ORIGINAL RESEARCH ARTICLE

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[illegible] Human adults share ample experiences with their spouse and offspring. Do these experiences produce shared neural correlates of reflection on oneself and family members? We addressed this issue by scanning 14 Chinese middle-aged married couples, using functional MRI, during personality trait judgments of the self, one's spouse, one's child, and a celebrity. We found common activations in the medial prefrontal cortex (MPFC) during trait judgments of the self, spouse, and child compared to a celebrity. Self- and spouse-judgments also elicited overlapping activations in the ventral thalamus and caudate. Female and male participants showed comparable MPFC activity during child-judgments but females exhibited stronger MPFC activity during spouse-judgments compared to males. Our neuroimaging findings suggest that life experiences with conjugal family members during adulthood shape the functional organization of the brain and result in shared neural representations of oneself and conjugal family members during reflection on personality traits.

[illegible] Self · Family · fMRI · MPFC · Ventral thalamus

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As partner and offspring provide pivotal physical and mental support for one's own life, our relationships with romantic partner and offspring constitute some of the most significant social connections that we have. These connections are so strong that we may actually come to incorporate our family members into our self-schemas (Aron et al. 1991; Smith et al. 1999). Consistent with the idea that close others may

(Zhu et al. 2007; Wang et al. 2012). A recent study of Chinese participants who newly arrived in the United States also reported greater MPFC activity to trait judgments on oneself than on one's mother (Chen et al. 2013). The finding that the MPFC activity differentiates between the self and mother in Westerner cultural contexts but not in Chinese cultural contexts suggest that participants' sociocultural experiences modulate the shared representation of the self and mother in the MPFC. This is consistent with Markus and Kitayama's (1991, 2010) proposal that East Asian cultures emphasize fundamental social connections, leading to an interdependent view of the self and partial overlap in representation of the self and close others whereas Western cultures encourage self-identity that is independent of social contexts and others, leading to an independent view of the self.

While the aforementioned brain imaging findings suggest that sociocultural experiences of a population can modulate the neural representations of oneself and one's mother, other studies also showed evidence that personal experiences with significant others also modulates shared neural representations of the self and others in the MPFC. For example, Heatherton et al. (2006) found that, while American adults showed greater MPFC activity during reflection on personality traits of the self compared to one's best friend, reflection on the best friend's personality traits failed to show MPFC activation even when compared with judgments on whether an adjective is printed in uppercase letters. Similarly, Wang et al. (2012) found that, while trait judgments of oneself and one's mother (vs. a celebrity,) significantly activated the MPFC in Chinese adults, trait judgments of one's best friend did not produce MPFC activation compared to trait judgments of a celebrity. Why did young adults show shared neural correlates in the MPFC during reflection on personality traits of the self and mother but not of the self and one's best friend in the previous studies? One possibility is that there is a critical period during which shared neural representations of the self and close others may be acquired and this is why the self-related MPFC is engaged in representation of mother with whom one interacts during early childhood (Wang et al. 2012; Zhu et al. 2007) whereas the MPFC is not involved in representation of a friend with whom one lacks early life experiences (Heatherton et al. 2006; Wang et al. 2012). If this is the case, then we would not expect people to have shared neural representations of the self and close others with whom one has no early life experiences. Alternatively, family relationship may be critical for developing shared neural correlates of reflection on oneself and close others whereas early life experiences are not necessary. If this is true, middle-aged adults may develop shared neural correlates of reflection on the self and their spouses and children due to their close relationship with family members even though they have no early life experiences with their spouse and children. The latter proposal is possible as a number of studies have shown evidence for considerable neural plasticity among adults (e.g., Draganski et al. 2004; Erickson et al. 2011) and temporary variations of neural representations of the self and mother/father by cultural priming in adults (i.e., Ng et al. 2010; Harada et al. 2010).

To test our hypothesis, the current work adopted a trait judgment task that has been used in fMRI studies of reflection on personal traits (Kelley et al. 2002; Moran et al. 2006; Ma and Han 2011; Han et al. 2008; 2010; Northoff et al. 2006; Shi et al.

2016). To examine whether personality trait judgments of the self and members of conjugal family induce overlapping activations in brain regions such as the MPFC, we scanned middle-aged Chinese adults using fMRI during trait judgments on themselves, their spouse and child, and a celebrity. Chinese culture empathizes self-family connectedness (Li 2002) and regards family as a fundamental cultural unit (Ho 1998) and has produced specific pattern of brain activity underlying the processing of the self and close others (Han and Northoff 2009; Han et al. 2013; Ma et al. 2014). Our participants started to know their spouses and offspring since they themselves became adults and thus had life experiences with one's partner and offspring only during adulthood. We tested whether trait judgments of self/spouse/child versus a gender-matched celebrity induce overlapping activations in the MPFC. We sought to explore whether the strength of the neural representation of spouse and child might depend on subjective feelings of intimacy and length of relationship with them. We also examined whether self-reported orientations toward individualism and collectivism might be associated with self-/spouse-/child-judgments given that brain activations associated with trait judgments of oneself and one's mother differed significant between individualistic (e.g., Western) and collectivistic (e.g., Chinese) cultures (Zhu et al. 2007; Ma et al. 2014). Because our participants had no contact with their family members before adulthood, our results helped to clarify whether early life experiences during childhood and adolescence are necessary for the development of shared neural representations of the self and family members.

Fourteen Chinese married couples (women aged between 39 and 54 years, $M = 46.6$, SD = 3.5; men aged between 45 and 55 years, $M = 47.7$, SD = 2.9) participated in this study as paid volunteers. Each couple had one child aged between 12 and 25 years ($M = 19.1$, SD = 3.7; 4 males, 10 females). Participants had first known their spouse since the age of 20–30 ($M = 23.0$, SD = 4.2), gave birth to children at the age of 25–31 years ($M = 28.2$, SD = 4.2), and had been married for 13–28 years ($M = 21.5$, SD = 3.7) at the time they took part in the study. All participants were right-handed, had normal or corrected-to-normal vision, and reported no abnormal neurological history. Informed consent was obtained prior to scanning. This study was approved by a local ethics committee.

Participants were asked to provide their spouse and child's names prior to the study. They were first imaged while performing trait judgment tasks. They were then given a 'surprise' memory test about 40 min after the scanning procedure. The stimuli used in the scanning procedure consisted of trait adjectives that were presented by an LCD projector onto a rear-projection screen viewed with an angled mirror positioned on the head-coil. 240 positive and 240 negative trait adjectives consisting of 2–4 Chinese characters were selected from established personality trait adjective pools (Liu 1990). The adjectives were classified into 10 lists of 48 words matched in word length and valence. Six lists of words were pseudo-randomly selected for the trait judgment tasks while the remaining 4 lists of words were used as distractors in the memory test.

A box-car design was used during six functional scans. Each scan consisted of 6 blocks of 8 trials for trait judgment tasks and lasted for 238 s. Each block of 28 s began with a 4-s instruction that required participants to judge whether a trait adjective was proper to describe the self, spouse, child, Xiang Liu (a well-known male Chinese athlete), Jingjing Guo (a well-known female Chinese athlete). A font judgment (bold- vs. light-faced) was included to control for semantic processing and motor responses. Participants made judgments by pressing one of the two buttons with the right index or middle finger. Two subsequent blocks were intervened by 10-s rest during which participants passively viewed two rows of asterisks (*). The order of the judgment tasks was counterbalanced across participants using a Latin Squire design. Each trial consisted of a “cue” word (either self, spouse’s name, child’s name, Xiang Liu, Jingjing Guo or ‘font’) above a trait adjective presented for 2 s at the center of the screen, followed by the cue word for 1 s when participants had to make a response. All instructions and trait adjectives were in Chinese. Each of the Chinese characters in the cue word and trait words subtended a visual angle of 0.34° × 0.45° (width × height) and 0.85° × 1.14°, respectively, at a viewing distance of 80 cm. The upper and lower asterisks presented during the rest between two neighboring blocks of trials subtended 0.23° × 0.23° (small ones) or 0.56° × 0.56° (large ones), respectively. All words and asterisks were white on a black background.

After the scanning procedure, participants were given a ‘surprise’ memory test. Thirty-two trait adjectives used in each judgment task (thus 192 in total in 6 conditions) were randomly selected and intermixed with 192 new trait adjectives. Each word was presented individually for 2 s and participants indicated whether the presented word has been shown during scanning by a button press.

Participants completed the Individualism and Collectivism Attitude Scale (Triandis 1995) to measure their cultural orientations. Intimacy of relationships between the self and family members was measured using the Chinese Interpersonal Relationship Affective subscale (Zhang 2000), which includes questions such as “how long have you known this person?”, “how familiar are you with this person?”, “how important is this person to you?”, and “how strongly does this person influence you?” Participants also indicated how long they had been married to their present spouse and how old their child was.

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Scanning was performed at Peking University First Hospital, on a GE 3-T scanner with a standard head coil. Thirty-two transversal slices of functional images covering the whole brain were acquired using a gradient-echo echo-planar pulse sequence (64 × 64 × 32 matrix with spatial resolution of 3.75 × 3.75 × 4 mm, TR = 2000 ms, TE = 30 ms, FOV = 24 × 24 cm, flip angle = 90°). Anatomical images were obtained using a 3D FSPGR T1 sequence (256 × 256 × 128 matrix with spatial resolution of 0.938 × 0.938 × 1.4 mm, TR = 7.4 ms, TI = 450 ms, TE = 3.0 ms, flip angle = 20 °).

Statistical Parametric Mapping software (SPM8, the Wellcome Trust Centre for Neuroimaging, London, United Kingdom) was used for fMRI data analysis. The functional images were corrected for head movements. Six movement parameters (translation; x, y, z and rotation; pitch, roll, yaw) were included in the statistical model. The anatomical image was coregistered with the mean realigned image and then normalized to the standard T1 Montreal Neurological Institute (MNI) template. The normalizing parameters were applied to the functional images, which were resampled to 2 mm of isotropic voxel size and spatially smoothed using an isotropic Gaussian kernel of 8 mm full-width half-maximum. The image data were modeled using a box-car function. Statistical analyses in SPM8 used a hierarchical random-effects model with two levels. In the first level of each subject, the onsets and durations of each block were modeled using a General Linear Model (GLM) according to the condition types. All seven conditions (self, spouse, child, Xiang Liu, Jingjing Guo, font, rest) were included in the model.

To control for potential effects of gender differences among self, spouse, and child, we defined the neural activity involved in the processing of self, spouse, and child by contrasting self-/spouse-/child-judgments with judgments of the same-gender celebrity in each participant using a fixed effect analysis. We first conducted a region-of-interest (ROI) analysis to test our hypothesis of shared neural activity in the MPFC in association with reflection on the self and family members. The MPFC was defined using functionally-defined brain regions in our previous research (Ma et al. 2014) that showed MPFC activation in Chinese participants during reflection on personality traits of oneself and a celebrity (MNI coordinates: −2/34/22). Spheres with 5 mm radii were constructed with the center at the coordinates of the MPFC. The parameter estimates of signal intensity related to self- and celebrity-judgments were calculated from this ROI using MarsBaR 0.38 (http://marsbar.sourceforge.net) and compared using t tests (Bonferroni corrected). Whole-brain random effect analyses were then conducted across the female and male participants based on statistical parameter maps from each individual participant. Conjunction analyses on the contrast images of self-/spouse-/child-judgments versus judgment of the same gender celebrity were conducted to identify brain regions in common for self-/spouse-/child-judgments. We also compared self-judgments with spouse- and child-judgments to examine the brain regions that differentiated between neural representations of the self and family members. Significant activations in the whole-brain analysis were identified using a threshold of $p < 0.05$ (topological FDR was used for multiple comparisons correction). ROI analyses were conducted to further assess potential gender differences in brain activity during self-, spouse-, and child-judgments. Parameter estimates of signal intensity were extracted from the brain regions that showed significant activations to self-/spouse-/child-judgments compared to celebrity-judgments, and were subjected to a repeated measure analysis of variance (ANOVA) with Judgment (self-/spouse-/child- vs. celebrity-judgment) as a within-subjects variable and Sex (male vs. female participants) as a between-subjects variable. MNI coordinates were reported in our study.

Results

Behavioral results

Response times to self-, spouse-, child-judgments did not differ from that to gender-matched celebrity-judgment ($ps > 0.1$, Table 1). Response accuracy and response time to font-judgment did not differ significantly between male and female participants (Accuracy: 89.7 vs. 85.0 %, Response time: 968 vs. 949 ms, $ps > 0.1$). Corrected recognition scores (i.e., hits minus false alarms) during the memory test were significantly higher for trait adjectives used for self- than celebrity-judgments [$F(1,27) = 26.031$, $p < 0.001$], for spouse- than celebrity-judgments [$F(1,27) = 7.329$, $p = 0.012$], and for child- than celebrity-judgments [$F(1,27) = 7.972$, $p = 0.009$]. The corrected recognition score of trait words used for self-judgments was significantly higher than those for child-judgments [$F(1,27) = 6.176$, $p = 0.019$] and marginally significantly higher than those for spouse-judgments [$F(1,27) = 3.722$, $p = 0.064$]. Corrected recognition scores did not differ between trait words used for spouse- and child-judgments [$F(1,27) = 0.800$, $p = 0.379$]. These effects did not differ between female and male participants ($ps > 0.05$).

Participants scored significantly higher in collectivistic than individualistic subscales (5.62 ± 0.45 vs. 4.83 ± 0.56, $t(27) = 6.68$, $p = 0.001$), suggesting dominance of collectivistic cultural orientations in our participants. Intimacy scores were significantly higher for spouse and child than for the gender-matched celebrity [$t(27) = 15.007$ and 15.006, $ps < 0.001$, Table 1]. Participants rated their

Table 1

relationship with their spouse as more intimate than their relationship with their child [t(27) = 2.374, $p = 0.025$].

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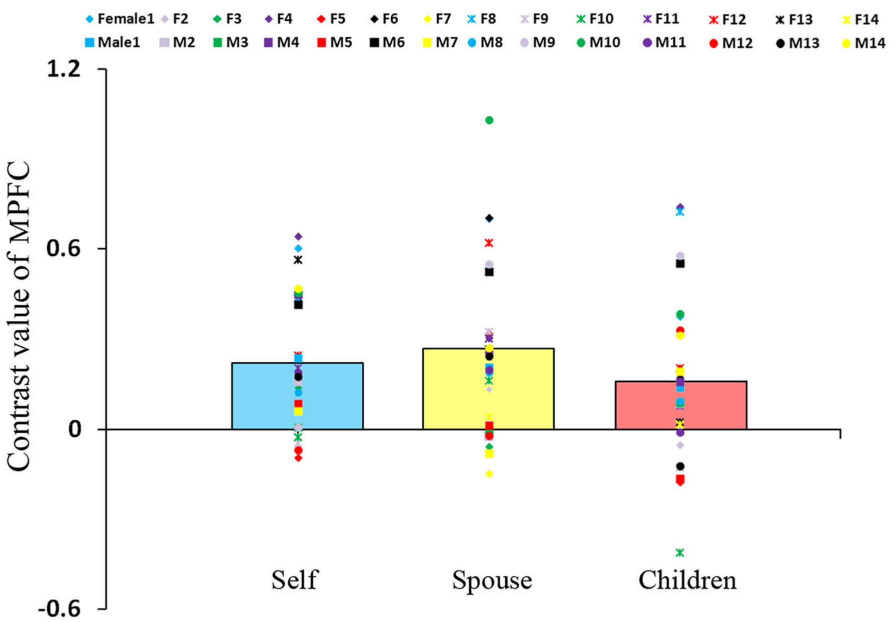
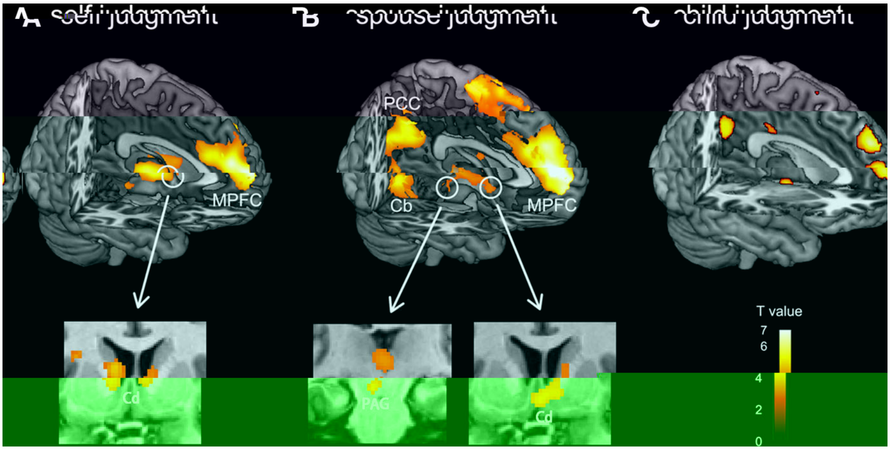
ROI analyses first showed that the neural activity in the MPFC defined based on the previous work (Ma et al. 2014) significantly increased during self-judgments compared to celebrity-judgments [t(27) = 5.515, $p < 0.001$]. Moreover, the neural activity in the same brain region was also significantly increased during spouse- and child-judgments compared to celebrity-judgments [t(27) = 5.128 and 3.174, $p < 0.00$ and $p = 0.004$, Fig. 1]. We also compared the contrast values (self-/spouse-/child-judgments vs. celebrity-judgments) to examine whether the MPFC activity significantly differs between self-judgments and spouse-/child-judgments. This analysis, however, failed to show significant results [self- vs. spouse-judgments: F(1, 27) = 1.010, $p = 0.324$; self- vs. child-judgments: F(1, 27) = 1.910, $p = 0.178$; spouse- vs. child-judgments: F(1, 27) = 3.673, $p = 0.066$]. The ROI results provide initial evidence for shared neural correlates of reflection on oneself and one's family members in the MPFC.

Whole-brain analyses were conducted to further examine share neural correlates of reflection on oneself and one's family members in other brain regions. The analyses revealed that self- versus celebrity-judgments significantly increased the activity in the MPFC/anterior cingulate (ACC) (−2/64/12, k = 4375, Z = 5.31) and thalamus/bilateral caudate (0/−12/4, k = 1341, Z = 4.85, Fig. 2a). Trait



F. 1 Illustration of the mean contrast values of self-/spouse-/child-judgments versus celebrity-judgments in the ROI analysis. The results of *each couple* were plotted using the *same number* and *color*. (Color figure online)



F . 2 Self- versus celebrity-judgments significantly activated the MPFC and the thalamus (extended into the bilateral caudate). Spouse- versus celebrity-judgments significantly activated the MPFC, the thalamus (extended into the PAG and the right caudate), the PCC, and the cerebellum. Child- versus celebrity-judgments significantly activated the MPFC. *MPFC* the medial prefrontal cortex, *PAG* the periaqueductal (central) gray; *PCC* the posterior cingulate; *Th* thalamus, *Cd* caudate, *Cb* cerebellum

judgments of spouse versus celebrity significantly activated the MPFC/ACC (4/52/14, 10/48/32, k = 9529, Z = 5.69), thalamus (2/2/−8, 0/−20/2, −2/−38/−6, k = 991, Z = 3.92), posterior cingulate (PCC, −4/−54/34) and cerebellum (−2/−68/−10, k = 3249, Z = 4.68, Fig. 2b). The thalamus activation extended into the periaqueductal (central) gray (PAG) and the right caudate. Child- versus celebrity judgments significantly activated the MPFC (−4/54/34, −4/50/14, k = 849, Z = 4.48, Fig. 2c).

Next we conducted conjunction analyses on the contrast images between self-/spouse-/child-judgments versus celebrity-judgments to examine the brain activations common for self-judgments and spouse-/child-judgments. The conjunction analysis of self-judgments and spouse-judgments showed significant activations in the MPFC (−4/60/12, k = 5060, Z = 5.96) and the bilateral caudate (−4/−12/0, k = 842, Z = 4.02) (Fig. 3a). The conjunction analysis of self- judgments and child-judgments showed significant activation in the MPFC (−2/60/12, K = 1336, Z = 4.61, Fig. 3b). The conjunction analysis of spouse- judgments and child-judgments also identified significant activations in the MPFC (−2/60/12, k = 1342, Z = 4.61, Fig. 3c). The contrast of spouse-judgments and self-judgments showed significantly increased activity in the PCC (−4/−60/34, k = 1161, Z = 5.10, Fig. 3d). However, there was no significant difference in MPFC activity when comparing self-judgments with spouse-/child-judgments.

Finally, to examine gender differences in the neural activity related to self-/spouse-/child-judgments, we compared contrast values of self-/spouse-/child-judgments versus celebrity-judgments for male and female participants. We found that activity in the MPFC and PCC during spouse-judgments was stronger in female participants than in male participants [MPFC: $t(26) = 2.348$, $p = 0.027$; PCC: $t(26) = 2.495$, $p = 0.019$, Fig. 4].

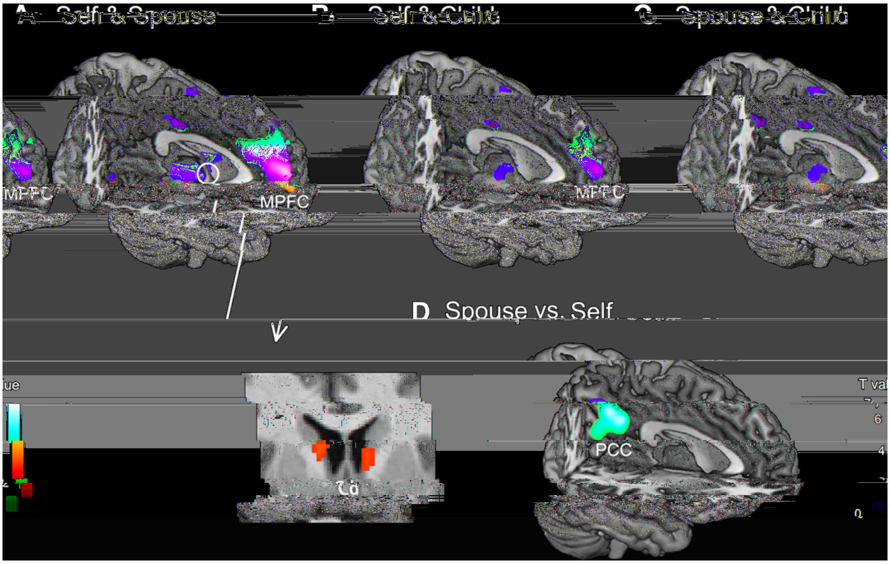


Fig. 3 The conjunction analysis of self- and spouse-judgments showed significant activations in the MPFC and the thalamus (extended into the bilateral caudate). The conjunction analysis of self- and child-judgments showed significant activations in the MPFC. The conjunction analysis of spouse- and child-judgments showed significant activations in the MPFC. Direct comparison between spouse- versus self-judgments showed significant activation in the PCC. *MPFC* the medial prefrontal cortex, *PCC* the posterior cingulate, *Th* thalamus, *Cd* caudate

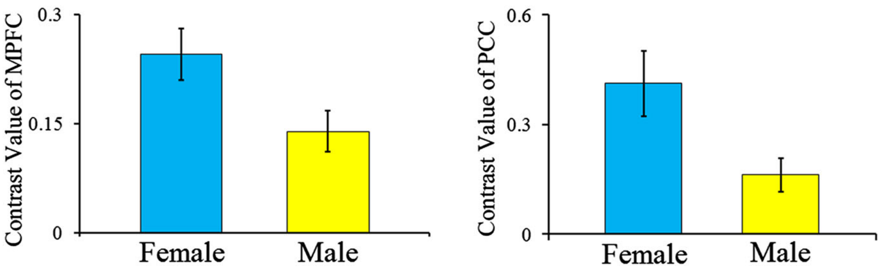


Fig. 4 Gender differences in MPFC and PCC activity related to spouse-judgments

Discussion

The present study investigated whether there are shared neural correlates of reflection on personality traits of oneself and one's family in middle-aged adults. Behavioral tests showed that recognition scores during the memory test were higher for self-/spouse-/child-judgments compared to celebrity-judgments. These behavioral results suggest enhanced encoding of information related to oneself and family members relative to a familiar person who is not a family member during trait judgments. Consistent with the behavioral performances, the brain imaging results showed significantly stronger MPFC activations during self-/spouse-/child-judgments compared to celebrity-judgments. The previous research has shown that MPFC activity related to trait judgments of oneself is positively correlated with the recall for self-related trait words (Macrae et al. 2004; Ma and Han 2011) and damage to the MPFC eliminates self-related processing advantages (Philippi et al. 2012). These findings are congruent with the proposal that the MPFC encodes self-relevance of stimuli during trait judgments (Han and Northoff 2009; Northoff et al. 2006). Family members are highly self-relevant in terms of one's own survival and development across the life span and are thus encoded with high self-relevance compared to non-family members in the MPFC. In this regards, family members may be essentially different from friends who do not produce shared neural representation in the MPFC with the self (Heatherton et al. 2006; Wang et al. 2012).

In addition, we found overlapping activations in the MPFC when reflecting on one's own traits and those of one's spouse and one's child. It has been shown that trait judgments of both self and mother induced comparable MPFC activations in young Chinese adults but not in young Westerners (Zhu et al. 2007; Moran et al. 2011; Wang et al. 2012). Young adults have more early life experiences with their mother during feeding and education compared to non-family members such as friends. Profound changes of brain structure and function occur during childhood into early adulthood (Gogtay et al. 2004). The previous findings left an open question of whether early life experiences are necessary for developing shared representations of the self and close others in the MPFC. In the present study, participants started to know their spouses and gave birth to a child during adulthood. Our work confirmed overlapping activations in the MPFC during self-/spouse-/child-judgments and the MPFC activity did not differentiate between trait judgments of oneself, spouse, and child. These results indicate that life experiences during childhood and adolescence are not necessary for developing shared representations of the self and conjugal family members in the MPFC. Familial bond built during adulthood can also produce shared neural correlates of reflection on personality traits of oneself and one's family members in the MPFC. Together our results suggest the MPFC activity in adults exhibits plasticity that allows functional reorganization to include conjugal family members in the same brain region that represents the self.

Unlike the MPFC activity, subcortical activities differentiated between family members as we showed that trait judgments of one's spouse but not one's child activated the thalamus including the PAG and caudate. These brain regions constitute the dopaminergic reward system (Perogamvros and Schwartz 2012) and are more strongly engaged when viewing a photograph of one's romantic partner compared to viewing a photograph of a familiar individual and thus may contribute to the "general arousal" component of romantic love (Bartels and Zeki 2000, 2004; Aron et al. 2005; Xu et al. 2011; Acevedo et al. 2012). Our results suggest that reflection on personality traits of one's spouse can also activate part of the reward system. If the dopaminergic reward system serves as an attraction mechanism that evolved to enable individuals to focus their mating choices in animals and humans (Fisher et al. 2005), trait reflection induced dopaminergic reward activity observed in our work may be specific to human beings. The fact that trait judgments of self and spouse induced overlapping activations in the thalamus and bilateral caudate suggest that our middle-aged participants might experience reward from reflection on both the self and their partners. Thus both perception of a romantic partner's face and reflection on one's spouse's personality traits may similarly activate the subcortical reward system in a way that facilitates shared representations of oneself and one's partner.

In our study, spouse-judgments elicited stronger activity in the PCC compared to self-judgments. Previous research documented similar PCC activation when viewing photographs of partner versus a familiar individual (e.g., Aron et al. 2005) and of kin faces versus friends' faces (Platek and Kemp 2009). Because the PCC has been shown to activate during reflection on spouse's personality traits (the current work) and during perception of one's own partner (e.g., Aron et al. 2005), it is unlikely the PCC activity observed in these studies indicated the simple processing of facial familiarity and identity. One possibility is that reflection on one's spouse's traits requires or activates additional episodic memory of events or behaviors related to one's spouse, given that the PCC plays a key role in retrieval of information from episodic memory (Cavanna and Trimble 2006). Alternatively, as the PCC is responsive to safety signals in social contexts (Eisenberger and Cole 2012), it is likely that both viewing pictures of one's partner and thinking about one's spouse's traits may remind participants of social support and thus produce feelings of safety that is associated with the PCC activity.

Although there were no gender differences in self-reported spousal intimacy, our ROI analyses suggested stronger MPFC and PCC activity in response to spouse-judgments among female participants than among male participants. To our knowledge, there has been no behavioral evidence for gender differences in coding spouse's self-relevance. Our fMRI results, however, suggest that reflection on one's spouse's traits leads to stronger neural encoding in the MPFC and PCC among female than male participants. Although the current work did not find significant difference in collectivistic/individualistic cultural values between the two sexes, there have been both theoretical assumptions and empirical findings that suggest that men tend to construct and maintain an independent self-construal whereas women tended to construct and maintain an interdependent self-construal (Cross and Madson 1997; Gabriel and Gardner 1999; Guimond et al. 2006) possibly due to early childhood experiences with parents peers and adulthood experiences that assign different social roles to females and males (Cross and Madson 1997). Gender differences in self-construals, i.e., women define themselves as higher in relational interdependence whereas and men define themselves as higher in independence than women (Guimond et al. 2006), and related sociocultural experiences may give rise to stronger feelings of self-relevance of spouse's personality traits and greater underlying neural activity in females and in males. The implications of our brain imaging findings deserve further exploration in future research.

One limitation of our study is the small sample size. We scanned 14 Chinese couples (28 adults) in the trait judgment tasks. In addition, our sample consisted solely of Chinese participants. Given previous findings with young adults that the overlapping neural representation between the self and mother is stronger in Chinese than in Westerners (Zhu et al. 2007), it is possible that the shared neural representations of the self and family members observed in our work might not generalize to people from more independent cultural contexts. However, if shared neural representation of the self and one's mate and offspring serves an evolutionary function, then one might expect similar results among middle-aged adults in other cultures. Future research might explore if culture plays a modulatory role in the neural representation of spouse and offspring.

In conclusion, our fMRI results provide evidence for shared neural correlates of reflection on personality traits of oneself and one's conjugal family members in the MPFC and thalamus among middle-aged Chinese adults. Our findings suggest that the human brain can be shaped during adulthood in order to develop shared neural representation of the self and significant others. The shared representations may guide prosocial actions toward family members and strengthen a sense of commitment. It would be interesting to test whether the strength of shared neural representations of the self and romantic partners and offspring predict future behavior related to parental investment and relationship fidelity.

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References

Acevedo, B. P., Aron, A., Fisher, H. E., & Brown, L. L. (2012). Neural correlates of long-term intense romantic love. *Social Cognitive and Affective Neuroscience, 7*, 145–159.

Aron, A., Aron, E. N., Tudor, M., & Nelson, G. (1991). Close relationships as including other in the self. *Journal of Personality and Social Psychology, 60*, 241–253.

Aron, A., Fisher, H., Mashek, D. J., Strong, G., Li, H., & Brown, L. L. (2005). Reward, motivation, and emotion systems associated with early-stage intense romantic love. *Journal of Neurophysiology, 94*, 327–337.

Bartels, A., & Zeki, S. (2000). The neural basis of romantic love. *NeuroReport, 11*, 3829–3834.

Bartels, A., & Zeki, S. (2004). The neural correlates of maternal and romantic love. *Neuroimage, 21*, 1155–1166.

Cavanna, A. E., & Trimble, M. R. (2006). The precuneus: A review of its functional anatomy and behavioral correlates. *Brain, 129*, 564–583.

Chen, P. H. A., Wagner, D. D., Kelley, W. M., Powers, K. E., & Heatherton, T. F. (2013). Medial prefrontal cortex differentiates self from mother in Chinese: Evidence from self-motivated immigrants. *Culture and Brain, 1*, 3–15.

Cross, S. E., & Madson, L. (1997). Models of the self: Self-construals and gender. *Psychological Bulletin, 122*, 5–37.

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Neuroplasticity: Changes in grey matter induced by training. *Nature, 427*, 311–312.

Eisenberger, N. I., & Cole, S. W. (2012). Social neuroscience and health: Neurophysiological mechanisms linking social ties with physical health. *Nature Neuroscience, 15*, 669–674.

Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., et al. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences USA, 108*, 3017–3022.

Fisher, H., Aron, A., & Brown, L. L. (2005). Romantic love: An fMRI study of a neural mechanism for mate choice. *Journal of Comparative Neurology, 493*, 58–62.

Gabriel, S., & Gardner, W. L. (1999). Are there "his" and "hers" types of interdependence? The implications of gender differences in collective versus relational interdependence for affect, behavior, and cognition. *Journal of Personality and Social Psychology, 77*, 642–655.

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., et al. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences USA, 101*, 8174–8179.

Guimond, S., Chatard, A., Martinot, D., Crisp, R. J., & Redersdorff, S. (2006). Social comparison, self-stereotyping, and gender differences in self-construals. *Journal of Personality and Social Psychology, 90*, 221–242.

Han, S., Gu, X., Mao, L., Ge, J., Wang, G., & Ma, Y. (2010). Neural substrates of self-referential processing in Chinese Buddhists. *Social Cognitive and Affective Neuroscience, 5*, 332–339.

Han, S., Mao, L., Gu, X., Zhu, Y., Ge, J., & Ma, Y. (2008). Neural consequences of religious belief on self-referential processing. *Social Neuroscience, 3*, 1–15.

Han, S., & Northoff, G. (2009). Understanding the self: A cultural neuroscience approach. *Progress in Brain Research, 178*, 203–212.

Han, S., Northoff, G., Vogeley, K., Wexler, B. E., Kitayama, S., & Varnum, M. E. W. (2013). A cultural neuroscience approach to the biosocial nature of the human brain. *Annual Review of Psychology, 64*, 335–359.

Harada, T., Li, Z., & Chiao, J. Y. (2010). Differential dorsal and ventral medial prefrontal representations of the implicit self modulated by individualism and collectivism: An fMRI study. *Social Neuroscience, 5*, 257–271.

Heatherton, T. F., Wyland, C. L., Macrae, C. N., Demos, K. E., Denney, B. T., & Kelley, W. M. (2006). Medial prefrontal activity differentiates self from close others. *Social Cognitive and Affective Neuroscience, 1*, 18–25.

Ho, D. Y. F. (1998). Interpersonal relationships and relationship dominance: An analysis based on methodological relationalism. *Asian Journal of Social Psychology, 1*, 1–16.

Huff, S., Yoon, C., Lee, F., Mandadi, A., & Gutchess, A. H. (2013). Self-referential processing and encoding in bicultural individuals. *Culture and Brain, 1*, 16–33.

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 Neuroscience, 14*, 785–794.

Li, H. Z. (2002). Culture, gender and self-close-other(s) connectedness in Canadian and Chinese samples. *European Journal of Social Psychology, 32*, 93–104.

Liu, Y. (1990). *Modern lexicon of Chinese frequently-used word frequency*. Beijing: Space Navigation Press.

Ma, Y., Bang, D., Wang, C., Allen, M., Frith, C., Roepstorff, A., et al. (2014). Sociocultural patterning of neural activity during self-reflection. *Social Cognitive and Affective Neuroscience, 9*, 73–80.

Ma, Y., & Han, S. (2011). Neural representation of self-concept in sighted and congenitally blind adults. *Brain, 134*, 235–246.

Macrae, C. N., Moran, J. M., Heatherton, T. F., Banfield, J. F., & Kelley, W. M. (2004). Medial prefrontal activity predicts memory for self. *Cerebral Cortex, 14*, 647–654.

Markus, H. R., & Kitayama, S. (1991). Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review, 98*

Philippi, C. L., Duff, M. C., Denburg, N. L., Tranel, D., & Rudrauf, D. (2012). Medial PFC damage abolishes the self-reference effect. *Journal of Cognitive Neuroscience, 24*, 475–481.

Platek, S. M., & Kemp, S. M. (2009). Is family special to the brain? An event-related fMRI study of familiar, familial, and self-face recognition. *Neuropsychologia, 47*, 849–858.

Shi, Z., Ma, Y., Wu, B., Wu, X., Wang, Y., & Han, S. (2016). Neural correlates of reflection on actual versus ideal self-discrepancy. *NeuroImage, 124*, 573–580.

Smith, E. R., Coats, S., & Walling, D. (1999). Overlapping mental representations of self, in-group, and partner: Further response time evidence and a connectionist model. *Personality and Social Psychology Bulletin, 25*, 873–882.

Triandis, H. C. (1995). *Individualism and collectivism*. Boulder: Westview Press.

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.

Xu, X., Aron, A., Brown, L., Cao, G., Feng, T., & Weng, X. (2011). Reward and motivation systems: A brain mapping study of early-stage intense romantic love in Chinese participants. *Human Brain Mapping, 32*, 249–257.

Zhang, Z. X. (2000). Chinese cognition on interpersonal relationship: A multi dimensional investigation. In C. F. Yang (Ed.), *Interpersonal relationship, affection and trust of the Chinese: From an interactional perspective* (pp. 159–179). Taipei: Yuen Liu Publishing Co.

Zhu, Y., Zhang, L., Fan, J., & Han, S. (2007). Neural basis of cultural influence on self representation. *NeuroImage, 34*, 1310–1317.