Rothermund & Wentura, 2004) and it may not be clear which of the paired categories is driving the effect. For example, when looking at self-esteem, we do not know for sure whether faster responses in the me/positive condition are due to stronger associations or similarities between me/positive categories or between not me/negative categories. If the effect is driven by the not-me/negative pairing, that would call into question whether the self-esteem IAT is in fact reflecting self-evaluative processing. There is some evidence that the nonspecific other category (i.e., the not-me category) may be inherently negative based on a result showing that a self-other IAT effect was not statistically different from a self-Hitler IAT effect (Karpinski, 2004). However, other evidence supports the idea that the not-me category is neutral; the self-Hitler IAT was actually larger than the self-other IAT when practice effects were taken into account. In addition, participants were slower to respond to the pairing of Hitler with positive compared to other with positive. In this same study, the authors demonstrated that an other–middle IAT (middle being a neutral category) using positive and negative contrasts did not produce an IAT effect (Pinter & Greenwald, 2005), suggesting that other and middle are equally neutral in valence. If the nonspecific other category is indeed neutral, then we can be more confident that the self-esteem IAT is a measure of self-evaluative processing. The present study provides further evidence for this suggestion by showing that high and low self-esteem individuals display differences at ERP components that we know to be sensitive to self-relevant (e.g., N250) and emotional (e.g., P3/LPP) processing.

The results reported in the present study in terms of the time course and topography of amplitude differences suggest certain patterns that can be followed up in future experiments. Both high and low self-esteem groups showed sensitivity to the distinction between positive and negative information in relation to the self (where me/negative generally displayed larger amplitudes than me/positive), but for high self-esteem individuals, this difference was generally larger, earlier, and most pronounced over left-hemisphere electrodes. These electrophysiological differences may reflect the amount of attentional resources devoted to teasing apart these two oppositely valenced associations. High self-esteem individuals appear to devote more automatic (early) attentional resources to strengthen the distinction between positively or negatively valenced information in relation to the self, and this may lead to changes in behavior.

CONCLUSION

We provide the first electrophysiological evidence of underlying neural signatures corresponding to implicit valenced self-processing in high vs. low self-esteem individuals. We used the self-esteem IAT (Greenwald & Farnham, 2000) to reveal time course differences between high and low self-esteem individuals at event-related components N1, P2, N250, and P3/LPP complex. Low self-esteem individuals had shorter frontal N1 latencies for pairings of the self with positive, suggesting that fewer early automatic resources are allocated to positive pairings with the self. Low self-esteem individuals also displayed larger posterior P2 responses for all words during the self-esteem IAT, which may reflect more anxiety-provoking thoughts about self. Both high and low self-esteem individuals displayed enhanced responses for positive vs. negative pairings with the self at the self-relevant N250 component, consistent with the self-positivity bias that is typically reported in behavioral studies. The P3/LPP complex revealed interesting time course differences between high and low self-esteem individuals, such that high self-esteem individuals appear to have an automatic cognitive buffer against negative associative pairings with the self, but that low self-esteem individuals do not; these left-lateralized neural processes predict a significant portion of the behavioral responses between the two groups. Overall, high self-esteem individuals appeared to devote more early attentional resources to distinguish between positive vs. negative pairings with the self, and this was associated with behavioral performance. These findings offer valuable insight into the cognitive self-processing differences between high and low self-esteem individuals and provide an avenue for future research on this topic.

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