P300 as an Attentional Modulator: Effects of Self-Referencing

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by

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Abstract

Numerous event-related potential (ERP) studies have established a link between the concept of self and a P300 component, and there is robust evidence from functional magnetic resonance imaging (fMRI) showing self-referential memory effects during encoding through the subsequent memory paradigm. The purpose of the present study was to investigate how self and other-referential information differ at encoding using ERP. It was hypothesized that the encoding of self-referential information would produce a P300 component to a greater extent than other-referential information. Participants were cued to evaluate either self or other by a descriptive adjective by making a yes/no key press during ERP recording. Contrary to expected results, it was found that the self and other-referent conditions did not differ from one another and both elicited equivalent P300 responses. This suggests that P300 modulates and orients attention, and indicates that perhaps differential encoding of self and other occurs at a different ERP component.
P300 AND SELF-REFERENCING

P300 as an Attentional Modulator: Evidence from Self-Referencing

The self-reference effect (SRE) was first investigated by Rogers, Kuiper and Kirker in 1977 as the phenomenon in which individuals have better subsequent memory for information encoded in relationship to themselves than information encoded relative to others. This working definition has since been amended to describe the effect in which self-referential strategies employed during encoding led to increased subsequent memory when compared to semantic and other-referential encoding strategies (Symons & Johnson, 1997). It has been shown to not only be an effective memory strategy but one that is preserved under many different conditions. This advantage in memory has been shown to hold true in self-referencing regardless of encoding context or triggering cue (Turk, Cunningham, & Macrae, 2008). Furthermore, it is of particular interest because age does not affect SRE, as it has been shown in children as young as five through older adulthood (Sui & Zhu, 2005; Gutchess, Kensinger, Yoon, & Schacter, 2007).

While other memory processes change and eventually decline throughout development, the SRE remains intact. The SRE goes beyond aiding in simply making old versus new decisions; it actually enhances source memory and specificity. Self-referenced information is encoded more richly through these contextual associations. It has been shown that self-referencing benefits memory for details of the source of the information in addition to memory for the item needed to support old vs. new decisions (Serbun, Shih & Gutchess, 2011). Source memory benefits for self-referenced information have been linked to mPFC activity, showing that the self-referential information is more richly encoded (Leshikar & Duarte, 2012). Through extensive study of the SRE using fMRI methods, multiple additional studies have converged on the mPFC as the self-referencing brain area with parietal neocortical circuit involvement (e.g., Powell et al., 2010; Mitchell, Macrae, & Banaji, 2006; Kelley et al., 2002). It has also been shown that mPFC
activity predicts subsequent memory performance and judgments of self-relevance (Macrae et al., 2004). There has also been work showing contributions of brain areas involved in both self-referential processing and episodic memory, and communication between the mPFC and hippocampus during the encoding process contributes to the self-reference effect (Morel et al., 2014). This converging evidence has led to the conclusion that mPFC activity is implicated in the processing of information related to the self.

It is clear that there are unique neural regions and components devoted to thinking about the self. As described above, the mPFC has been identified as the neural correlate of self-referencing (Macrae et al., 2004; Yaoi, Osaka & Osaka, 2015). In addition, evidence from ERP, such as the common neural signature found when self-referential processing is applied to both noetic (general knowledge)/autonetic (personal experience), and scalp distribution and temporal properties of self-referential processing, are in line with the mPFC and parietal neocortical circuits implicated through fMRI studies (Magno & Allan, 2007).

Although it has been shown through ERP that self-evaluation manifests in multiple cognitive processes (Wu et al., 2015), there has been converging ERP evidence that P300 is a marker of self-referential processing (Fan et al., 2013; Herbert et al., 2010,). There is also evidence that the P300 responds to the degree of self-referencing. In other words, there is no P300 component for self-irrelevant information, a slightly larger amplitude P300 component for somewhat self-relevant information, and a robust P300 component for highly self-referential information (Fan et al., 2013). It has further been shown that prolonged P300 peak latencies show highly self-relevant stimuli processed preferentially relative to less self-relevant stimuli, showing that degree effects of self-relevance can create preferential processing in addition to memory benefits (Chen et al., 2008). P300 has also been implicated in attentional processing and there is some evidence
that components N1 and N2 are also involved in self-referential processing, but this could be due to an expectation effect due to attention and not specific to the self-relevance of the content (Fan et al., 2011; Zhong et al., 2013). The link between P300 and attentional effects is thought to be related to self-relevance’s role in the selection of information that merits further processing. P300 latency analyses show that self-relevant effects are present during processing related to selective attention (Gray, Ambady, Lowenthal, & Deldin, 2003).

When investigating how the positivity and negativity of information affects memory, Leshikar, Dulas, & Duarte (2015) found that valence modulated memory effects as a function of the similarity of others to the self. When the similarity to self was related to a positive impression, there was memory enhancement, and when self-similarity was related to a negative impression, there was reduction of memory. These data suggest that self-referencing is influenced by valence and leads to more detail-rich representations in memory, which leads to higher rates of recognition. The overwhelming evidence that the self-reference effect improves memory combined with research showing that P300 components are involved in self-referential processing but not other processing suggests that self-referential information is encoded differently than other information.

Differences of information encoding can also be used to predict subsequent memory using ERP-measured responses to stimuli. The subsequent memory paradigm is defined as a method which uses neural responses to predict which stimuli will be subsequently remembered or forgotten. Paller and Wagner reviewed evidence that neural responses measured using ERP can predict which events will be remembered or forgotten (Paller & Wagner, 2002). However, later research has further refined understanding of the underlying processes that predict successful subsequent memory. The Paller and Wagner model has since been updated to show
that old/new ERP components occur during encoding and predict if an event will be subsequently remembered or forgotten (Griffin et al., 2013). Furthermore, the distinction has since been shown to be more nuanced than old/new decision making. It has been shown that familiarity and recollection reflect the outcome of neurally distinct memory processes at both encoding and retrieval (Duarte et al., 2004). Clearly, measurements taken during encoding can successfully predict subsequent memory, which suggests that the same methods can be applied to predicting subsequent memory for self-referential information.

In this study, we aim to investigate whether self-referencing at encoding will produce a P300 component with an increased amplitude for only self-referenced items, and will then determine if the P300 component during encoding can enhance retrieval of self-referenced items using a subsequent memory paradigm. The electrical activity of the brain will be measured at the scalp using ERP. It is hypothesized that items encoded under the self condition will be better remembered than other-referential items due to preferential processing and memory benefits elicited by the P300 component, which will be present during self-referential encoding, but not other encoding. These predicted results would not only provide further evidence for the idea that self-referential information is encoded differently than information with less personal relevance, but could also provide new insights into the processes underlying the self-reference effect. If the predicted results prove to be valid, it will provide evidence for the proposed mechanism behind self-referencing, as follows: the P300 component is involved in both self and attention and because of this link, a P300 response to self-referential stimuli causes the individual to prioritize attending to self-referential information. Therefore, the individual pays more attention to the self-referential stimuli and encodes the self-referential information more richly, which results in enhanced memory for self-referential information. This is important because it could potentially
show at the neural level how self-referential encoding increases the likelihood of successful retrieval. If we can better understand the SRE, it could be adapted into an effective tool to help counteract the effects of memory loss, especially as the self-reference effect has been shown to be preserved into older adulthood. Furthermore, changes in electrical activity for information that is remembered compared to information that is forgotten could potentially reveal what components of electrical activity at encoding are critical in predicting subsequent memory. Using ERP in this way could not only help to elucidate the mechanisms behind the self-reference effect, but could also provide insights into what predicts successful subsequent memory at encoding.

**Methods**

**Participants**

Twenty-one younger adults recruited from Brandeis University participated after providing informed consent. Five participants needed to be excluded due to excessive artifacts in ERP (defined as rejecting >60% of trials); there were ultimately 16 participants included in analyses (18-26 years old (M=19.89); 10 females) Participants were all right-handed, native English speakers (defined as either the first language or learned before the age of five) with normal or corrected-to-normal vision were used exclusively to remove any confounds from handedness or language level. All participants have no history of neurological, affective, or psychiatric disorders. The Institutional Review Board at Brandeis University approved this study.
Stimuli and Procedure

The stimuli were presented using E-Prime software by Psychology Software Tools on the computer screen. Participants were shown the following instructions: “Your task is to decide if the word describes either your self or Albert Einstein by indicating yes or no.” After a brief training period in which participants learned to respond with “1” for yes and “2” for no for each trial, they completed the formal task. After viewing a jittered fixation cross of 1000-1500 ms, participants were shown a cue of either “Self,” or other (“Albert Einstein”) for 1000 ms. Albert Einstein was used to represent the other because he is a familiar and neutral figure whom people do not know personally. Participants then viewed an adjective for 2000 ms and then made a yes or no response to whether the adjective described the target person (self or Albert Einstein) once a question mark appeared on their screen. There were 3 blocks of encoding, each with 150 words for a total of 300 words, which were evenly divided into self/other. Participants had a self-timed break in between the three blocks. The words list was be generated with an equal number of positive and negative words and equated for likeability, as per Anderson (1968). There were three different versions of the task counterbalanced for which words were evaluated for self and which were evaluated for Albert Einstein.

Following the encoding period, there was a standard 12-minute period between encoding and retrieval in order to control for potential differences in encoding times between participants. During this time, the EEG cap was removed and participants completed a pen and paper digit comparison task and a Shipley vocabulary task on the computer through E-Prime software. Once the 12-minute period had passed, participants began the retrieval task. Participants were instructed to recall if the presented adjective was one they had seen in the encoding task, or if it was a new word. They again used a “1” key press to indicate yes and “2” to indicate no, making
self-timed responses as soon as the adjective appeared on the screen. This retrieval task had three counterbalances corresponding with each of the retrieval versions, but this time each version had 450 words: 300 adjectives from the encoding phase and 150 new adjectives. Because this procedure was self-timed and did not have fixation crosses or cues, there were no breaks built in to the protocol. Finally, participants completed a self-construal scale adapted from Singelis, Triandis, Bhawuk, & Gelfand, (1995) to evaluate individual independence and interdependence.

**ERP Recording and Data Analysis**

EEG signals were recorded using 32 Ag/AgCl electrodes following the International 10-20 system and electrode impedances were below 5kΩ. Two supplementary electrodes were used to support signal processing, with one below the left eye and one at the outer right canthus. Signals were recorded using a BioSemi ActiveTwo amplifier from Cortech Solutions at a 512-Hz rate of sampling. An off-line re-referencing of the EEG signals on the left and right mastoids, EEG signals were filtered using a 1-Hz high-pass filter. Then, ICA was run to correct for ocular artifacts using the runica algorithm in the open-source toolbox EEGLAB 13.4.4b (Delorme & Makeig, 2004) through Matlab 8.2.29 by MathWorks. Then, using another open-source toolbox, ERPLAB 4.0.3,1 (Lopez-Calderon & Luck, 2014), the following analyses were performed. Epochs were created to range from 200ms after the stimulus onset to 800 ms after, and then baseline corrected by subtracting the mean amplitude from -200 to 0 ms pre-stimulus interval. They were also semi-automatically inspected for eye movements, muscle artifacts, shifting and other anomalies, and if a segment contained one of these artifacts with +/- 100µV, it was rejected. After artifact rejection, the average percentage of trials remaining was 68.0%. Averaged ERPs were generated using the ERP signals that are not rejected and averaging them per participant and condition, and were then filtered with a 30-Hz low-pass filter. The P300 mean
amplitudes were analyzed for each participant for the self-referential and other-referential trials. We focused on three channels: Fz, Cz, and Pz, because P300 effects emerged at these midline channels in prior studies (e.g. Gray, Ambady, Lowenthal, & Deldin, 2003).

Results

Behavioral Data

In order to assess performance, memory scores for both Self and Other were calculated for each participant. This consisted of the hit rate for studied “old” items minus the false alarm rate of new items as a measure of corrected recognition. A paired samples t-test revealed that the self condition (M=0.42, SD=0.18) resulted in better memory scores than the other condition (M=0.28, SD=0.12), t(20)=8.564, p<0.001, the difference between self and other being the self-referential memory improvement score. These findings indicate that the participants did show a self-reference effect in memory, providing a manipulation check verifying that the paradigm was able to elicit a self-reference effect at the behavioral level.

ERP Data

The grand-average ERP waveforms of the three selected midline channels (Fz, Cz, and Pz) for the Self and Other conditions in addition to the difference wave between them (Self-Other) were calculated for the 16 participants who remained after artifact rejection. Peak amplitude values were extracted for each participant at each midline channel, with a peak being defined as larger than the 2 points (4 ms given a 500-Hz sampling rate) on either side of the peak. An a priori defined P300 window was defined as 350-650 ms based on averages from the literature (Gray, Ambady, Lowenthal, & Deldin, 2004). Paired samples t-tests revealed that the average amplitude during the 350-650 ms P300 window was not significantly different at any of
the three sites for the self condition. For Fz self (M=5.21, SD=2.61) and other (M=5.20, SD=2.24), t(15)=0.022, p=0.982, see Figure 1a. For Pz self (M=3.46, SD=2.74) and other (M=3.37, SD=2.90), t(15)=0.171, p=0.866, see Figure 1b. For Cz self (M=4.66, SD=2.81) and other (M=4.89, SD=2.98), t(15)=−0.601, p=0.557, see Figure 1c. We topographically plotted scalp activations for the mean amplitude of the self and other stimuli in a representative participant during the P300 window (350-650 ms), which indicated that the P300 component emerged in anterior midline channels, particularly during the later time windows for self and other, see Figure 1d. Because self and other didn’t differ from each other, we tested whether a P300 effect occurred for each condition separately using one-sample t-tests for self averaged amplitude at each of the midline channels (M_{Fz}=5.21, SD_{Fz}=2.61; M_{Pz}=3.46, SD_{Pz}=2.74; M_{Cz}=4.66, SD_{Cz}=2.81). When compared to 0, there was a significant P300 response (see Figure 1), t_{Fz}(15)=7.993, p_{Fz}<0.001; t_{Pz}(15)=5.045, p_{Pz}<0.001; t_{Cz}(15)=6.629, p_{Cz}<0.001. The same was found using a one-sample t-test for the other averaged amplitude (M_{Fz}=5.20, SD_{Fz}=2.24; M_{Pz}=3.37, SD_{Pz}=2.90; M_{Cz}=4.89, SD_{Cz}=2.98) compared to 0, t_{Fz}(15)=9.286, p_{Fz}<0.001; t_{Pz}(15)=4.647, p_{Pz}<0.001; t_{Cz}(15)=6.553, p_{Cz}<0.001, see Figure 1.

To assess whether self and other conditions differed in peak latency, values were extracted for each participant at each midline channel, with a peak defined as being larger than the 2 points on either side of the peak. A paired samples t-test revealed that the average latency during the a priori defined P300 window (350-650 ms) was significantly different between the self (M=536.83, SD=63.68) and other (M=559.51, SD=62.84) conditions at the Pz channel, t(15)=−2.399, p<0.05; see Figure 1b. For the Cz channel, the difference between the average latencies of the self (M=526.64, SD=32.23) and other (M=544.13, SD=27.54) conditions was also significant, t(15)=−2.118, p=0.05, see Figure 1c. At the Fz channel, the average latency was
not significantly different between the self (M=532.14, SD=29.00) and other (M=539.31, SD=41.00) conditions, \( t(15)=-8.37, p=0.416 \), see Figure 1a.

**Valence Effects**

Because we failed to find the predicted differences between self and other during the P300 window, we considered whether valence could be an important factor to consider. As a first step, we compared all positive trials to all negative trials at each of the midline channels using paired samples t-tests. For amplitude, there were no significant differences found between the effects of positive and negative stimuli. For Fz positive (M=4.95, SD=2.23) and negative (M=5.04, SD=2.27), \( t(15)=-0.419, p=0.681 \). For Pz positive (M=3.00, SD=2.61) and negative (M=3.19, SD=2.67), \( t(15)=-0.632, p=0.537 \). For Cz positive (M=4.50, SD=2.89) and negative (M=4.77, SD=2.91), \( t(15)=-0.653, p=0.524 \). The same was found for latency, in which there were no significant differences found between the effects of positive and negative stimuli. For Fz positive (M=526.86, SD=24.47) and negative (M=531.68, SD=34.20), \( t(15)=-0.757, p=0.461 \). For Pz positive (M=562.26, SD=56.19) and negative (M=556.06, SD=71.86), \( t(15)=-0.386, p=0.705 \). For Cz positive (M=532.01, SD=29.44) and negative (M=536.07, SD=26.94), \( t(15)=-0.935, p=0.365 \). These results indicate that there were not any significant effects of valence on ERP activity at the 3 midline channels. Because there was no difference between positive and negative stimuli, a one sample t-test was then performed for the amplitudes of the positive and negative stimuli separately at each of the midline channels to see if each valence elicits a P300 response independently. It was found that when compared to 0, the positive stimuli elicit P300 at all three midline channels. For Fz (M=4.95, SD=2.23), \( t(15)=8.875, p<0.001 \). For Pz (M=3.00, SD=2.62), \( t(15)=4.590, p<0.001 \). For Cz (M=4.50, SD=2.88), \( t(15)=6.246, p<0.001 \). The same was found when the one-sample t-tests were performed for the negative stimuli compared to 0.
For Fz (M=5.04, SD=2.27), t(15)=4.778, p<0.001. For Pz (M=3.19, SD=2.67), t(15)=4.778, p<0.001. For Cz (M=4.77, SD=2.91), t(15)=6.56, p<0.001. Because positive and negative valences do not seem to differently impact the P300, it seems unlikely that valence effects would account for the failure to detect difference in the P300 between self and other.

**Relationship between Self/Other Effects and Memory**

As a first pass at examining potential connections between the P300 response to self and other and memory, the difference between the behavioral self and other memory responses was compared against the ERP data for the self/other difference waves from the three midline channels (Fz, Pz, and Cz). Because the self condition resulted in better behavioral memory scores than the other condition, we correlated the magnitude of the self-referencing effect, using the difference in the self and other memory scores, with the magnitude of the P300 effect. There were significant positive correlations between the behavioral self/other memory difference scores and the ERP self/other differences at the Fz (r=0.502, p=0.048; see Figure 2a) and Cz (r=0.528, p=0.035; see Figure 2b) channels. There was not a significant correlation at the Pz channel (r=0.372, p=0.156; see Figure 2c).

**Exploratory Analyses**

We also conducted exploratory analyses to examine whether individual differences in the ways in which one thinks about the self in relation to others could influence the magnitude of the neural response to self vs. other. We predicted that participants with higher independence scores would have a larger distinction in the P300 to self in comparison to other. In contrast, we predicted that participants with higher interdependence scores would have a larger distinction in the P300 to other in comparison to self. In order to analyze the effects of individual differences
between subjects on the ERP data for self and other, independence and interdependence scores from the Self-Construal Scale were correlated with the difference waves between self and other at the three midline sites. There was a significant negative correlation between interdependence and the self-other difference wave at Cz \((r=-0.541, p=0.030)\); see Figure 3c), such that those participants who scored lower on the interdependence scale exhibited a greater difference in the P300 for self vs. other. However, there were no other significant correlations for interdependence at the other two channels: Fz \((r=-0.358, p=0.173)\); see Figure 3a) and Pz \((r=-0.113, p=0.677)\); see Figure 3b). There were also no significant correlations between independence scores and the three midline channels: Fz \((r=-0.387, p=0.138)\); see Figure 4a), Pz \((r=-0.389, p=0.136)\); see Figure 4b), and Cz \((r=-0.312, p=0.239)\); see Figure 4c).

**Discussion**

This study assessed whether self-referential stimuli would elicit a larger P300 component than other-referential stimuli. This would reflect prioritized processing of information relating to the self above other information, and provide a neural basis for the self-reference effect of memory using ERP. This hypothesis was not supported by the data, as we found that both self- and other-referential stimuli elicited equivalent P300 responses in terms of amplitude during the defined window (350-650 ms) in the experimental paradigm. Interestingly, we did find latency differences at the Pz and Cz channels, indicating that the P300 response occurs slightly earlier for self than other stimuli.

Perhaps the results do not support the hypothesis because the experimental paradigm differs from previous ERP studies examining how self relates to the P300 component. Previous
P300 studies used self-related stimuli that were more specific, so that participants were able to relate to them in a more rich and meaningful way. Zhu, Luo, Zhao, Hu, Yan, & Gao (2015) used a modified oddball task in their comparison of self-related and negative-related stimuli and found that self-face stimuli elicited a larger P300 response than other faces. Wu, Gu, Cai, & Zhang (2016) used an Implicit Association Test to show a positivity effect of self-evaluation and an associated P300 response. Fan et al. (2011) used another oddball task, but this time used the participant’s own name, as well as the names of close friends, acquaintances, and strangers, as stimuli. Other studies have used pictures of the subject’s hand, images of the subject’s handwriting, or autobiographical facts such as the participant’s phone number to serve as the self-relevant stimuli (Chen et al., 2008; Su et al., 2010; Gray, Ambady, Lowenthal, & Deldin, 2004). In all of these instances, it is not only clear that the experimental designs are very different from the current study, but also that the stimuli used in the self conditions were much more meaningful to individual participants. Perhaps the fact that we used adjectives that were potentially applicable to both self and other conditions rather than inherently self-relevant stimuli, such as an image of the participant’s own face, contributed to the lack of differences between the self and other conditions in the current study.

It is surprising that we did not see the predicted effect when using the self-reference effect paradigm in ERP because the difference between self and other is robust when the same paradigm was used in fMRI studies. Kelley, Macrae, Wyland, Caglar, Inati, & Heatherton (2002) used this paradigm to show that a specific region in the medial prefrontal cortex was selectively engaged during self-referential processing. Jenkins, Macrae, & Mitchell (2008) found the same effect and linked self-referencing to ventromedial prefrontal cortex engagement. Using the same paradigm, Gutchess, Kensinger, & Schacter (2007) showed that the medial prefrontal cortex and
mid-cingulate are engaged during self-referencing using this paradigm, and that this effect is robust enough to be preserved into older adulthood. Based on the strong evidence that this paradigm elicits the self-referential effect in fMRI, it is possible that ERP is insufficiently sensitive to the self-referential effect and therefore requires self cues with more self-relevance in order to elicit a differential response from the other condition.

Because self and other did not differ from one another in that they both elicited a P300 response, we did not conduct the originally planned subsequent memory analyses to compare the processes involved in successfully forming self-referential memories compared to other-referential memories. This is also because the high rate of artifact rejection meant that there would not have been enough trials per bin necessary for subsequent memory analyses. Although we did not have enough trials to perform the subsequent memory analyses, we conducted preliminary correlational analyses to determine whether there was a relationship between memory performance and ERP responses. We found that at two of the midline channels, the memory advantage of self-referencing compared to other-referencing relates to the P300 component. This suggests that these P300 may be sensitive to, and differently respond to self and other when the data are split by memory. This gives hope that re-doing artifact rejection to be less conservative and having more trials available in order to perform subsequent memory analyses could be promising.

It is possible that collapsing across the positive and negative trials negated any differences between the P300 for self and other trials. As a first step to address this possibility, we compared the P300 for positive and negative trials. This analysis allowed for the maximum possible positive and negative trials to go into the analysis. We found that the positive and negative stimuli did not differ from one another and both elicited a P300 response, meaning that
the lack of a difference between self and other in ERP was not due to valence. Although the P300 did not differ for positive and negative words in the present paradigm, other research provides evidence that positive traits are more readily paired with “self” than negative traits in Implicit Association Tests. Wu, Gu, Cai, & Zhang (2016) used an IAT to show that there is a larger P300 component elicited when evaluating self for positive traits than for negative traits, suggesting a positive nature in implicit self-evaluation. Because other studies showed that valence can impact P300 for self-referencing, it suggests that the reason our results did not show an effect of valence was because the self/other differences were not strong enough.

We also tested individual differences in the P300 response based on the degree to which one’s self-concept was independent or interdependent. We found that an individual’s level of interdependence may play a role in the ERP activity elicited from self-referential or other-referential stimuli at Cz, but found no relationship between an individual’s level of independence and ERP activity. This potentially means that although one’s level of interdependence is a factor in eliciting a P300 response to self and other stimuli, independence does not factor in. Because these results are based on a single scale assessing independent and interdependent selves, it is uncertain whether the result would be robust when replicated in another larger sample when other measures are used to assess self-concept. For example, there is also evidence that the way self-measurement is tested can greatly impact the results. Grace and Cramer (2003) showed that there were low intercorrelations between the SCS and the Twenty Statements Test (Singelis, 1994; Kuhn & McPartland, 1954). It would be interesting to further evaluate participants’ interdependence using alternative measures, as a high level of interdependence may have contributed to the convergence of self and other in the ERP data.
Although we did not have a priori prediction, we found latency differences at the Pz and Cz channels, indicating that the P300 response occurs slightly earlier for self than other stimuli. Previous research has found that latency for attentional components becomes delayed with age, reflecting a slowing down of the speed of processing (Gazzaley, 2011). Perhaps it is the case that items that are not prioritized show attentionally-modulated delays in latency. Conversely, when a stimulus is prioritized, latency is accelerated by attention. In the context of the current study, this suggests that it takes longer to process other-referential information over self-referential information, meaning that self is prioritized over other in processing. Further experiments investigating speed of processing as it relates to attention by comparing latency to a control condition may provide a potential link between prioritized attention and earlier latency.

In addition to limitations caused by high artifact rejection and insufficient numbers of trials, another limitation in this study was the lack of a control condition. P300 has also been implicated in attentional processing and orienting of attention (Fan et al., 2011; Zhong et al., 2013). The link between P300 and attentional effects is thought to be related to the role of self-relevance in the selection of information that merits further processing. P300 latency analyses show that self-relevant effects are present during processing related to selective attention (Gray, Ambady, Lowenthal, & Deldin, 2003). It is possible that because the paradigm elicited the same amount of attention from the participants, the P300 was elicited for both self and other conditions because they were similarly prioritized in attentional processing. Although we established the presence of a P300 for both self and other conditions by comparing them to a baseline of 0, being able to compare the self and other conditions against a control condition could provide some additional insights into the underlying processes. For example, results could indicate that because the P300 component is likely elicited by attentional orienting, a control condition in which an
adjective is presented on the screen with cues to attend or ignore would elicit a reduced P300 response in the ignore condition, in contrast to the prioritized processing for both self and other conditions. This could serve as a check of whether or not the P300 was elicited by attention in this paradigm. It is also clear that a next step for this research is to run an experiment using more self-relevant cues, such as autobiographical facts or a picture of the participant’s face. This will provide further insights into the attentional nature of the P300 component and will allow for analyses of subsequent memory.

The results presented here suggest new directions in research for both the P300 component of ERP and for the self-referential effect of memory. It is clear that self-referencing is sensitive to task demands, and that small differences across paradigms can result in very different effects. The present work is important in beginning to unite fMRI research on self-referencing with ERP research. Although using cued evaluation of self and other for adjectives, the paradigm employed in the present study, revealed strong self-referencing effects of memory using fMRI methods it may be the case that ERP is insufficiently sensitive to these effects and requires a stronger manipulation of self-relevance to elicit the same results as with fMRI (Kelley, Macrae, Wyland, Caglar, Inati, & Heatherton 2006; Jenkins, Macrae, & Mitchell 2008; Gutchess, Kensinger, & Schacter 2007). It may also be the case that P300 is not the component that best differentiates self from other. As previously discussed, P300 has been implicated in attentional processing (Fan et al., 2011). However, there is some evidence that other attentional components, such as N1 and N2, are involved in self-referential processing, but this could be due to an expectation effect due to attention and not specific to self-relevance (Zhong et al., 2013). In other words, it is possible that the paradigm created expectations that might have allowed participants to prepare differently for self versus other trials, rather than reflecting attention
differences elicited by the stimuli themselves. A late positive potential (LPP) is another component that has been implicated in effortful encoding and self-evaluation (Waters & Tucker, 2016). It is possible that there would be self/other differences found at the LPP that were not picked up in this experiment due to the time window not extending to the peak of LPP, as there is some evidence of a larger LPP elicited for self-related stimuli than other-related stimuli (Zhu, Luo, Zhao, Hu, Yan, & Gao, 2015). Even though there does not appear to be evidence of an LPP before 800 msec in our data, a timepoint that would typically capture the start of an LPP, it may be that self and other affect the peak of the LPP at a time point outside of our measurement window (Zhu, Luo, Zhao, Hu, Yan, & Gao, 2015). The possibility of the involvement of other components beyond P300 certainly warrants further investigation. Considering the ways in which the P300 reflects memory formation for self- versus other-referenced trials is a tantalizing new step for the research. This direction may be particularly promising given suggestions that the magnitude of the difference in the P300 response to self when compared to other is related to the degree of memory enhancement for self-referenced information (Fan et al., 2011). This experiment shows that both self-referential and other-referential stimuli modulate attention at the P300 component, suggesting new insights into the interaction between attention and self-referential processing.
References


Figure 1. Effects of self and other; P300 effect was similar for self and other at Fz (a), Pz (b), and Cz (c). Grand averages per condition and difference waves (self – other) for three midline sites. Grand average waveforms for self (black), other (red) and difference waves (blue) for three midline sites; positive plotted upwards.
Figure 1d. Scalp activations shown for the mean amplitude of the self and other stimuli in a representative participant during the P300 window (350-650 ms).
Figure 2. Correlations between the self-referential memory improvement score, the difference between the behavioral self and other memory conditions, and the differences in ERP elicited from self and other stimuli. At the Fz (a) and Cz (c) channels, behavioral differences between self and other stimuli as they affect memory correspond to ERP differences elicited from self and other stimuli. At Pz (b), there was not a significant difference wave correlation.
**Figure 3.** Individual level of interdependence (from SCS measures) was correlated with the difference waves between self and other at Fz (a), Pz (b), and Cz (c). The significant negative correlation between the difference wave at Cz (c) means that an individual’s level of interdependence may play a role in the ERP activity elicited from self-referential or other-referential stimuli at Cz. There were no significant correlations found for interdependence at Fz (a) or Pz (b).
Figure 4. Individual level of independence (from SCS measures) was correlated with the difference waves between self and other at Fz (a), Pz (b), and Cz (c). There were no significant correlations between independence scores and the three midline channels.