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# Oxytocin effects on neural correlates of self-referential processing

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ABSTRACT

Oxytocin (OT) influences how humans process information about others. Whether OT affects the processing of information about oneself remains unknown. Using a double-blind, placebo-controlled within-subject design, we recorded event-related potentials (ERPs) from adults during trait judgments about oneself and a celebrity and during judgments on word valence, after intranasal OT or placebo administration. We found that OT vs. placebo treatment reduced the differential amplitudes of a fronto-central positivity at 220–280 ms (P2) during self- vs. valence-judgments. OT vs. placebo treatment tended to reduce the differential amplitude of a late positive potential at 520–1000 ms (LPP) during self-judgments but to increase the differential LPP amplitude during other-judgments. OT effects on the differential P2 and LPP amplitudes to self- vs. celebrity-judgments were positively correlated with a measure of interdependence of self-construals. Thus OT modulates the neural correlates of self-referential processing and this effect varies as a function of interdependence.



## 1. Introduction

Oxytocin (OT) is a peptide hormone produced in the hypothalamus and plays an important role in social cognition and social behavior. Animal studies have shown that OT contributes to the development of prosocial behavior such as mother–infant attachment, grooming, and approach behavior (see Lim & Young, 2006 for review). In humans, OT promotes social trust and cooperation such that individuals receiving intranasal sprays of OT compared to a placebo are more inclined to invest money in others even when there is no guarantee of reciprocation (Kosfeld, Heinrichs, Zak, Fischbacher, & Fehr, 2005). To account for the enhanced prosociality induced by OT, previous studies focused on how OT treatment affects the processing of information about conspecific others. It has been shown that, relative to placebo administration, intranasal OT results in increased sensitivity to others' facial expressions (Marsh, Yu, Pine, & Blair, 2010; Schulze et al., 2011), better understanding of others' thoughts and intentions (Domes, Heinrichs, Michel, Berger, & Herpertz, 2007), and enhanced perception of trustworthy and attractiveness of others' faces (Theodoridou, Rowe, Penton-Voak, & Rogers, 2009, see Campbell, 2010 for review).

There is also increasing evidence that OT modulates neural activities involved in the processing of social cues (see Zink & Meyer-Lindenberg, 2012 for review). Functional magnetic resonance imaging (fMRI) studies found that intranasal OT administration decreased neural responses in the amygdala during implicit (Domes, Heinrichs, Glascher, et al., 2007) and explicit (Gamer, Zurowski, & Buchel, 2010) processing of fearful facial expressions in males but increased amygdala activity during explicit processing of fearful faces in females (Domes et al., 2010). An electroencephalograph (EEG) study showed that, while perception of social stimuli (e.g., a point-light display of human biological motion) was associated with suppression of EEG activity in the mu/alpha and beta bands (Perry, Troje, & Bentin, 2010; Ulloa & Pineda, 2007), this suppression was significantly enhanced following intranasal OT versus placebo treatment (Perry, Bentin, et al., 2010). OT also modulated the amplitudes of event-related potentials (ERPs) elicited by facial stimuli such that OT, compared to a placebo, increased the amplitude of a frontal positivity at 140–180 ms and the amplitude of a late positive potential (LPP) at 400–800 ms over the parietal region in response to emotional faces (Huffmeijer et al., 2013). Moreover, OT interacts with social factors to modulate neural activities to emotional cues. Sheng, Liu, Zhou, Zhou, and Han (2013) recorded ERPs from Chinese adults while they perceived pain or neutral facial expressions of Asian and Caucasian models. They first showed that, in the placebo condition, pain compared to neutral expressions increased the amplitude of a fronto-central positive activity at 128–188 ms (P2) and this effect was evident for Asian but not for Caucasian models. This replicates the racial bias in empathic neural responses (Sheng & Han, 2012). Moreover, Sheng et al. (2013) found that OT compared to a placebo increased the P2 empathic neural responses to pain vs. neutral

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expressions of Asian but not Caucasian models, suggesting that OT may selectively enhanced the neural activity to facial expressions of racial in-group (but not out-group) members.

The reciprocally interconnected role of self related and other related processing in social cognition has been widely discussed. How one thinks of the self and the relationship between the self and others significantly influence social interaction. For example, a person may expend self-concept to include close others in order to acquire resources, perspectives, and identities from others and to enhance one's own ability to accomplish goals (Aron et al., 2004). Self-other merging facilitates cooperation in social dilemmas (Cremer & Stouten, 2003) and perceived "oneness" (i.e., one comes to incorporate the self within the boundaries of the other) or perceptions of self in relation to others links to emotional empathy (Burris & Rempel, 2012; Cialdini, Brown, Lewis, Luce, & Neuberg, 1997). Previous studies of OT effects on neural correlates of social cognition have focused exclusively on other-related processing. There has been no existing data so far on how OT affects neural correlates of self-related processing.

Consistent with the idea that the processes of the self and others are the two sides of social cognition (Iacoboni, 2006; Sedikides & Skowronski, 2009), it has been shown that priming independent vs. interdependent self-construals in Chinese participants speeded their responses to their own faces but slowed their responses to others' faces (Sui & Han, 2007). Moreover, while fMRI studies suggest that the medial prefrontal cortex and anterior cingulate cortex are engaged in self-referential processing of personality traits (Heatherton, 2011; Kelley et al., 2002; Ma & Han, 2011; Ma et al., 2013; Northoff et al., 2006; Wang et al., 2012; Zhu, Zhang, Fan, & Han, 2007), priming bicultural Chinese (i.e., students from Hong Kong) with Chinese vs. Western cultures enhanced the medial prefrontal activity related to self-referential processing but decreased the medial prefrontal activity involved in other-related processing (Ng, Han, Mao, & Lai, 2010). These findings suggest that the same psychological manipulation can modulate the neural processing of oneself and others in opposite directions. OT may produce similar effects, that is, if OT alters social cognition by increasing the salience of social cues related to others or enhancing attentional processing of others (Bartz, Zaki, Bolger, & Ochsner, 2011; Perry, Bentin, et al., 2010; Shamay-Tsoory et al., 2009), it may be proposed that OT would decrease the salience of self-related information or weaken self-related processing in tasks such as trait judgments.

A recent behavioral study found that intranasal OT versus placebo administration increased self-reported ratings of one's own extraversion and openness to experiences (Cardoso, Ellenbogen, & Linnen, 2012). This finding suggests that OT influences self-perceived personality traits that are important for social affiliation. However, measurements of subjective ratings do not reveal how the neurocognitive mechanisms involved in self-referential processing are affected by OT treatment. Thus the present study investigated how intranasal OT influences the neural activity involved in self-referential processing by recording ERPs during a self-referential task that requires judgments about the personality traits of oneself. A trait judgment task performed on a celebrity who was known to all participants was included to test whether OT also modulates the neural processing of others during trait judgments. A valence judgment task was included to serve as a baseline to control for semantic processing and motor responses.

Previous ERP research has linked self-referential processing to positive activities over broad regions (Fields & Kuperberg, 2012; Magno & Allan, 2007; Mu & Han, 2010). Particularly related to the current work, Mu and Han (2010) found that a fronto-central positive activity was associated with self-referential processing because trait judgments of oneself versus a celebrity elicited larger amplitudes of the fronto-central positivity as early as 200 ms after sensory stimulation. Given that modulations of ERPs related to the processing of others (e.g., Sheng & Han, 2012; Sheng, Liu, Zhou, Zhou, & Han, 2013) and the self (e.g., Mu & Han, 2010) occurs in the same time course and over the same brain regions, it may be hypothesized that OT relative to a placebo may produce opposite effects on self- and other-referential processing during trait judgments. This hypothesis has a premise that the fronto-central activity in the P2 time window associated with self-referential processing and the processing of others arises from the same neural structure and OT effects occurs in the same time course during self-referential and other-referential processing. Specifically, we predicted that, relative to placebo treatment, OT treatment may decreases the fronto-central activity related to self-referential processing during the task of trait judgment. In contrast, OT vs. placebo may increase the frontal-central activity associated with the processing of others during the trait judgment task.

In addition, we examined whether OT effects on self-referential processing vary across individuals with different self-construals. It has been shown that the effects of OT in the social domain are constrained by features of situations and/or individuals (Bartz et al., 2011). OT (vs. placebo) effects on memories of childhood maternal care and closeness are moderated by the attachment representations people possess (Bartz, Zaki, Ochsner, et al., 2010). These findings suggest that OT effects on neural activities involved in social cognition may vary as a function of individuals' attributes. It is well known that individuals from Western cultures view the self as an autonomous entity that is independent of social contexts and others (i.e., having independent self-construals), whereas East Asians view the self as being strongly connected with others (i.e., having interdependent self-construals) (Han & Northoff, 2009; Markus & Kitayama, 1991, 2010; Zhu & Han, 2008). Moreover, the effect of social influences on self-related processing is stronger in individuals from sociocultural contexts that encourage interdependent than independent self-construals (Liew, Ma, Han, & Aziz-Zadeh, 2011; Ma & Han, 2009, 2010). Therefore, the current study tested whether differential self- versus other-referential processing is more sensitive to biological influences (i.e., intranasal OT treatment) in individuals with stronger interdependent self-construals.

## 2. Methods

### 2.1. Participants

Twenty male adults (mean age = 22.0, SD = 1.96 yrs) participated in this study as paid volunteers. Exclusion criteria included self-reported medical or psychiatric illness and use of medication. All were right-handed and had normal or corrected-to-normal vision. Informed consent was obtained prior to participation. This study was approved by a local ethics committee.

### 2.2. Stimuli and procedure

288 Chinese trait adjectives, each consisting of two Chinese characters, were selected from an established personality trait adjective pool (Liu, 1990) for personality trait or valence judgments. For each participant these trait adjectives were randomly classified into 4 lists of 72 words with half positive and half negative words in each list.

In a double-blind, placebo-controlled within-subject design, participants participated in two EEG sessions with an interval of at least 6 days. Before each EEG session, 32 IU OT or placebo (containing all of the active ingredients except for the neuropeptide) was administered with a nasal spray. The spray was administered to participants four times to each nostril and each administration consisted of one inhalation of the spray with 4 IU. The procedure of OT and placebo administration was similar to the previous work that showed significant OT effects on either behavior (De Dreu et al., 2010; Mikolajczak, Pinon, Lane, de Timary, & Luminet, 2010) and brain activity (Petrovic, Kalisch, Singer, & Dolan, 2008; Sheng et al., 2013). Treatment (OT vs. placebo) orders were counterbalanced across participants. After OT or placebo administration, participants took a break of 45 min before EEG recording.

The experimental procedure is illustrated in Fig. 1. After OT or placebo administration, each participant performed 4 blocks of 72 trials for trait/valence judgments while EEG was recorded. Two lists of 72 words were used twice for each EEG session. Within each block participants had to make yes/no judgments on whether a trait

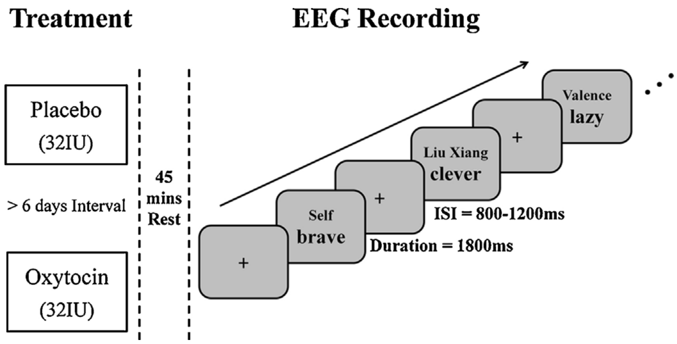


**Fig. 1.** Illustration of the procedure and stimuli used in the current study. Both the cue and stimuli words were in Chinese.

adjective can describe the self on 24 trials, whether a trait adjective can describe Liu Xiang (a well-known Chinese athlete) on 24 trials, and the valence (positive vs. negative) of a trait adjective on 24 trials. Half positive and half negative trait adjectives were used for each type of judgments within each block.

We used an event-related design with the target person and the adjective were presented in a random order within each block. On each trial, a trait adjective were presented at the center of the screen with a cue word (self, Liu Xiang, valence) above it for 1800 ms, which were followed by a fixation with a duration that varied randomly between 800 and 1200 ms. Each character of a trait word subtended a visual angle of $0.7^\circ \times 0.7^\circ$ and each character of the cue word subtended a visual angle of $0.51^\circ \times 0.51^\circ$ at a viewing distance of 120 cm. Participants responded to each trait adjective by pressing one of the two buttons using the left or right thumb. The relation between responding hands and yes/no response for trait judgments and positive/negative response for valence judgments were counterbalanced across participants.

Participants completed the Self-Construal Scale (Singelis, 1994) after the second session of EEG recording. The Self-Construal Scale consists of 24-items that assess one's independent and interdependent self-construals on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). Interdependence was defined by the difference between the sum score of the12 interdependent self-construal items and the sum score of the 12 independent self-construal items. Higher difference scores indicate greater interdependent cultural values, similar to the previous research (Ma et al., 2013).

### 2.3. EEG data recoding and analysis

EEG was recorded during the judgment tasks from 62 scalp electrodes that were mounted on an elastic cap according to the extended 10–20 system. EEG was referenced to the algebraic average of the electrodes at the left and right mastoids. The electrode impedance of each electrode was kept less than 5 kΩ. Eye blinks and vertical eye movement were monitored with electrodes located above and below the left eye. The horizontal electrooculogram was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. The EEG was amplified (band pass 0.01–100 Hz), digitized at a sampling rate of 250 Hz and stored for off-line analysis. Trials contaminated by eye blinks, eye movements, or muscle potentials exceeding $\pm 50\,\mu V$ at vertical electrode and trials containing behavioral errors (in valence-judgment task) were excluded from further analysis. ERPs were calculated separately in each condition (self-judgment, celebrity-judgment and valence-judgment after OT or placebo treatment). The ERPs in each condition were averaged separately off-line with an epoch beginning 200 ms before stimulus onset and continuing for 1800 ms. Similar numbers of trials remained in the analysis after the artifacts rejection (ranged between 40 and 94 across all participants, mean number of trials included were self/other/valence = 75.5/75.5/72.3 in the OT condition, and self/other/valence = 74.0/74.1/72.0 in the placebo condition, $Ps > 0.05$). Preliminary repeated measures analyses of variance (ANOVAs) of ERP data at bilateral electrodes included Hemisphere (electrode over the left vs. right hemispheres) as a within-subjects variable. The effect of Hemisphere and its interaction with other variables was not significant and thus was not reported in Section 3.

Both voltage topography and the standardized Low Resolution Brain Electromagnetic Tomography (sLORETA, Pascual-Marqui, 2002) were used to estimate potential sources of the OT effects on the neural activity related to self- vs. other-referential processing. sLORETA is a linear method of computing statistical maps from EEG data that reveal locations of the underlying source processes and does not require a priori hypotheses regarding the field distribution of the active sources. We performed analysis using sLORETA to assess the 3D current source of neural activity that showed an effect of OT on differential ERPs between self- and other-reference. A boundary element model was first created with about 5000 nodes from a realistic head model. Statistical nonparametric mapping was calculated in specific time windows to estimate potential sources of OT effects on the neural activity related to self- vs. other-referential processing. The log of the F ratio of averages was used and considered with a 0.95 level of significance.

## 3. Results

### 3.1. Behavioral results

Reaction times to trait and valence-judgments were subjected to an ANOVA with Treatment (OT vs. placebo) and Task (Self, Other vs. Valence) as independent within-subjects variables. There was a significant main effect of Task ($F(2, 38) = 7.59$, $P < 0.01$) due to faster responses to self-judgments than to celebrity-judgments ($P < 0.01$) or valence-judgments ($P < 0.01$). However, these effects did not differ between OT and Placebo conditions ($F < 1$). Questionnaire measurement of independent and of interdependent self-construal showed that each was above the midpoint and the interdependence score was significantly higher than the independence score ($62.68 \pm 7.41$ vs.$55.89 \pm 6.59$, $t(18) = 3.27$, $P = 0.004$). Rating scores of interdependence and independence were not correlated with each other ($r(19) = 0.17$, $P = 0.49$)

### 3.2. ERP results

Fig. 2 illustrates the ERPs to trait and valence judgments after placebo and OT treatment, respectively. Trait adjectives during both trait and valence judgments elicited a frontal negativity at 80–120 ms (N1), a positivity at 220–280 ms (P2) widely distributed over the frontal/central/parietal electrodes, and a late positive potential (LPP) at 520–1000 ms over the frontal/central/parietal regions.

Mean amplitudes of the N1, P2 and LPP were measured in the time window around the peak latency of each component (i.e., N1: 80–120 ms; P2: 220–280 ms; LPP: 520–1000 ms). The analyses of ERPs amplitudes focused on the P2 components over the fronto-central electrodes and the LPP amplitudes over the fronto-centro-parietal electrodes because the amplitudes of ERPs in the P2 and LPP time windows over these electrodes have been shown to be sensitive to the processing of one self (Mu & Han, 2010) and others (Sheng & Han, 2012; Sheng et al., 2013). The mean amplitude of each ERP components was first subjected to ANOVAs with Treatment (OT vs. Placebo) and Task (Self, Celebrity, or Valence judgments) as within-subjects independent variables. The ANOVAs of the mean N1 amplitude at 80–120 ms over the frontal electrodes showed no significant main effects or interactions ($Fs < 2$, $Ps > 0.1$). However, the ANOVAs of the mean P2 amplitude at 220–280 ms showed a significant interaction between Treatment and Task over the fronto-central electrodes ($F(2, 38) = 3.70$–$10.33$, $Ps < 0.05$ at F4, F8, FC2, FC4, C3, C5, CP3, CP5). Similarly, the ANOVAs of the mean LPP amplitudes at 520–1000 ms also showed significant interactions between Treatment and Task over the fronto-central electrodes ($F(2, 38) = 3.30$ to $3.98$, $Ps < 0.05$ at F5, FZ, FC1, FC5). These results suggest that the modulations of the P2 and LPP by trait and valence judgment tasks were different between OT and placebo conditions.

To further examine OT effects on self-referential and other-referential processing, we first compared N1, P2 and LPP amplitudes to valence-judgments between OT and Placebo conditions and did not find significant differences ($t = -1.13$ to $1.86$, $Ps > 0.05$). This indicates that the valence-judgment task is an adequate control condition controlling for the perceptual and motor demands of the task but not interacting with the key variables under investigation. Then we calculated difference waves by subtracting ERPs to valence-judgments from those to self- and celebrity -judgments to assess the neural activity related to self-referential and other-referential processing in OT and Placebo condition, respectively. We then conducted 2 (Treatment: OT vs. placebo) by 2 (Task: Self vs. Celebrity) ANOVAs of the amplitudes of difference waves to examine differential OT effects on the neural activity involved in self- and other-referential processing. The ANOVAs of the mean differential amplitudes in the N1 time window did not

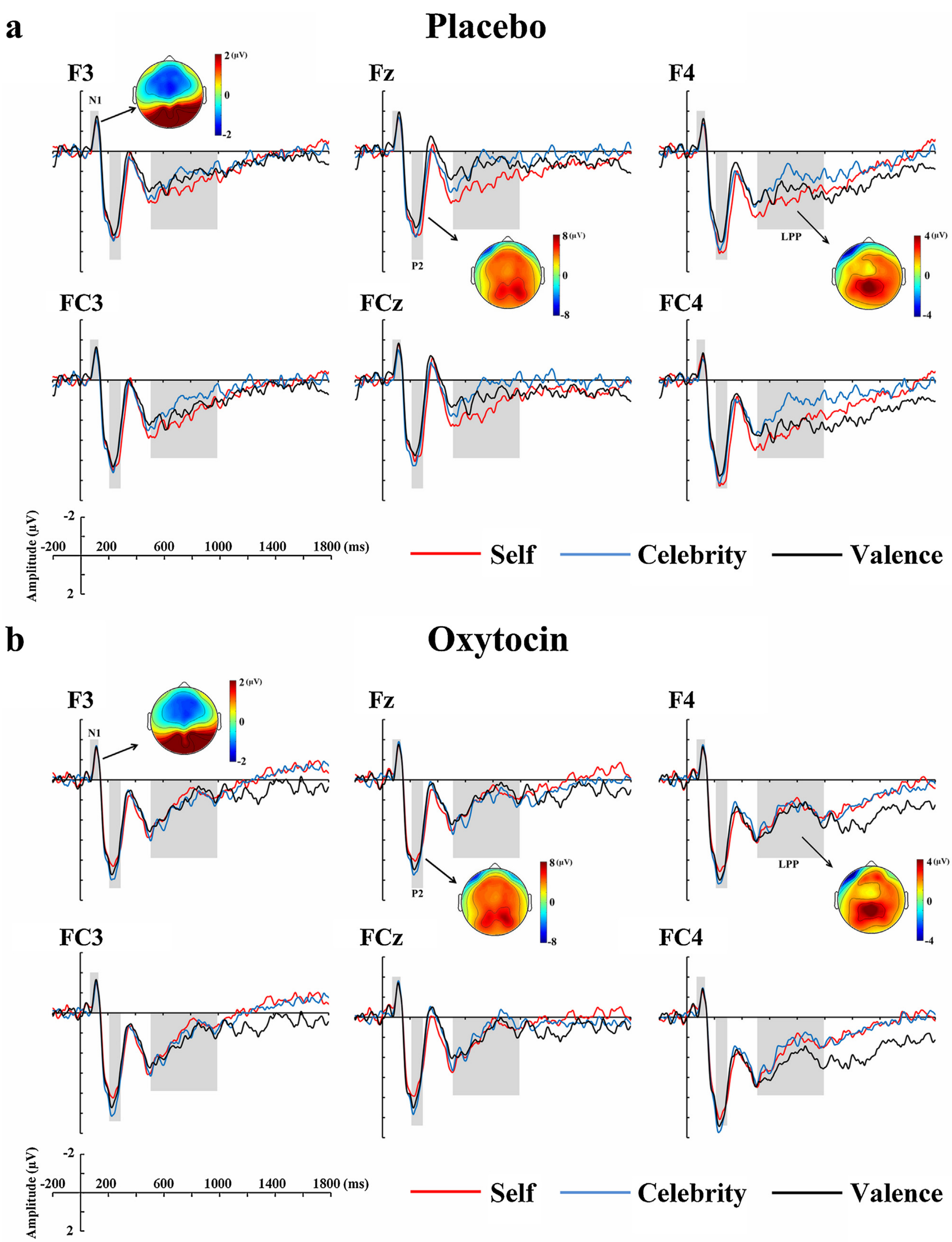


**Fig. 2.** Illustration of ERPs recorded at F3, F4, Fz, FC3, FC4, FCz to self-, celebrity-, and valence-judgment and the topographies of N1, P2 and LPP after (a) placebo and (b) oxytocin treatment. The gray areas indicate the time windows in which the P2 and LPP amplitudes were measured.

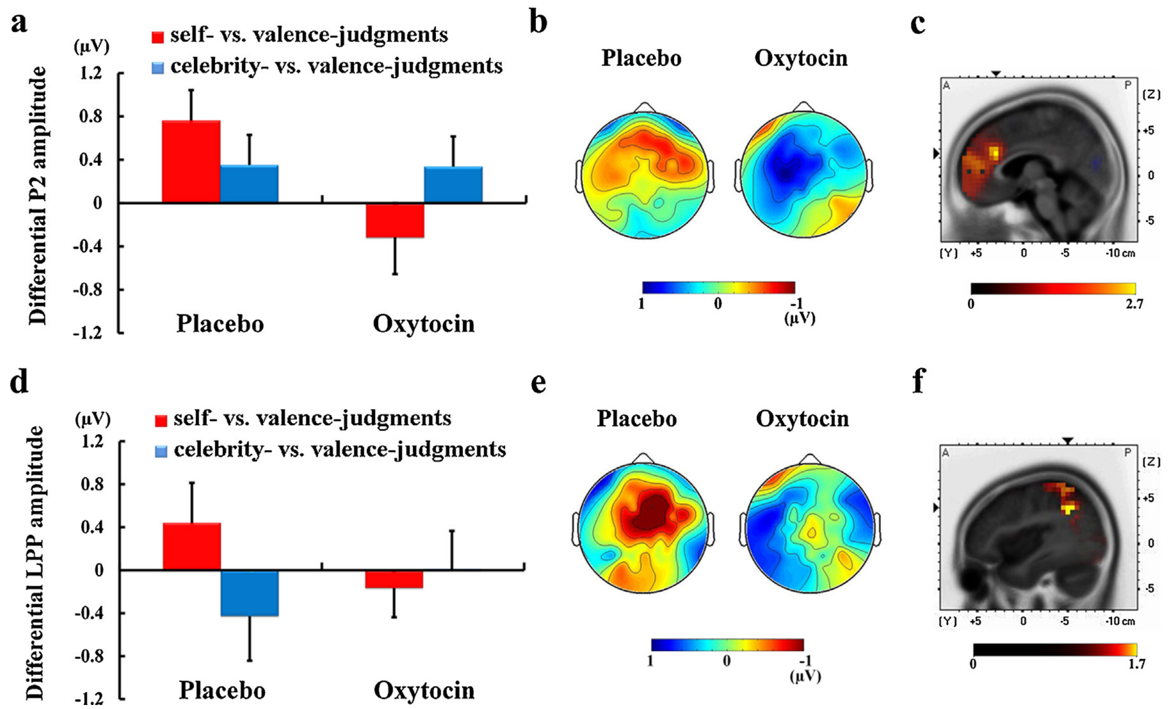


**Fig. 3.** (a) The mean amplitude of the difference wave at 220–280 ms obtained by subtracting the ERPs to valence-judgment from those to self- or celebrity-judgment at fronto-central electrodes. (b) Topographies of the difference wave of self- vs. celebrity-judgments in the P2 time window in OT and placebo conditions, respectively. The difference wave showed a positivity over the fronto-central region in the placebo condition but a negative over the same region in the OT condition. (c) Source estimation of the OT effect in the P2 time window on self- and other-referential processing. The maximum OT effect was observed over the anterior cingulated and medial prefrontal cortex. (d) The mean amplitude of the difference wave at 520–1000 ms obtained by subtracting ERPs to valence-judgment from those to self- or celebrity-judgment at fronto-central electrodes. (e) Topographies of the difference wave of self- vs. celebrity-judgment in the LPP time window in OT and placebo conditions, respectively. The difference wave showed a positivity over the fronto-central region in the placebo condition but not in the OT condition. (f) Source estimation of the differential OT effect in the LPP time window on self- and other-referential processing. The maximum OT effect was observed over the right inferior parietal lobule.

show any significant main effects or interactions ($Fs < 3$, $Ps > 0.05$). The ANOVAs of the mean differential amplitude in the P2 time window did not show significant main effects of Task or Treatment either ($Fs < 3$, $Ps > 0.05$). However, there was a significant interaction between Treatment and Task over the fronto-central electrodes ($F$ (1, 19) = 8.51–23.83; $Ps < 0.01$ at F4, F5, F6, F8, FC1, FC4, FC5, C3, C5, CP3, CP5, Fig. 3a and b). Simple effect analyses were further conducted and confirmed that OT treatment significantly reduced the P2 amplitudes to self- vs. valence-judgments compared with placebo treatment ($Ps < 0.05$). In contrast, the P2 amplitudes to celebrity- vs. valence-judgments did not differ significantly between OT and placebo conditions ($Ps > 0.1$).

The ANOVAs of the mean amplitudes of the difference waves in the LPP time window showed a significant main effect of Task over the fronto-central electrodes ($F$(1, 19) = 5.79–7.72, $Ps < 0.05$ at C2, CZ, FCZ, FC4). The main effect of Treatment was not significant ($Fs < 2$, $Ps > 0.05$). But there was a significant interaction between Treatment and Task ($F$ (1, 19) = 8.49–12.88; $Ps < 0.01$ at F2, F4, F5, FZ, FC1), suggesting that OT tended to decrease LPP amplitudes to self- vs. valence-judgments but to increase LPP amplitudes to celebrity- vs. valence-judgments (Fig. 3d and e). Simple effects did not show significant OT effects respectively on either self- or other-referential processing ($Ps > 0.05$), though the difference of LPP amplitudes between self- and other-referential processing was significant in the placebo condition ($Ps < 0.05$ at F2, F4, F6, FZ, FC1, FC4, FCZ, C3, C6) but not in the OT condition ($Ps > 0.05$).

To assess whether the OT effects in different time courses were independent, we first calculated the differential P2 and LPP amplitudes to self- vs. valence-judgments (and to celebrity- vs. valence-judgments) in the placebo and OT conditions, respectively. The OT effects were then quantified by subtracting the differential P2 (or LPP) amplitudes in the placebo condition from those in the OT condition. We then conducted correlation analyses to examine whether the OT effect in the P2 time window correlated with the OT effect in the LPP time window. This revealed significant correlations between the OT effects in the P2 and LPP time windows related to both self-referential and other-referential processing over the frontal and central electrodes (self: $r(20)$ = .476–.731, $Ps < .05$; other: $r(20)$ = .457–.737, $Ps < .05$; at F3–F8, FZ, FC1–FC6, FCZ, C1–C6, CZ). These results suggest that the OT effects in successive time windows of the processing of either the self or others were not independent.

To estimate the source of the differential OT effects on self- vs. other-referential processing, we first calculated the difference waves (self-judgments minus celebrity-judgments) in Placebo and OT conditions and then used sLORETA to assess the brain regions that showed significant discrepancy in the difference waves between placebo and OT conditions. This suggested potential sources of the differential OT effects in the P2 time window in the anterior cingulate and the medial prefrontal cortex (peak MNI coordinates: 5, 30, 25, Fig. 3c). Similar analysis of the differential OT effects in the LPP time window suggested a potential source in the right inferior parietal lobule (peak MNI coordinates: 40, −50, 40, Fig. 3f).

Finally, we assessed whether the differential OT effects on self- vs. other-referential processing (i.e., $(\text{Self-Other})_{\text{placebo}}$ minus $(\text{Self-Other})_{\text{OT}}$) were associated with participant's degree of interdependent self-construal. As subjects always completed the self-construal scale after the second session of the experiment, we included treatment order as a covariate for the correlation analysis to exclude the potential effect of treatment order on individuals' self-reported self-construal. We found that the differential OT effects on the differential P2 amplitudes to self- vs.

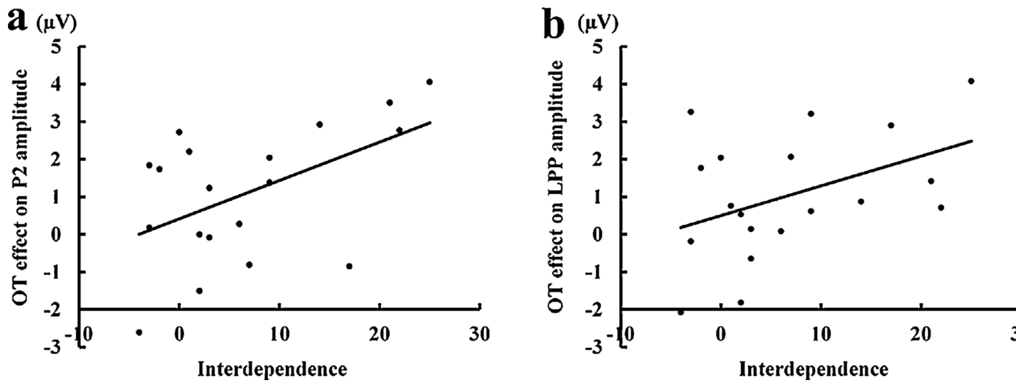


**Fig. 4.** (a) The correlation between the OT effect on the P2 amplitude at F5 to self- vs. celebrity-judgments (i.e., $(\text{Self-Other})_{\text{placebo}}$ minus $(\text{Self-Other})_{\text{OT}}$) and the rating score of interdependence. (b) The correlation between the OT effect on LPP amplitude at F5 to self- vs. celebrity-judgment (i.e., $(\text{Self-Other})_{\text{placebo}}$ minus $(\text{Self-Other})_{\text{OT}}$) and the rating score of interdependence.

celebrity-judgments were significantly positively correlated with the measurement of interdependence over the frontal/central/parietal electrodes ($rs = 0.81–0.51$; $Ps < 0.05$ at F4, F5, FC1, FC4, FC5, C3, C5, CP3, CP5; Fig. 4a). Similarly, the differential OT effects on the LPP amplitudes were positively correlated with the measurement of interdependence ($rs = 0.48–0.59$; $Ps < 0.05$ at F2, F5, FC1; Fig. 4b). Participants who self-reported greater interdependence showed greater OT effects on the neural activity related to self- vs. other-referential processing in P2 and LPP time windows.

## 4. Discussion

The present research examined the OT effects on the neural activity involved in self-referential processing. We recorded ERPs elicited by trait judgments about oneself and a celebrity and valence judgments of trait adjectives after placebo and OT treatment. Behavioral measurements showed faster responses during self-judgments compared to celebrity-judgments and valence-judgments. The ERP results in the placebo condition showed that self-referential processing was associated with increased ERP amplitudes over the fronto-central region in the LPP time window, whereas the N1 and P2 amplitudes failed to show evidence for modulations by self-referential processing. Several previous ERP studies have shown that the increased fronto-central positivity in the P2 and LPP time windows was associated with the processing of self-relevant vs. other-relevant stimuli such as personality trait words (Mu & Han, 2010), name/date of birth (Hu, Wu, & Fu, 2011), and sentences about life events (Fields & Kuperberg, 2012). The P2 self-referential effect may be sensitive to the paradigms used in these studies as an event-related designed was employed in the current work and a block design was used in the previous research (Mu & Han, 2010). The LPP findings suggest that the increased fronto-central positivity in the LPP time window related to self-relevant stimuli may be independent of stimuli and tasks and play an important functional role in self-referential processing. Most interestingly, the present work showed evidence that intranasal OT tended to decrease the neural activity related to self-referential processing in the P2 and LPP time window and these effects were not observed during other-referential processing. These findings uncovered the OT effects on neural activities specifically involved in self-referential processing.

Source estimation suggested that the OT effect on self- vs. other-referential processing in the P2 time window may be linked to the modulation of neural activity in the medial prefrontal cortex. This is consistent with the fact that the medial prefrontal cortex is activated in fMRI studies during trait judgments of oneself vs. others to encode self-relevance of stimuli (Han & Northoff, 2009; Heatherton, 2011; Kelley et al., 2002; Ma & Han, 2011; Ma et al., 2013; Northoff et al., 2006; Wang et al., 2012; Zhu et al., 2007). In addition, OT as a neurotransmitter can reach the medial prefrontal cortex and anterior cingulate cortex through volume transmission (Macdonald & Macdonald, 2010; Meyer-Lindenberg, Domes, Kirsch, & Heinrichs, 2011) where OT receptors are distributed (Macdonald & Macdonald, 2010; Skuse & Gallagher, 2009). Animal studies suggest that OT can produce significant suppression of glutamatergic neurotransmission in the medial prefrontal cortex (Ninan, 2011). Therefore, it is possible that self-referential processing in these brain regions may be inhibited by intranasal OT administration. Although the analysis of LPP amplitudes showed significant interaction of Treatment × Task over the frontal/central electrodes, the LPP showed the maximum amplitude over the parietal region and the results of source estimation suggested that the differential OT effect on self- vs. other-referential processing in the LPP time window may arise from the right parietal cortex. This seemingly inconsistency can be understood if we hypothesize that the positive pole of dipoles in the parietal cortex that underwent OT modulations pointed to the frontal lobe, though this speculation should be examined in future research. The right parietal cortex plays a role in recognition of one's own face (Uddin, Molnar-Szakacs, Zaidel, & Iacoboni, 2006) and the LPP has been shown to be sensitive to evaluative categorization processes, with the LPP amplitude reflecting the extent to which a particular categorization process involves context updating (Cacioppo, Crites, Gardner, & Berntson, 1994). Thus our results suggest that OT treatment may weaken self-related processing in both early encoding of stimulus self-relevance and late evaluative processes. This result makes a key contribution toward understanding of the mechanisms with which OT may render its effects on sociality. It is possible that the primary effect of OT is to alter the balance between self- and other-referential processing and that the OT effect on self-referential processing may constitute an important factor driving the influence of OT on social behavior.

Interestingly, our ERP results showed evidence that individuals' cultural traits may interact with OT to shape its effect on the neural activity in responses to self-referential processing. Participants who reported greater interdependence of self-construals showed a stronger OT effect on the differential neural activity related to self- vs. other-referential processing in the P2 and LPP time windows. Self-construal reflects a set of cultural values and is critically influenced by development in a specific social context. Previous research has demonstrated that self-referential processing in Chinese individuals with high interdependence of self-construal is more susceptible to social influences such as negative social feedback or the presence of significant others (Liew et al., 2011; Ma

& Han, 2009, 2010). The current ERP results provide evidence that self-referential processing in Chinese individuals with higher interdependence of self-construals are more susceptible to specific hormone biological influences (e.g., intranasal OT). Thus trait level differences in self-construal are sensitive to both social development and biological factors. Evidence suggests that the OT receptor system is shaped by early interpersonal experiences (e.g., maternal separation, Meinlschmidt & Heim, 2007) and exhibits substantial plasticity (Gordon, Martin, Feldman, & Leckman, 2011). Therefore OT effects on social cognition and prosocial behavior may vary across individuals as a function of life experience. This is further supported by our data demonstrating that sociocultural experiences reflected in self-construals interact with intranasal OT to modulate the neurocognitive processes involved in self-referential processing.

These findings are consistent with the proposal that the social effects of OT in humans are context and person dependent (Bartz et al., 2011). Declerck, Boone, and Kiyonari (2010) found that OT enhanced cooperation in an economic game when social information was present whereas OT decreased cooperation when social information was lacking. De Dreu et al. (2010) reported that OT compared to placebo increased trust and love to in-group members but not to out-group members. OT compared with placebo also led to defensive forms of aggression to out-group members but not to in-group members. Sheng et al. (2013) found that OT increased empathic neural responses in the P2 time window to pain expressions, but this OT effect was strongly modulated by the social relationship between an observer and a target, being enhanced to racial in-group members compared to racial out-group members. Taken together, these findings suggest that social context and cultural traits interacts with OT to shape its effects on social cognition and behavior.

Participants in our study responded faster to trait judgments of oneself than of a celebrity, but this behavioral difference did not differ between OT and placebo conditions. Therefore, different OT effects on neural correlates of self-referential processing could not arise from task difficulty. OT versus placebo treatment in our study did not produce significant modulations of behavioral performances. Similarly, a recent behavior study examined OT effects on recall or recognition of personality terms that were self-relevant or irrelevant but failed to find significant differences in memory performances between OT and placebo conditions (Di Simplicio, Massey-Chase, Cowen, & Harmer, 2009). Thus it is likely that the neural activity involved in self-referential processing may be more sensitive to OT treatment compared to behavioral performances related to self-referential processing.

One may noticed that our ERP results did not show direct evidence that OT vs. placebo treatment enhances other-referential processing of personality traits, even though OT vs. placebo treatment tended to increase the neural activity associated with other-referential processing in the LPP time window. This is different from our prediction that OT enhances other-referential processing during trait judgments. Previous EEG/ERP studies found that OT administration enhanced the neural activity associated with the processing of others' biological motion (Perry, Bentin, et al., 2010) and pain expression (Sheng et al., 2013). The lack of OT effects on other-referential processing in our work suggest that the processing of others' internal personality traits may be less sensitive to OT compared to the processing of others' external motion and emotion. Moreover, other-referential processing and self-referential processing of personality traits may arise from different brain regions that are differentially sensitive to OT influences. Future research should further address the differential OT effects on self-referential and other-referential processing using other brain imaging techniques such as fMRI.

It should be noted that the current study only tested male participants. Previous fMRI studies showed that intranasal OT administration might produce opposite effects on neural responses in the amygdala to fearful faces in males and females (Domes et al., 2010; Gamer et al., 2010). Thus future research should address whether self-referential processing in females is affected by OT treatment in a way similar to what we observed here with male participants. Another potential limitation of our study is that we only tested OT effect on self-referential processing in one domain (i.e., the processing of one's own personality traits). It has been known since William James (1950) that the self as a multi-componential concept consists of different dimensions such as social roles, personality traits, and physical attributes. It has been recently demonstrated that the processing of different (mental, social and physical) dimensions of self-concept may engage distinct neural mechanisms (Ma et al., 2013). Our work cannot inform on potentially different influences of OT on the processing of self-related information in these different dimensions, and further research addressing this issue would be beneficial.

In conclusion, our ERP results present the first evidence that intranasal OT decreases the neural activity related to self-referential processing. Such OT effects were not present during other-referential processing. Our findings provide insight into the functional significance of OT in self-referential processing. Moreover, the OT effect on the differential self- vs. other-referential processing was associated with individuals' interdependent self-construal, suggesting that a cultural value (i.e., interdependent self-construals) may interact with a biological factor (i.e., OT as a neuropeptide) to affect the differential self- vs. other-referential processing. While the previous research suggests that OT may promote prosociality by changing the processing of information about others (e.g., empathy, Bartz, Zaki, Bolger, et al., 2010; Hurlemann et al., 2010; Sheng et al., 2013), future research should address how OT influences prosocial behavior by modulating self-related neurocognitive processing.

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## References

Aron, A., McLaughlin-Volpe, T., Mashek, D., Lewandowski, G., Wright, S. C., & Aron, E. N. (2004). Including others in the self. *European Review of Social Psychology*, *15*, 101–132.

Bartz, J. A., Zaki, J., Ochsner, K. N., Bolger, N., Kolevzon, A., Ludwig, N., et al. (2010). Effects of oxytocin on recollections of maternal care and closeness. *Proceedings of National Academy of Sciences of the United States of America*, *107*, 21371–21375.

Bartz, J. A., Zaki, J., Bolger, N., Hollander, E., Ludwig, N. N., Kolevzon, A., et al. (2010). Oxytocin selectively improves empathic accuracy. *Psychological Science*, *21*, 1426–1428.

Bartz, J. A., Zaki, J., Bolger, N., & Ochsner, K. N. (2011). Social effects of oxytocin in humans: Context and person matter. *Trends in Cognitive Sciences*, *15*, 301–309.

Burris, C. T., & Rempel, J. K. (2012). The crystal globe: Emotional empathy and the transformation of self. *Consciousness and Cognition*, *21*, 1526–1532.

Campbell, A. (2010). Oxytocin and human social behavior. *Personality and Social Psychology Review*, *14*, 281–295.

Cardoso, C., Ellenbogen, M. A., & Linnen, A. M. (2012). Acute intranasal OT improves positive self-perceptions of personality. *Psychopharmacology*, *220*, 741–749.

Cacioppo, J. T., Crites, S. L., Gardner, W. L., & Berntson, G. G. (1994). Bioelectrical echoes from evaluative categorizations: I. A late positive brain potential that varies as a function of trait negativity and extremity. *Journal of Personality and Social Psychology*, *67*, 115–125.

Cialdini, R. B., Brown, S. L., Lewis, B. P., Luce, C., & Neuberg, S. L. (1997). Reinterpreting the empathy–altruism relationship: When one into one equals oneness. *Journal of Personality and Social Psychology*, *73*, 481–494.

Cremer, D. D., & Stouten, J. (2003). When do people find cooperation most justified? The effect of trust and self–other merging in social dilemmas. *Social Justice Research*, *16*, 41–52.
Declerck, C. H., Boone, C., & Kiyonari, T. (2010). Oxytocin and cooperation under conditions of uncertainty: The modulating role of incentives and social information. *Hormones and Behavior*, *57*, 368–734.
De Dreu, C. K. W., Greer, L. L., Handgraaf, M. J. J., Shalvi, S., Van Kleef, G. A., Baas, M., et al. (2010). The neuropeptide OT regulates parochial altruism in intergroup conflict among humans. *Science*, *328*, 1408–1411.
Di Simplicio, M., Massey-Chase, R., Cowen, P. J., & Harmer, C. J. (2009). Oxytocin enhances processing of positive versus negative emotional information in healthy male volunteers. *Journal of Psychopharmacology*, *23*, 241–248.
Domes, G., Heinrichs, M., Michel, A., Berger, C., & Herpertz, S. (2007). Oxytocin improves "mind-reading" in humans. *Biological Psychiatry*, *61*, 731–733.
Domes, G., Heinrichs, M., Glascher, J., Buchel, C., Braus, D. F., & Herpertz, S. C. (2007). Oxytocin attenuates amygdala responses to emotional faces regardless of valence. *Biological Psychiatry*, *62*, 1187–1190.
Domes, G., Lischke, A., Berger, C., Grossmann, A., Hauenstein, K., Heinrichs, M., et al. (2010). Effects of intranasal oxytocin on emotional face processing in women. *Psychoneuroendocrinology*, *35*, 83–93.
Fields, E. C., & Kuperberg, G. R. (2012). It's all about you: An ERP study of emotion and self-relevance in discourse. *Neuroimage*, *62*, 562–574.
Gamer, M., Zurowski, B., & Buchel, C. (2010). Different amygdala subregions mediate valence-related and attentional effects of oxytocin in humans. *Proceedings of National Academy of Sciences of the United States of America*, *107*, 9400–9405.
Gordon, I., Martin, C., Feldman, R., & Leckman, J. F. (2011). OT and social motivation. *Developmental Cognitive Neuroscience*, *1*, 471–493.
Han, S., & Northoff, G. (2009). Understanding the self: A cultural neuroscience approach. *Progress in Brain Research*, *178*, 203–212.
Heatherton, T. F. (2011). Neuroscience of self and self-regulation. *Annual Review of Psychology*, *62*, 363–390.
Hu, X., Wu, H., & Fu, G. (2011). Temporal course of executive control when lying about self- and other-referential information: An ERP study. *Brain Research*, *1369*, 149–157.
Huffmeijer, R., Tops, M., Alink, L. R. A., Grewen, K. M., Light, K. C., Bakermans-Kranenburg, M. J., et al. (2013). The impact of oxytocin administration and maternal love withdrawal on event-related potential (ERP) responses to emotional faces with performance feedback. *Hormones and Behavior*, *63*, 399–410.
Hurlemann, R., Patin, A., Onur, O., Cohen, M., Baumgartner, T., Metzler, S., et al. (2010). Oxytocin enhances amygdala-dependent, socially reinforced learning and emotional empathy in humans. *Journal of Neuroscience*, *30*, 4999–5007.
Iacoboni, M. (2006). Failure to deactivate in autism: The co-constitution of self and other. *Trends in Cognitive Sciences*, *10*, 431–433.
James, W. (1950). . *The principles of psychology* (Vols. 1 & 2) New York: Dover (Original work published 1890).
Kelley, W. M., Macrae, C. N., Wyland, C. L., Caglar, S., Inati, S., & Heatherton, T. F. (2002). Finding the self? An event-related fMRI study. *Journal of Cognitive Neurosciences*, *14*, 785–794.
Kosfeld, M., Heinrichs, M., Zak, P. J., Fischbacher, U., & Fehr, E. (2005). Oxytocin increases trust in humans. *Nature*, *435*, 673–676.
Liew, S. L., Ma, Y., Han, S., & Aziz-Zadeh, L. (2011). Who's afraid of the boss: Cultural differences in social hierarchies modulate self-face recognition in Chinese and Americans. *PLoS ONE*, *6*, e16901. http://dx.doi.org/10.1371/journal.pone.0016901
Lim, M. M., & Young, L. J. (2006). Neuropeptidergic regulation of affiliative behavior and social bonding in animals. *Hormones and Behavior*, *50*, 506–517.
Liu, Y. (1990). *Modern lexicon of Chinese frequently-used word frequency*. Beijing: Space Navigation Press.
Ma, Y., & Han, S. (2011). Neural representation of self-concept in sighted and congenitally blind adults. *Brain*, *134*, 235–246.
Ma, Y., & Han, S. (2009). Self-face advantage is modulated by social threat – Boss effect on self-face recognition. *Journal of Experimental Social Psychology*, *45*, 1048–1051.
Ma, Y., & Han, S. (2010). Why respond faster to the self than others? An implicit positive association theory of self advantage during implicit face recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 619–633.
Ma, Y., Bang, D., Wang, C., Allen, M., Frith, C., Roepstorff, A., et al. (2013). Sociocultural patterning of neural activity during self-reflection. *Social Cognitive and Affective Neuroscience*, in press.
Macdonald, K., & Macdonald, T. M. (2010). The peptide that binds: A systematic review of oxytocin and its prosocial effects in humans. *Harvard Review of Psychiatry*, *18*, 1–21.
Magno, E., & Allan, K. (2007). Self-reference during explicit memory retrieval: An event-related potential analysis. *Psychological Science*, *18*, 672–677.
Markus, H. R., & Kitayama, S. (1991). Culture and the self: Implication for cognition, emotion and motivation. *Psychological Review*, *98*, 224–253.
Markus, H. R., & Kitayama, S. (2010). Cultures and selves: A cycle of mutual constitution. *Perspectives on Psychological Science*, *5*, 420–430.
Marsh, A. A., Yu, H. H., Pine, D. S., & Blair, R. J. R. (2010). Oxytocin improves specific recognition of positive facial expressions. *Psychopharmacology*, *209*, 225–232.
Meinlschmidt, G., & Heim, C. (2007). Sensitivity to intranasal OT in adult men with early parental separation. *Biological Psychiatry*, *61*, 1109–1111.
Meyer-Lindenberg, A., Domes, G., Kirsch, P., & Heinrichs, M. (2011). Oxytocin and vasopressin in the human brain: Social neuropeptides for translational medicine. *Nature Reviews Neuroscience*, *12*, 524–538.
Mikolajczak, M., Pinon, N., Lane, A., de Timary, P., & Luminet, O. (2010). Oxytocin not only increases trust when money is at stake, but also when confidential information is in the balance. *Biological Psychology*, *85*, 182–184.
Mu, Y., & Han, S. (2010). Neural oscillations involved in self-referential processing. *Neuroimage*, *53*, 757–768.
Ng, S. H., Han, S., Mao, L., & Lai, J. C. L. (2010). Dynamic bicultural brains: A fMRI study of their flexible neural representation of self and significant others in response to culture priming. *Asian Journal of Social Psychology*, *13*, 83–91.
Ninan, I. (2011). Oxytocin suppresses basal glutamatergic transmission but facilitates activity-dependent synaptic potentiation in the medial prefrontal cortex. *Journal of Neurochemistry*, *119*, 324–331.
Northoff, G., Heinzel, A., De Greck, M., Bermpohl, F., Dobrowolny, H., & Panksepp, J. (2006). Self-referential processing in our brain – A meta-analysis of imaging studies on the self. *Neuroimage*, *1*, 440–457.
Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sLORETA): Technical Details. *Methods and Findings in Experimental and Clinical Pharmacology*, *24D*, 5–12.
Perry, A., Troje, N. F., & Bentin, S. (2010). Exploring motor system contributions to the perception of social information: Evidence from EEG activity in the mu/alpha frequency range. *Social Neuroscience*, *5*, 272–284.
Perry, A., Bentin, S., Shalev, I., Israel, S., Uzefovsky, F., Bar-On, D., et al. (2010). Intranasal oxytocin modulates EEG mu/alpha and beta rhythms during perception of biological motion. *Psychoneuroendocrinology*, *35*, 1446–1453.
Petrovic, P., Kalisch, R., Singer, T., & Dolan, R. J. (2008). Oxytocin attenuates affective evaluations of conditioned faces and amygdala activity. *Journal of Neuroscience*, *28*, 6607–6615.
Schulze, L., Lischke, A., Greif, J., Herpertz, S. C., Heinrichs, M., & Domes, G. (2011). Oxytocin increases recognition of masked emotional faces. *Psychoneuroendocrinology*, *36*, 1378–1382.
Shamay-Tsoory, S. G., Fischer, M., Dvash, J., Harari, H., Perach-Bloom, N., & Levkovitz, Y. (2009). Intranasal administration of oxytocin increases envy and schadenfreude, gloating. *Biological Psychiatry*, *66*, 864–870.
Sedikides, C., & Skowronski, J. J. (2009). Social cognition and self-cognition: Two sides of the same evolutionary coin? *European Journal of Social Psychology*, *39*, 1245–1249.
Sheng, F., & Han, S. (2012). Manipulations of cognitive strategies and intergroup relationships reduce the racial bias in empathic neural responses. *Neuroimage*, *61*, 786–797.
Sheng, F., Liu, Y., Zhou, B., Zhou, W., & Han, S. (2013). Oxytocin modulates the racial bias in neural responses to others' suffering. *Biological Psychology*, *92*, 380–386.
Singelis, T. M. (1994). The measurement of independent and interdependent self-construals. *Personality and Social Psychology Bulletin*, *20*, 580–591.
Skuse, D. H., & Gallagher, L. (2009). Dopaminergic–neuropeptide interactions in the social brain. *Trends in Cognitive Sciences*, *13*, 27–35.
Sui, J., & Han, S. (2007). Self-construal priming modulates neural substrates of self-awareness. *Psychological Science*, *18*, 861–866.
Theodoridou, A., Rowe, A. C., Penton-Voak, I. S., & Rogers, P. J. (2009). Oxytocin and social perception: Oxytocin increases perceived facial trustworthiness and attractiveness. *Hormones and Behavior*, *56*, 128–132.
Uddin, L. Q., Molnar-Szakacs, I., Zaidel, E., & Iacoboni, M. (2006). rTMS to the right inferior parietal lobule disrupts self-other discrimination. *Social Cognitive and Affective Neuroscience*, *1*, 65–71.
Ulloa, E. R., & Pineda, J. A. (2007). Recognition of point-light biological motion: Mu rhythms and mirror neuron activity. *Behavioral Brain Research*, *183*, 188–194.
Wang, G., Mao, L., Ma, Y., Yang, X., Cao, J., Liu, X., et al. (2012). Neural representations of close others in collectivistic brains. *Social Cognitive and Affective Neuroscience*, *7*, 222–229.
Zhu, Y., Zhang, Li., Fan, J., & Han, S. (2007). Neural basis of cultural influence on self representation. *Neuroimage*, *34*, 1310–1317.
Zhu, Y., & Han, S. (2008). Cultural differences in the self: From philosophy to psychology and neuroscience. *Social and Personality Psychology Compass*, *2*, 1799–1811.
Zink, C. F., & Meyer-Lindenberg, A. (2012). Human neuroimaging of oxytocin and vasopressin in social cognition. *Hormones and Behavior*, *61*, 400–409.