NeuroImage 67 (2013) 247–256

Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Neural oscillations dissociate between self-related attentional orientation versus evaluation

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ARTICLE INFO

Article history:
Accepted 14 November 2012
Available online 27 November 2012

Keywords:
EEG
Neural oscillation
Phase synchrony
Self-reflection
Trait judgment

ABSTRACT

To investigate whether self-reflection on personality traits engages distinct neural mechanisms of self-related attentional orientation and self-related evaluation, we recorded electroencephalograms from adults while they made trait judgments about themselves and an age- and gender-matched friend, or judgments of word valence. Each trial consisted of a cue word that indicated a target person for trait judgment or instructed valence judgment, followed by a trait adjective to be evaluated. Using a wavelet analysis, we calculated time–frequency power at each electrode and phase synchrony between electrode pairs associated with self-, friend- or valence-cues and with trait adjectives during trait or valence judgments. Relative to friend- and valence-cues, self-cues elicited increased synchronous activity in delta (2–4 Hz), theta (5–7 Hz), alpha (8–13 Hz), beta (14–26 Hz), and gamma (28–40 Hz) bands, and increased large-scale phase synchrony in these frequency bands. Self-related evaluation compared to friend-related evaluation during trait judgments induced stronger desynchronization in alpha, beta and gamma band activities, and decreased phase synchrony in alpha and gamma band activities. Our findings suggest that self-related attentional orientation and self-related evaluation engage distinct neural mechanisms that are respectively characterized by synchrony and desynchrony of neural activity in local assemblies and between long-distance brain regions.

Introduction

Self-reflection is an important feature of human thought and plays a key role in human behavior. The neural substrates underlying self-reflection have been investigated extensively by combining functional magnetic resonance imaging (fMRI) (for reviews, see Han and Northoff, 2009; Heatherton, 2011; Northoff et al., 2006) with the self-referential task that requires judgments of one's own personality traits (Rogers et al., 1977). Increased blood-oxygen-level-dependent (BOLD) signals in the cortical midline structure, including the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC), have been observed during trait judgments of the self compared to a celebrity (Fossati et al., 2003; Han et al., 2008; Heatherton et al., 2006; Kelley et al., 2002; Ma and Han, 2011; Ma et al., in press; Macrae et al., 2004; Moran et al., 2006; Zhu et al., 2007; Zysset et al., 2002), indicating that these brain regions are involved in self-reflection on personality traits. While the self-referential task requires both orienting attention to the self and evaluating one's own personality traits, the previous fMRI findings did not dissociate the neural substrates involved in self-related attentional orientation and self-related evaluation due to the low time resolution of the BOLD signal and the paradigms employed by fMRI studies.

Previous fMRI studies of self-referential processing have primarily employed two behavioral paradigms. The first paradigm used a block design in which participants performed a self-judgment task in one block of trials and a celebrity-judgment task in another (e.g., Han et al., 2008, 2010; Ma et al., in press; Wang et al., 2012; Zhu et al., 2007). This paradigm required an attentional shift towards the self or a celebrity between successive blocks of trials but not between successive trials, and thus cannot dissociate the neural activity related to self-related attentional orientation versus self-related evaluation. The second paradigm utilized an event-related design in which each trial consisted of a cue word that defines the judgment task and trait adjective for evaluation (e.g., Heatherton et al., 2006; Kelley et al., 2002; Moran et al., 2006). In this paradigm, the judgment task varied across trials such that participants had to shift their attention towards either the self or others first and then to evaluate whether the trait adjective described the target person. However, as the cue word and trait adjective were presented simultaneously in this paradigm (e.g., Heatherton et al., 2006; Kelley et al., 2002), the previous fMRI research using this event-related design was unable to separate the neural substrates involved in self-related attentional orientation versus self-related evaluation either.

To disentangle the neural mechanisms involved in self-related attentional orientation and self-related evaluation, it is necessary to record the neural activity that is elicited by cue words and trait adjectives in the self-referential task, separately. This requires a technique to record neural activity with a high temporal resolution.

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1053-8119/$ – see front matter
http://dx.doi.org/10.1016/j.neuroimage.2012.11.016

Electroencephalogram (EEG) has a temporal resolution of a millisecond and has been used in recent studies of neural activity underlying self-referential processing (e.g., Fields and Kuperberg, 2012; Magno and Allan, 2007; Mu and Han, 2010; Shestyuk and Deldin, 2010; Watson and Dritschel, 2007). Using a block design, Mu and Han (2010) found that phase-locked event-related potentials (ERPs) showed an increased positivity at 200–400 ms after stimulus onset over the frontal area (P2) and an enlarged positivity at 400–1000 ms over the frontal/central areas (P3) during trait judgments on the self compared to a celebrity. Shestyuk and Deldin (2010) also used a block design to investigate ERPs sensitive to the valence of self-referential words and found that positive versus negative words evoked larger amplitudes of the P2 and a late positive component. Magno and Allan (2007) used an event-related design to examine the neural activity associated with autobiographical memory. On each trial, the cue “self” or “friend” was presented first, followed by a word that served as an autobiographical memory cue. The self or friend cue instructed participants to retrieve a specific personal episode that was related to the autobiographical memory cue. Similarly, Magno and Allan (2007) identified neural correlates of self-referential processing by contrasting ERPs evoked by autobiographical memory cues in the self versus friend conditions and found that retrieval of one's own specific personal episodes elicited an increased positive shift of the ERPs at 100–1700 ms. Fields and Kuperberg (2012) also reported increased positivity over the frontal/central region to neutral words imbedded in a sentence when referenced to the self compared to others.

Self-referential processing has also been associated with modulations of non-phase-locked neural oscillations. Using the wavelet analysis (Kronland–Martinet et al., 1987), Mu and Han (2010) analyzed non-phase-locked time–frequency (TF) power linked to trait adjectives referenced to the self or to a celebrity at theta (5–7 Hz), alpha (8–13 Hz), beta (14–27 Hz), and gamma (28–40Hz) bands. They found that, relative to other-referential trait adjectives, self-referential trait adjectives induced event-related synchronization (ERS) of theta-band activity over the frontal area at 700–800 ms and of alpha-band activity over the central area at 400–600 ms. In contrast, event-related desynchronization (ERD) associated with self-referential trait adjectives was observed in beta band activity over the central/parietal area at 700–800 ms and in gamma-band activity over the frontal/central area at 500–600 ms. These findings suggested that both ERS and ERD of neural oscillations were engaged in the self-referential processing but did not distinguish neural activity elicited by cues that shifted attention to the self or others from that elicited by trait adjectives during evaluation of self or others. Thus it remains unclear whether self-related attentional orientation and self-related evaluation are mediated by distinct neural mechanisms.

The current study used a modified event-related design to disentangle the neural activity underlying self-related attentional orientation versus evaluation during the self-referential task. In Experiment 1, trials consisted of an instruction cue followed by a trait adjective (Fig. 1). A cue word, which was either “self,” a friend's name, or “valence,” was presented first. Self-cue and friend-cue instructed participants to make judgments of whether the following trait adjective described the self or the friend, respectively. Valence-cue indicated judgments of valence (positive vs. negative) of the following trait adjective. We recorded EEG to both cue words and trait adjectives during trait and valence judgments. This allowed us to analyze the neural activity linked to the process of both self-related attentional orientation by comparing EEGs to self-cue and friend-cue and the neural activity associated with self-related evaluation by comparing EEGs to trait adjectives during self- or friend-judgments. Valence-cues and valence-judgment provided a baseline to control for semantic processing and motor responses. To assess the degree to which neural activity in response to the cues in Experiment 1 reflected semantic processing of the self-, friend-, and valence-cues, Experiment 2 presented participants with only the cue words and asked them to perform a semantic discrimination task on the cue words. The neural activity that was elicited by the cue words in Experiment 1, but not modulated by the same cue words in Experiment 2, was specifically associated with self-related attentional orientation.

Similar to our previous research (Mu and Han, 2010), the current study used wavelet analysis to calculate non-phase-locked TF power with a high temporal resolution elicited by cue words and trait adjectives, separately. We compared the non-phase-locked neural activity to the cue words and trait adjectives referenced to the self versus a friend to dissociate neural oscillations involved in self-related attentional orientation and self-related evaluation of personality traits. It has long been known that ERD of non-phase-locked neural activity is associated with increased cellular excitability in thalamo-cortical systems (Steriade and Llinas, 1988) and is interpreted as an electrophysiological correlate of activated cortical areas involved in processing of sensory or cognitive information (Pfurtscheller, 1992). An increased ERD may reflect the involvement of a larger neural network or more cell assemblies in information processing. ERS reflects the synchronized activity of a large number of neurons (Pfurtscheller et al., 1996). ERS of low frequency band activity (e.g., alpha band) occurs during an idling brain state or during expectation of sensory stimuli whereas ERS of high frequency band activity (e.g., gamma band) is associated with a binding of sensory information or sensorimotor integration (see Pfurtscheller and Lopes da Silva, 1999 for review). Mu and Han's (2010) findings suggest that complicated neural processes are engaged in self-referential processing. However, the block design used in the study did not allow us to test whether the ERS and ERD activity was engaged in self-related attentional orientation or self-related evaluation, or both. If, for example, the alpha band ERS arose from an inner-directed attentional demand during the self-referential processing, whereas the alpha band ERD reflects enhanced task demand during evaluation of self-related trait adjectives (Mu and Han, 2010), the ERS and ERD activity patterns may dissociate

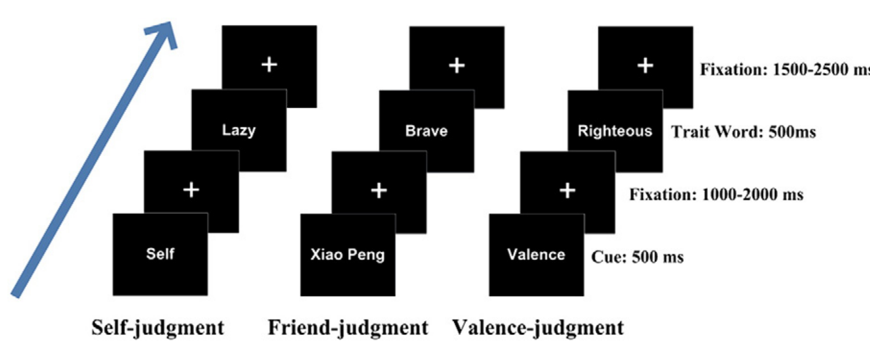

Fig. 1. Illustration of the event-related design in Experiment 1. Each trial consisted of a cue of upcoming task demand, followed by a trait adjective for trait judgments on oneself or a friend or for valence judgments. Both cue words and trait adjectives were in Chinese.