

Neural correlates of evaluating self and close-other in physical, academic and prosocial domains

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Abstract

Behavioral studies showed that self-concept can be distinguished into different domains, but few neuroimaging studies have investigated either domain-specific or valence-specific activity. Here, we investigated whether evaluating self- and mother-traits in three domains (physical, academic, prosocial) relies on similar or distinct brain regions. Additionally, we explored the topical discussion in the literature on whether vmPFC activity during self-evaluations is induced by valence or importance of traits. Participants evaluated themselves and their mothers on positive and negative traits in three domains. Across all domains, evaluating traits resulted in right dlPFC, left middle temporal cortex, bilateral thalamus, and right insula activity. For physical traits, we found specific neural activity in brain regions typically implicated in mentalizing (dmPFC, IPL). For academic traits, we found a brain region typically implicated in autobiographical memories (PCC), and for prosocial traits, social brain regions (temporal pole, TPJ) were activated. Importantly, these patterns were found for both self and mother evaluations. Regarding valence, rACC/vmPFC showed stronger activation for positive than for negative traits. Interestingly, activation in this region was stronger for highly important traits compared to low/neutral important traits. Thus, this study shows that distinct neural processes are activated for evaluating positive and negative traits in different domains.

Keywords: self, fMRI, medial prefrontal cortex, self-concept

1. Introduction

Understanding the way self-concept is built is important, as disturbances in self-image have been linked to disorders like depression, eating- and personality disorders (Orth, Robins & Roberts, 2008; Stein & Corté 2003; Vater, Schröder-Abé, Weisgerber, Roepke & Schütz, 2015) and low performance at school or at work (Choi, 2005; Judge, Erez & Bono, 1998). Self-concept has received much interest in recent brain imaging research, with the discovery that brain regions within the medial prefrontal cortex (mPFC) are specifically active when thinking about traits of self relative to traits of others (for meta-analyses, see Denny, Kober, Wager & Ochsner, 2012; Murray, Schaer & Debbané, 2012). These meta-analyses have highlighted that self-related regions are especially active when thinking of self relative to distant others, whereas less differentiation is observed when thinking about self-traits relative to traits of close others, possibly because close others are perceived as more similar to self. Indeed, several studies have reported that especially ventral mPFC (vmPFC) activity was increased for evaluations of self and similar others, but not for evaluations of dissimilar others (Heleven & Van Overwalle, 2016; Jenkins, Macrae & Mitchell, 2008; Mitchell, Macrae & Banaji, 2006).

Compared to the number of studies that have examined general self-related areas, much less is known about the way self- and close-other evaluations are made for different domains. There is limited evidence for a difference in neural activity for physical versus character domains, such that evaluations about physical self-traits were associated with increased activity in lateral prefrontal cortex and posterior cingulate cortex (PCC), whereas character evaluations were related to activity in mPFC (Moran, Lee & Gabrieli, 2010). Another study showed representations of social traits in the mPFC (Ma et al., 2014), whereas representations for competence traits were represented in mPFC and precuneus (Ma, Wang, Yang, Feng & Van Overwalle, 2016). A prior study that focused on adolescent development

showed stronger mPFC activity when evaluating one's own social traits from the perspective of friends, while mPFC activation was stronger for academic traits when making evaluations from the perspective of mothers (Pfeifer et al., 2009). However, this study did not directly test which neural regions differentiate between these domains for self-evaluations. In addition, the studies that distinguished between domains did not differentiate between positive and negative traits.

One study that focused on valence differences suggested that vmPFC activity, particularly ventral anterior cingulate cortex (vACC), a region in vmPFC, is more active when the self-traits describe positive characteristics of self compared to when sentences describe negative traits (Moran, Macrae, Heatherton, Wyland & Kelley, 2006). This is interesting because people tend to define positive traits as more important and negative traits as less important to self (Harter & Monsour, 1992). Indeed, a portion of the ventral mPFC was previously specifically activated in response to the attached importance to self-views (D'Argembeau et al., 2012). It has been suggested that vmPFC activity may relate to personal significance or importance of self-related contents rather than valence (D'Argembeau, 2013), but the exact function of the vmPFC remains largely unknown. Taken together, to date most neuroimaging studies on self- and close-other-evaluations focused on either domain-specific neural activity (Jankowski, Moore, Merchant, Kahn & Pfeifer, 2014; Moran et al., 2010; Pfeifer et al., 2009) or on valence-related neural activity in vmPFC (Moran et al., 2006), but it is not yet known if these processes are carried out by overlapping or distinct brain regions.

To specify whether neural activities for evaluating traits in different domains and across valences are specific to self or are general for rating traits of people significant to the self, it is important to compare self-evaluations relative to evaluations of close others. Prior studies used several types of close others, such as friends (Benoit, Gilbert, Volle & Burgess, 2010; Heatherton et al., 2006; Veroude, Jolles, Croiset & Krabbendam, 2014) or family

members (Ray et al., 2010; Zhu, Zhang, Fan & Han, 2007). These studies show that there are brain regions that are specific for self, although others reported much overlap between self and close others (Krienen, Tu & Buckner, 2010; Vanderwal, Hunyadi, Grupe, Connors & Schultz, 2008). One interesting comparison condition is rating self versus mothers, as participants have usually known their mothers as long as they know themselves, although they can differ in closeness (Ray et al., 2010; Vanderwal et al., 2008; Zhu et al., 2007). Prior studies that have examined neural activity in relation to evaluating traits of self relative to traits of mothers reported predominantly similar activation patterns, but indicated stronger activation in mPFC and superior frontal sulcus in the self-versus mother contrast (Ray et al., 2010; Vanderwal et al., 2008; Zhu et al., 2007). Whether traits of different domains and valence are evaluated similarly or differently for close others has not yet been investigated.

The main goal of this study was to test whether trait evaluations in different domains and valences rely on overlapping or dissociable brain regions. Furthermore, we investigated whether the domain- and valence-related activation is different for self- compared to close-other-evaluations. Likewise, we tested whether similar or distinct brain regions are activated for general evaluation of self- and close-other traits. In addition, we explored the role of mPFC in valence and importance of traits. For this purpose, participants completed two trait evaluation tasks in which they rated themselves and their mothers on short trait sentences on a scale from 1 to 4 (Holt et al., 2011; Moran et al., 2010; Ray et al., 2010; Vanderwal et al., 2008; Zhu et al., 2007). The domains were based on prior studies showing a difference between physical and character traits (Moran et al., 2010) and within character traits between academic and prosocial traits (Pfeifer et al., 2009; Van Overwalle, Ma & Baetens, 2016). All traits were presented in positive and negative valence sentences to examine to what extent valence based evaluations are dissociable from domain-specific evaluations.

First, we expected that evaluating physical traits would be associated with activity in lateral PFC whereas evaluating character (academic and prosocial) traits would result in activity in (ventral) mPFC (Ma et al., 2014; Ma et al., 2016; Moran et al., 2010). Prior studies have not yet dissociated between academic and prosocial domains, but it would be expected that evaluations in the academic domain rely more on autobiographical memory processes such as the posterior cingulate cortex (Fink et al., 1996; Summerfield, Hassabis & Maguire, 2009), while evaluations in the prosocial domain would be expected to rely more on social brain regions including anterior temporal lobe, superior temporal sulcus (STS) and temporal parietal junction (TPJ) (Frith, 2007; Ross & Olson, 2010). For the valence comparison we expected that vmPFC would be more involved for evaluating traits of positive valence over negative valence (Moran et al., 2006). Second, we expected largely overlapping activations for evaluating self- and mother-traits across all domains and valences (Ray et al., 2010; Vanderwal et al., 2008; Zhu et al., 2007). Third, as an earlier study suggested that the stronger vmPFC activity for positive than for negative trait evaluations may result from a greater assigned importance to positive than to negative traits (D'Argembeau, 2013), we explored the potential role of importance in vmPFC activation.

In summary, in this study participants evaluated positive and negative trait sentences in the physical, academic and prosocial domain for both self and mother. We aimed to examine the differential brain regions involved in making evaluations in different domains and valences regarding self and mother. Moreover, we explored contributions of importance in valence-specific activation (d'Argembeau, 2013; Moran et al., 2010) in evaluations of self and mother.

2. Method

2.1 Participants

Participants were 31 right-handed adults, one of whom one was excluded due to excessive head movements during the fMRI scan (more than 3mm). The resulting sample consisted of 30 healthy adults (15 female) between 20 and 24 years old (mean age = 22.6 years, $SD = 1.2$ years). IQ was estimated using four subtests of the WAIS-III (Picture Completion, Similarities, Block Design and Arithmetic). Estimated IQ scores fell within the normal range: all IQ scores fell between 87.5 and 126.25 ($M = 107.17$ $SD = 8.86$). All participants signed informed consent before inclusion in the study and the study was approved by the University Medical Ethical Committee. Prior to the scan session, participants were screened for MRI contra indications and self-reported psychiatric diagnoses or psychotropic medication.

2.2 Task Description

The fMRI task (see Figure 1) consisted of two runs of 60 trials, each lasting approximately 6 minutes. In both runs, participants were presented with 60 sentences describing either positively or negatively valenced traits. These traits belonged to either the physical domain (e.g. 'I am unattractive'), to the academic domain (e.g. 'I am smart'), or to the prosocial domain ('I help others'). Twenty sentences were shown for each domain; ten with a positive valence and ten with a negative valence.

In the first part, the 'Self' task, participants had to indicate to what extent the trait sentences applied to them. They responded by pressing a button between 1 ('not at all') and 4 ('completely') with their right hand. In the second part, the 'Mother' task, participants responded to the exact same sentences but this time indicated to what extent the traits applied to their mother. Before the MRI session, participants practiced 3 items per domain for both the Self and Mother experiment. During practice, different trait sentences were shown than during the actual experiment.

Each trial began with a 400ms fixation cross. Subsequently, the stimulus was presented for 5000ms, which consisted of the trait sentence and the response options (1-4). Within this timeframe, participants could rate themselves or their mother on the trait sentence. To assure participants that their choice had been registered, the number they chose turned yellow for the remaining stimulus time. If the participant failed to respond within the 5000ms, they were shown the phrase ‘Too late!’ for 1000ms. These trials were modeled separately and were not included in the analysis. Too late responses occurred on 0.2% of the trials in the Self task and on 0.7% of trials in the Mother task. The order of conditions was optimized using Optseq (Dale, 1999). Additionally, OptSeq was used to jitter intertrial intervals, that varied between 0 and 6.6 seconds.

2.2.1 Importance and Valence

After the scanning session, participants were again presented with the same sentences. This time, participants were first instructed to rate all items on importance on a scale of 1 (it’s very important to me not to have this trait) to 5 (it’s very important to me to have this trait).

Second, all participants indicated with a 0/1 response whether they rated the trait as either positive or negative. These ratings showed that in almost all cases, sentences were valenced the way we had anticipated. Deviant rating occurred on 2.7% of the trials, but no single item was differently rated by all participants.

2.3 fMRI Data Acquisition

MRI scans were acquired on a Philips 3T MRI scanner, using a standard whole-head coil. Functional scans were acquired in two runs with T2*-weighted echo-planar imaging (EPI) sequence (TR = 2200m msec, TE = 30 msec, sequential acquisition, 38 slices of 2.75 mm, FOV = 220 x 220 x 114.68 mm). The first two volumes were discarded to account for T1

saturation. After the functional scans, a high-resolution 3D T1-FFE scan for anatomical reference was obtained (TR = shortest msec, TE = 4.61 msec, 140 slices, voxel size = 0.875 mm, FOV = 224 x 177.33 x 168 mm). Sentences were projected on a screen behind the scanner and could be seen by the participant via a mirror attached to the head coil. Head movement was restricted by placing foam inserts inside the coil.

2.4 fMRI Preprocessing and Statistical Analysis

All data were analyzed using SPM8 (Wellcome Department of Cognitive Neurology, London). The functional scans were corrected for slice-timing acquisition and differences in rigid body movement. All structural and functional volumes were spatially normalized to T1 templates. The normalization algorithm used a 12-parameter affine transformation together with a nonlinear transformation involving cosine basis functions. The algorithm resampled the volumes to 3 mm cubic voxels. Templates were based on the MNI305 stereotaxic space (Cocosco, Kollokian, Kwan & Evans, 1997). Functional volumes were spatially smoothed with an 6 mm FWHM isotropic Gaussian kernel.

Condition effects for each participant were estimated using the general linear model in SPM8. The fMRI time series were modelled as a series of zero duration events convolved with the hemodynamic response function (HRF). Modelled events of interest for the Self and Mother experiment separately were “PhysicalPositive”, “PhysicalNegative”, “AcademicPositive”, “AcademicNegative”, “ProsocialPositive” and “ProsocialNegative”. Trials in which participants failed to respond were modelled as events of no interest. The events were used as covariates in a general linear model, along with a basic set of cosine functions that high-pass filtered the data. Motion regressors were added to the model. The resulting contrast images, computed on a subject-by-subject basis, were submitted to group analyses.

At the group level, a 2 (target: Self, Mother) x 3 (domain: Academic, Physical, Prosocial) x 2 (valence: Positive, Negative) ANOVA was computed. Domain-, valence-, and target-related responses were thresholded by using a False Discovery Rate (FDR) cluster level correction ($p < .05$) at an initial uncorrected threshold of $p < .001$. In Table 1, 2, and 3 we reported all coordinates for these analyses.

In follow-up analyses to examine effects of valence versus importance, we reanalysed the fMRI data based on the importance ratings outside of the scanner. This analysis was collapsed across domains to ensure enough trials to dissociate valence from importance. We included a total of 4 conditions for high and low/neutral importance evaluations on positive and negative trait sentences, resulting in the following modelled events:

“HighImportancePositive”, “HighImportanceNegative”, “Low/NeutralImportancePositive”, “Low/NeutralImportanceNegative”. Participant’s ratings of importance were interpreted as high when they responded with the numbers 4 or 5 and low/neutral when they responded with the numbers 1, 2 or 3. Trials in which participants failed to respond were modelled as events of no interest and were excluded from further analyses.

3. Results

3.1 Behavioral results

First, we tested how participants rated themselves and their mothers on all traits. Applicability scores for all types of traits to the Self and Mother were analyzed in a 2 (target) x 3 (domain) x 2 (valence) repeated measures ANOVA. We found a target x domain x valence interaction effect ($F(2, 58) = 9.36, p < .001, \eta_p^2 = .24$) (Figure 2). Post hoc tests for the Self task revealed that, when evaluating positive traits, participants rated that academic and prosocial traits applied more to them than physical traits ($F(2, 58) = 12.63, p < .001$). For negative trait sentences, participants rated themselves higher on academic traits than on physical and

prosocial traits ($F(2, 58) = 4.47, p=.016$). Post hoc tests on the Mother task revealed that, when evaluating their mothers' positive traits, participants were most positive about their mothers prosocial traits, and least positive about their mothers physical traits ($F(2, 58) = 38.75, p<.001$). For negative trait sentences, participants were most negative about their mothers physical traits, and least negative about their mothers prosocial traits ($F(2, 58) = 15.24, p<.001$). When directly comparing self- and mother-traits, we found that academic negative ($p=.035$) and prosocial negative traits ($p<.001$) were rated to fit better with the self, whereas physical negative ($p=.027$) and prosocial positive traits ($p=.001$) were rated to fit better with mother.

Second, we tested how participants rated importance of the traits outside of the scanner. Ratings showed that it is important to participants to have the positive traits, while the negative traits are more important not to have ($F(1, 29) = 152.46, p<.001, \eta_p^2 = .84$). We found a main effect of domain ($F(2, 58) = 7.13, p=.002, \eta_p^2 = .20$) and a domain x valence interaction effect ($F(2, 58) = 3.97, p=.024, \eta_p^2 = .12$). Post-hoc tests revealed that participants reported that it is more important to have positive prosocial traits than to have positive academic ($p=.022$) or positive physical traits ($p=.002$) ($F(2, 58) = 7.30, p=.001, \eta_p^2 = .20$). Negative traits had similar importance ratings across all domains ($F(2, 58) = 3.03, p=.056, \eta_p^2 = .09$).

3.2 fMRI results

We performed a 2 (target) x 3 (domain) x 2 (valence) whole brain ANOVA to investigate first domain- and valence specific neural activation. Second, we examined whether domain- and valence-specific neural activation was different for self- compared to mother-evaluations. Third, we investigated potential distinct neural processes for trait evaluations of self and mother.

3.2.1 Domain- and valence-specific neural activation

To investigate domain- and valence-specific neural activation for trait evaluations regarding self and mother, we looked at several contrasts within the conducted 2 x 3 x 2 ANOVA. First, we examined domain-specific brain activation by testing the contrasts academic > physical and prosocial, physical > academic & prosocial, and prosocial > academic and physical (Table 1). Second, we examined valence-specific brain activation by testing the contrasts positive > negative and negative > positive (Table 2).

In the contrast physical > academic and prosocial, we found significant activation in bilateral dlPFC, bilateral inferior parietal lobule (IPL), PC/PCC, left supplementary motor area (SMA), and dmPFC (Figure 3a). In the academic > physical and prosocial contrast, we found significant activation in precuneus/posterior cingulate cortex (PC/PCC), vmPFC, left middle occipital gyrus, and right fusiform gyrus (Figure 3b). In the prosocial > academic and physical contrast, we found activation in left temporal pole, right TPJ, left postcentral gyrus, and right calcarine gyrus (Figure 3c) (see Table 1). In order to find common activation for trait evaluations in all three domains, we conducted a conjunction analyses in SPM8 in which we examined overlapping activation for physical traits versus fixation, academic traits versus fixation, and prosocial traits versus fixation. The results showed common activation in right dlPFC, left middle temporal cortex, bilateral thalamus, right insula, and occipital gyrus.

Regarding valence, the contrast positive > negative evaluations showed significant activation in rostral anterior cingulate cortex/vmPFC (rACC/vmPFC). In the contrast negative > positive evaluations, we found significant activation in left lingual gyrus. (see Table 2; Figure 3d).

Finally, we tested whether there were interactions between domain x valence. This interaction analysis did not result in significant activation.

3.2.2 Self-Mother differences in domain- and valence-specific neural activation

To investigate whether domain- and valence-specific neural activation was different for self- compared to mother-evaluations, we examined the target x domain and target x valence interactions within the 2 x 3 x 2 ANOVA. In both interaction contrasts, no significant neural activation was found.

3.2.3 Self- versus Mother evaluations

Within the 2 (target) x 3 (domain) x 2 (valence) ANOVA we examined the contrasts Self > Mother and Mother > Self to investigate distinct neural processes for trait evaluations of self and mother (see Table 3; Figure 4). In the Self > Mother contrast, we found significant activation in ventrolateral prefrontal cortex (vlPFC), left middle temporal gyrus, right inferior temporal gyrus, left thalamus and right cerebellum. For the reverse contrast Mother > Self, no significant activation was found.

3.2.4 Role of importance in vmPFC activation

To explore the effects of importance on valence (D'Argembeau, 2013), we re-analyzed our data using the importance ratings outside the scanner to create a 2 (self and mother) x 2 (high and low/neutral importance) x 2 (positive and negative valence) ANOVA. The results indicated no main effect of importance after FDR cluster correction. Since we aimed to explore whether valence-related vmPFC activation could be explained by subjective importance of traits, we extracted the rACC/vmPFC ROI from the positive > negative contrast described above for this model as well. A subsequent 2 (target) x 2 (importance) x 2 (valence)

ANOVA showed a main effect of importance, indicating that rACC/vmPFC activation was stronger for traits that were rated as important to have than for traits rated to be important not to have ($F(1, 15) = 7.961, p = .013$), regardless of valence. There was no interaction between valence and importance.

4. Discussion

The main goal of this paper was to dissociate brain activation for trait evaluations in different domains and valences. First, the results showed domain-specific activity patterns, which were similar for self and for close other. For evaluating physical traits, activation in bilateral dlPFC, bilateral IPL, PC/PCC, and dmPFC was found. There was increased PC/PCC and vmPFC activation for evaluating academic traits. Evaluating prosocial traits resulted in increased activation in left temporal pole, and right TPJ. We found stronger brain activation in the rACC extending to the vmPFC, and in bilateral insula for positive than for negative evaluations across domains (Moran et al., 2006). Moreover, this activation was stronger for traits that were rated high on importance than for traits rated to be low/neutral on importance. Interestingly, self and close-other evaluations relied on similar neural activations such that no domain and valence specific regions were differentially activated when making self and mother evaluations. The discussion is organized along these findings.

4.1 Evaluations in different domains and valences

The main goal of this study was to test for domain and valence specificity when rating self and close-other traits. As no interactions between target and domain or target and valence were found, we interpret the domain and valence results to hold for both self and close-other evaluations.

In accordance with the study of Moran et al., (2010), activation for physical evaluations was found in bilateral dlPFC and PC/PCC. Previous studies have shown that these regions are important for semantic (dlPFC: Badre & Wagner, 2007; Martinelli, Sperduti, & Piolino, 2012; Thompson-Schill, Bedny, & Goldberg, 2005) and autobiographical (PC/PCC: Fink et al., 1996; Northoff & Bermpohl, 2004; Van der Meer et al., 2010) memory retrieval in evaluating one's physical traits. Physical trait evaluations were also associated with more activation in dmPFC and bilateral IPL. Dorsomedial PFC activation in self-referential processing has been found to be activated in evaluations less relevant to the self or evaluations of relatively dissimilar others (D'Argembeau et al., 2007; Denny et al., 2012; Mitchell et al., 2006, Murray et al., 2012). Moreover, this region has often been related to mental state attributions and impression formations (Mitchell, Banaji, & Macrae, 2005; Mitchell, Macrae, & Banaji, 2005, 2006). IPL is known to be involved in social processes such as empathy and mentalizing, and was previously implicated in perspective taking as well (David et al., 2006; Vogeley et al., 2004; Ruby & Decety, 2003). Moreover, IPL has recently been suggested to play a role in identifying the difference between other's and the self's preferences (Janowski, Camerer, & Rangel, 2013). Possibly, these results suggest that participants reason more from the perspective of others when evaluating physical traits, compared to when evaluating academic and prosocial traits.

We found PC/PCC and vmPFC involvement during academic trait evaluations, which is in line with our expectations and with previous research showing involvement of these regions in competence traits (Ma et al., 2016). First, PCC is known to play an important role in the integration of autobiographical and emotional information (Fink et al., 1996; Northoff & Bermpohl, 2004; Van der Meer et al., 2010). One earlier study using trait evaluations in different domains found PCC activation for the physical domain instead (Moran et al., 2010). This could be explained, however, by the author's use of more objective physical traits (like

“beard” or “bald”), rather than the more subjective statements such as “I look attractive” that were used in the current study. Future studies should test to what extent objective (I have a beard) versus subjective physical traits (I am attractive) are associated with different behavioral judgments and involvement of PCC. Second, the increased vmPFC activation for evaluating academic traits versus evaluating traits in other domains is in line with several previous studies that found heightened (ventral) mPFC activation in response to character or competence traits (Ma et al., 2014; Ma et al., 2016; Moran et al., 2010).

A different set of brain regions was involved when making prosocial trait evaluations, which were mostly part of the social brain network. As expected, evaluations of prosocial traits of self and close-other resulted in left temporal pole and right TPJ activation (Frith, 2007; Ross & Olson, 2010). Both the temporal poles and TPJ are social brain regions, often implicated in mentalizing (Frith & Frith, 2003, 2006; Saxe, 2006). More specifically, TPJ is thought to be important in third-person perspective-taking processes (Aichhorn, Perner, Kronbichler, Staffen, & Ladurner, 2006; Apperly, Samson, Chiavarino, & Humphreys, 2004; Ruby & Decety, 2003; Samson, Apperly, Chiavarino & Humphreys, 2004; Saxe & Kanwisher, 2003; Saxe & Wexler, 2005), whereas the temporal pole has been suggested to be important for storage of social and personal semantic knowledge, binding perceptions and emotions (Olson, McCoy, Klobusicky, & Ross, 2013; Olson, Plotzker, & Ezzyat, 2007). The temporal pole plays a critical role in representing and retrieving social knowledge, and is shown to be more sensitive to social than to non-social knowledge (Olson et al., 2013; Skipper, Ross & Olson, 2011). To our knowledge, this is the first study examining neural activation for prosocial trait evaluations. Future studies should further investigate the exact way in which these social brain regions aid (pro)social self and close-other evaluations.

Previous studies often collapsed across valences when testing for neural activity for self-evaluations. Here, we aimed to test whether there were specific regions involved in

positive versus negative self-evaluations. We found rACC activation extending into the vmPFC for the evaluation of positive trait sentences as we expected based on prior research investigating valence in self-reflections (Moran et al., 2006). This result is in line with studies that have linked activation in this region to positive valuation processes (Peters & Büchel, 2010; Kringelbach & Rolls, 2004). Additionally, we found increased activation in bilateral insula, a region often activated in conjunction with mPFC in self-referential tasks with emotional components (Pfeifer et al., 2012). Insula activation has been found to be stronger for evaluating the self compared to a public-other, but similar for self and a close-other (Murray et al., 2012). These findings suggest that activation in this region increases with self-relatedness or salience of the task (Murray et al., 2012; Pfeifer et al., 2012).

4.2 Evaluations of self and close-other

In this study, we tested for commonalities and differences in brain activation for self and close-other (mother) evaluations. There were no differences in neural activation between self and close-other evaluations in medial prefrontal cortex, consistent with prior studies showing that mPFC is involved in self and close-other processing (Ray et al., 2010; Vanderwal et al., 2008; Zhu et al., 2007).

Behaviorally, participants rated themselves more positively on physical traits than their mothers, and their mothers more positively on prosocial and academic traits. These findings may indicate that the social bond with their mothers was evaluated as the most applicable trait for their mothers, whereas in their perspective the positive physical traits were most applicable to themselves. These differences were possibly too subtle to detect at the neural level but provide interesting directions for future research.

4.3 The role of importance in vmPFC activation

We addressed the question if brain regions that are involved in positive trait evaluations are also more active for traits that are judged as more important. Interestingly, the valence-related rACC/vmPFC activation was stronger for highly important traits compared to low/neutral important traits. These findings suggest that valence and importance have additive effects on rACC/vmPFC activation (see also D'Argembeau, 2013). An interesting question for future research will be to examine in more detail individual profiles for which traits are most important for whom, and test if vmPFC activity tracks with these importance ratings. These profiles may also be important for a better understanding of psychological conditions where specific domains are rated as less or more important, such as fear for academic failure (Neff, Hsieh, & Dejitterat, 2005) or eating disorders (Davis, Shuster, Blackmore, & Fox, 2004; Lieberman, 1995).

4.4 Limitations

There are some limitations to this study related to the stimuli and the tasks we used. First, prosocial sentences were longer than academic sentences (academic mean: 16.20 letters; physical mean: 19.15 letters; prosocial mean: 24.45 letters; $F(2, 18) = 7.56, p = .004$), but sentence length was equal across valences (positive mean: 19.17 letters; negative mean: 20.70 letters; $F(1, 9) = .623, p = .450$). Previous research found stronger occipital, fusiform, and lingual gyrus activation with increasing word length (Mechelli, Humphreys, Mayall, Olson & Price, 2000; Schuster, Hawelka, Hutzler, Kronbichler & Richlan, 2016). Therefore, we did not interpret the occipital cortex and calcarine/lingual gyrus activation we found for the domain contrasts. Second, we did not randomize the order of tasks (self and mother), all participants completed the first run about themselves and the second run about their mothers. Future studies should randomize task orders to avoid confounding effects of task order.

4.5 Conclusions

This study aimed to distinguish between neural activity for self and close-other evaluations in different domains and valences. Even though in the behavioural literature it is well established that individuals may differ in their self descriptions according to different domains (Harter, 2015; Harter, Whitesell & Junkin, 1998), few neuroimaging studies made these distinctions. Here, we showed that there was specific neural activity in brain regions typically implicated in mentalizing for physical traits, in brain regions typically implicated in autobiographical memories for academic traits, and in the social brain regions prosocial traits. The finding that these patterns were consistent for self and mother evaluations, confirmed our hypothesis that these regions are important for that particular domain of thinking about the self. Together, these findings provide important evidence for domain and valence specificity when evaluating self and close others.

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Table 1.*Regions activated during the domain contrasts*

	<i>Region</i>	<i>BA</i>	<i>Coordinates</i>			<i>Cluster Size</i>	<i>F</i>
<i>(A) Academic > Physical and Prosocial</i>							
<i>(FDRc <.001 = 40)</i>							
Frontal cortex/ Subcortical	R Medial Frontal (vmPFC)	10	3	53	-8	54	4.69
	L Medial Frontal	10	-6	50	-8		4.33
	R. Fusiform gyrus	37	30	-31	-23	40	3.93
	R Parahippocampal	36	24	-25	-26		3.78
	R Hippocampus	54	30	-19	-20		3.34
Parietal cortex	L Precuneus (PC/PCC)	23	-3	-58	19	240	8.51
	L Middle Cingulum	23	-3	-40	34		4.05
Occipital cortex	L Middle Occipital	39	-42	-76	34	47	5.60
<i>(B) Physical > Academic and Prosocial</i>							
<i>(FDRc <.001 = 45)</i>							
Frontal cortex / Subcortical	L Inferior Frontal (dlPFC)	46	-48	35	16	1034	9.30
	L Precentral	8	-39	8	34		5.95
	L Precentral	6	-45	8	40		5.69
	L Sup. Med. Frn. (dmPFC)	9	-9	38	31	69	4.31
	L Sup. Med. Frontal	9	-6	47	19		3.76
	L Sup. Med. Frontal	9	-3	50	31		3.24
	L Suppl. Motor Area	6	-6	17	55	226	5.15
	R Suppl. Motor Area	6	12	14	61		4.14
	R Sup. Med. Frontal	8	9	32	55		3.24
	R Inferior Frontal (dlPFC)	46	48	35	16	512	6.32
	R Middle Frontal		51	20	46		6.28
	R Inferior Frontal	9	51	29	25		5.73
	R Superior Frontal		24	38	-11	67	4.82
	R Insula	13	30	20	-14		4.02
Parietal cortex	L Inferior Parietal (IPL)	39	-33	-58	43	471	6.85
	L Inferior Parietal	39	-30	-67	40		6.07
	L Inferior Parietal	39	-42	-49	40		4.74
	L Post. Cing. (PC/PCC)		0	-34	28	45	4.98
	R Inferior Parietal (IPL)	39	42	-55	52	286	6.27
	R Supramarginal	40	48	-40	43		3.67
<i>(B) Prosocial > Academic and Physical</i>							
<i>(FDRc <.001 = 47)</i>							
Parietal cortex	L Postcentral		-54	-7	49	47	4.26
	L Precentral		-51	-7	58		4.11
	L Postcentral	6	-48	-10	40		3.53
	R Rolandic Operc. (TPJ)	40	57	-28	22	62	4.00
Temporal cortex	L Superior Temporal (temporal pole)	38	-57	2	-14	51	4.26
Occipital cortex	R Calcarine	17	9	-82	1	1243	7.12
	L Lingual	18	-9	-76	-5		5.69
	R Cuneus	18	15	-97	10		5.21

Names were based on the Automatic Anatomical Labeling (AAL) atlas.

Table 2.
Regions activated during the valence contrasts

	Region	BA	Coordinates			Cluster Size	F
<i>Positive > Negative</i>							
<i>(FDRc <.001 = 76)</i>							
Frontal cortex/ Subcortical	L Anterior Cingulum		-3	35	7	258	
	(rACC/vmPFC)	24					5.41
	R Anterior Cingulum	32	6	35	13		4.49
	L Anterior Cingulum	32	0	26	28		4.42
	L Suppl. Motor Area	6	-3	-19	52	435	5.05
	L Suppl. Motor Area	6	-6	-10	55		4.77
	L Mid Cingulum	24	-6	2	43		4.53
	R Olfactory	25	3	14	-8	76	4.57
	L Anterior Cingulum		-12	29	-5		3.81
	L Anterior Cingulum	32	-3	23	-8		3.79
	R Insula	6	48	2	4	325	5.08
	R Insula	13	45	8	-8		4.47
	R Rolandic Operculum		42	-1	16		4.29
	Parietal cortex	L Postcentral		-39	-31	67	465
L Superior Parietal		7	-27	-49	64		3.80
L Postcentral		5	-24	-43	55		3.66
L Rolandic Operculum							
(Insula)		40	-48	-22	19	377	5.10
L Insula		13	-39	2	7		4.71
L Insula		13	-42	-16	1		4.25
R Supramarginal		40	51	-28	25	153	4.30
R Superior Temporal			69	-31	22		4.17
R Supramarginal		40	60	-25	31		3.95
Occipital cortex	R Lingual	18	9	-79	-2	449	8.68
	R Cerebelum		18	-52	-20		5.73
	Vermis		6	-52	-8		3.36
<i>Negative > Positive</i>							
<i>(FDRc <.001 = 55)</i>							
Occipital cortex	L Lingual	18	-12	-82	-8	55	4.51
	L Lingual	18	-18	-85	-14		3.76

Names were based on the Automatic Anatomical Labeling (AAL) atlas.

Table 3.*Regions activated during the target contrasts*

<i>Region</i>		<i>BA</i>	<i>Coordinates</i>			<i>Cluster Size</i>	<i>F</i>
<i>Self > Mother</i>							
<i>(FDRc <.001 = 62)</i>							
Frontal cortex/ Subcortical	L Inferior Frontal (vlPFC)	47	-30	26	-11	222	5.31
	L Middle Temporal	38	-51	5	-23		4.98
	L Middle Temporal Pole	38	-51	14	-26		4.57
	L Thalamus	50	-9	-19	1	62	4.49
	L Thalamus		18	-22	-2		4.26
	L Pallidum		-24	-16	-5		4.05
Temporal cortex	L Middle Temporal	21	-54	-31	1	89	5.42
	L Middle Temporal	22	-60	-40	10		3.59
	L Middle Temporal	22	-51	-19	-5		3.24
	R Inferior Temporal	20	48	2	-35	105	5.01
	R Middle Temporal	38	57	8	-29		4.76
Cerebellum	R Cerebellum		30	-61	-23	3871	6.55
	R Cerebellum		30	-46	-23		6.21
	L Cerebellum		-3	-70	-8		6.07

Names were based on the Automatic Anatomical Labeling (AAL) atlas.



Figure 1. Example of a trial. Each trial started with a black screen with a jittered duration between 0 and 6600ms. Subsequently, a fixation cross was shown for 400ms after which the stimulus appeared. Participants rated on a scale of 1 to 4 to what extent the traits fit themselves or their mothers. The stimulus was shown for 5000ms. If participants responded within this timeframe, the number of their choice would turn yellow. If participants failed to respond within this timeframe, a screen with the phrase ‘Too Late!’ was shown for an additional 1000ms after which the next trial would start.

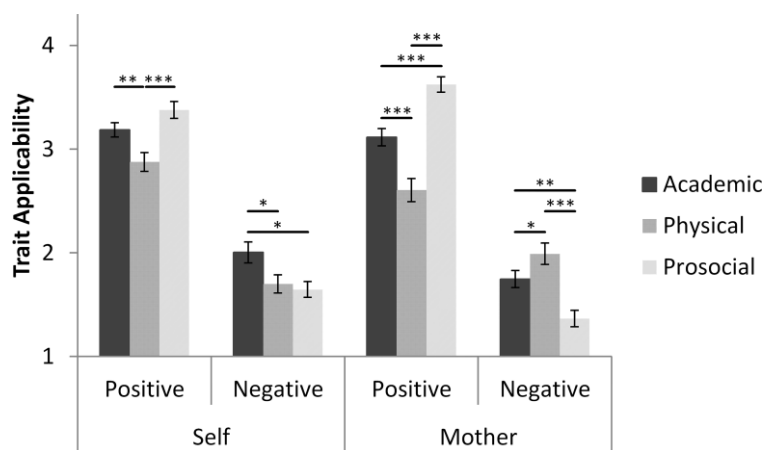


Figure 2. Applicability scores in the Self and the Mother task. *Self.* Positive academic and positive prosocial traits are more applicable to self than positive physical traits. Negative academic traits are more applicable to self than negative physical and prosocial traits. *Mother.* Positive prosocial traits apply most to the participant’s mothers, while positive physical traits apply the least to the participant’s mothers. Negative physical traits are most applicable to the participant’s mothers, while negative prosocial traits are the least applicable to the participant’s mothers.

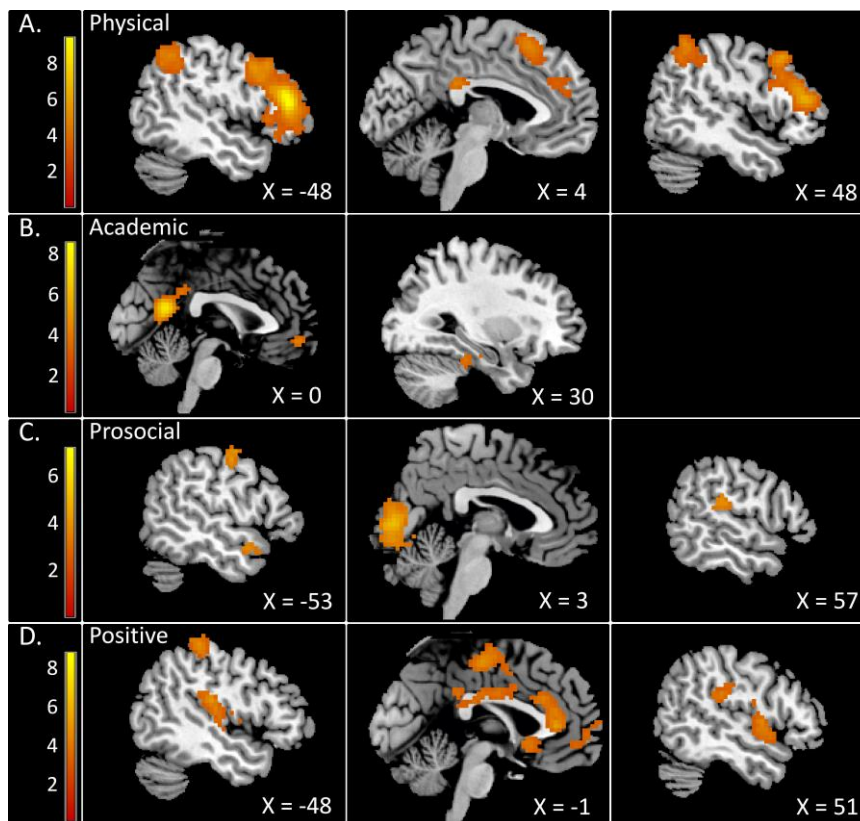


Figure 3. The whole brain effects of domain and valence. *A.* The t-contrast academic > physical & prosocial showed activation in PC/PCC, vmPFC, left middle occipital gyrus, and right fusiform gyrus. *B.* The t-contrast physical > academic & prosocial showed activation in bilateral dlPFC, bilateral IPL, PC/PCC, left SMA, and mPFC. *C.* The t-contrast prosocial > academic & physical showed activation in left STS, right TPJ, left postcentral gyrus, and right calcarine gyrus. *D.* The t-contrast positive > negative showed activation in rACC/vmPFC, bilateral insula, left SMA, left postcentral gyrus, right olfactory gyrus, right supramarginal gyrus, and right lingual gyrus.

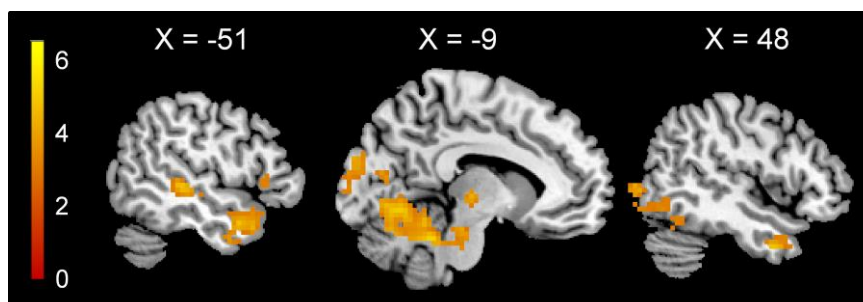


Figure 4. The t-contrast self > mother showed activation in left vlPFC, left thalamus, left middle temporal cortex, left inferior temporal cortex, and right cerebellum.

Supplement

Trait sentences used in both the self and the mother task. Participants were asked: ‘does this trait apply to me?’ (self task) or ‘does this trait apply to my mother?’ (mother task).

Academic	
positive	negative
Ik ben een harde werker	Ik ben onverstandig
Ik ben goed in het maken van toetsen	Ik ben snel afgeleid
Ik ben slim	Ik werk sloom
Ik leer snel	Ik vind school moeilijk
Ik ben gemotiveerd op school	Ik stel dingen uit
Ik werk zelfstandig	Ik werk slordig
Ik heb mijn werk altijd op tijd klaar	Ik werk chaotisch
Ik haal goede cijfers	Ik ben lui
Ik doe het goed op school	Ik heb veel hulp nodig op school
Ik leer graag	Ik ben dom
Physical	
positive	negative
Ik zie er aantrekkelijk uit	Ik ben dik
Ik ben mooi	ik heb overgewicht
Ik ben knap	Ik ben lelijk
Ik zie er goed uit	Ik zie er suf uit
Ik heb een goede kledingstijl	Ik zweet veel
Ik heb een goed lichaam	Ik ben te zwaar
ik heb een mooi figuur	Ik ben onaantrekkelijk
ik mag blij zijn met mijn lichaam	Ik zie er onverzorgd uit
Ik zie er stralend uit	Ik heb lelijke tanden
Ik heb een mooie lach	Ik heb een slechte huid
Prosocial	
positive	negative
Ik troost anderen	Ik zorg alleen voor mezelf
Ik doe graag iets voor een ander	Ik houd alleen rekening met mezelf
Ik houd rekening met anderen	Ik laat anderen hun problemen zelf oplossen
Ik leef met anderen mee	Ik houd alles voor mezelf
Ik geef om anderen	Ik help anderen alleen als ik er iets voor terug krijg
Ik voel met anderen mee	Ik kies altijd voor mezelf
Ik help anderen	Ik denk vooral aan mezelf
Ik zorg graag voor anderen	Ik neger anderen problemen
Ik kom voor anderen op	Ik leen mijn spullen niet graag uit
Ik deel graag met anderen	Ik help nooit een vreemde