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Recent functional neuroimaging studies have shown that reflecting on representations of the present self versus temporally distant selves is associated with higher activity in the medial prefrontal cortex (MPFC). In the current fMRI study, we investigated whether this effect of temporal perspective is symmetrical between the past and future. The main results revealed that the MPFC showed higher activity when reflecting on the present self than when reflecting on past and future selves, with no difference between past and future selves. Temporal perspective also modulated activity in the right inferior parietal cortex but in the opposite direction, activity in this brain region being higher when reflecting on past and future selves relative to the present self (with again no difference between past and future selves). These findings show that differences in brain activity when thinking about current versus temporally distant selves are symmetrical between the past and the future. It is suggested that by processing degrees of self-relatedness, the MPFC might sustain the process of identifying oneself with current representations of the self, whereas the right inferior parietal cortex might be involved in distinguishing the present self from temporally distant selves.

Keywords: Medial prefrontal cortex; Inferior parietal cortex; Self-referential processing; Social neuroscience; fMRI.

INTRODUCTION

Within the past decade, social neuroscientists have made important progress in identifying brain regions that are involved in processing information about the self (Heatherton, Macrae, & Kelley, 2004; Lieberman, 2007; Northoff et al., 2006). One of the most consistent findings is that cortical midline structures (CMS) such as the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC) are engaged when we reflect on our own personal characteristics (Craik et al., 1999; D'Argembeau et al., 2005, 2007; Fossati et al., 2003; Heatherton et al., 2006; M. K. Johnson et al., 2006; S. C. Johnson et al., 2002; Kelley et al., 2002; Lieberman, Jarcho, & Satpute, 2004; Moran, Macrae, Heatherton, Wyland, & Kelley, 2006; Pfeifer, Lieberman, & Dapretto, 2007; Saxe, Moran, Scholz, & Gabrieli, 2006; Schmitz, Kawahara-Baccus, & Johnson, 2004). For example, several functional neuroimaging studies have reported that the MPFC is more active when participants make judgments about their own character traits (e.g., am I sociable?) than when they make judgments about the traits of another person (e.g., is Chris reliable?), even when the other person is a closer other (D'Argembeau et al., 2007, 2008; Heatherton et al., 2006; Zhu, Zhang, Fan, & Han, 2007; although see the conflicting results of Ochsner et al., 2005; Vanderwal, Hunyadi, Grupe, Connors, & Schultz, 2008).

Although the interpretation of these findings is still debated (Gillihan & Farah, 2005; Legrand & Ruby, 2009), many researchers believe that CMS (and in particular the MPFC) play some specific roles in self-referential processing (D'Argembeau et al., 2008; Moran et al., 2006; Northoff & Bermpohl, 2004; Northoff et al., 2006; Schmitz & Johnson, 2007). In particular, it has been suggested that CMS may support supramodal processes that appraise and code the self-relatedness or self-relevance of information (Northoff & Bermpohl, 2004; Northoff et al., 2006; Schmitz & Johnson, 2007). According to this view, CMS may mediate dynamic processes that locate information on a continuum of self-relatedness or self-relevance: The more activity a particular stimulus or mental content elicits in CMS, the more strongly it will be related to the self (see D'Argembeau et al., 2005, and Moran et al., 2006, for evidence that CMS activity increases in a linear fashion with increasing self-relevance).

If CMS are indeed involved in processing self-relatedness, then factors that diminish the perceived degree of self-relatedness of information should modulate activity in CMS accordingly. Recent studies that have examined the effects of temporal perspective on self-representations suggest that this is the case. Research in social psychology has revealed that people tend to distance themselves from representations of psychologically remote former selves, which are then regarded as "other persons" (Libby & Eibach, 2002; Pronin & Ross, 2006; Wilson & Ross, 2003). We recently found that activity in CMS is sensitive to these effects of temporal perspective (D'Argembeau et al., 2008). Specifically, we asked participants to reflect on their own character traits and those of an intimate other, for both the present life period (i.e., at college) and a past life period (i.e., high school years) that involved significant personal changes. CMS were commonly recruited by the four reflective tasks (reflecting on the present self, past self, present other, and past other), relative to a control condition (making valence judgments). Importantly, however, the degree of activity in CMS also varied significantly according to the target of reflection, with the MPFC and PCC being more recruited when reflecting on the present self than when reflecting on the past self or when reflecting on the other person.

Differential activity in CMS as a function of temporal perspective has also been reported in another recent study that compared judgments regarding the present self with judgments regarding the future self (Ersner-Hershfield, Wimmer, & Knutson, 2009). Participants were scanned while making judgments about their own character traits and those of another person, for both the present time period and a future time period (i.e., 10 years from now). Ersner-Hershfield et al. (2009) found that the rostral anterior cingulate cortex (rACC) was more activated in the present self condition than in the future self condition (and was also more activated in the present self condition than in the present and future conditions referring to the other person). Furthermore, individual differences in the magnitude of this effect predicted the tendency to devalue future monetary gains (relative to immediate gains) in a subsequent behavioral task, suggesting that perceived connectedness to future selves has implications for financial saving (see also

Ersner-Hershfield, Garton, Ballard, Samanez-Larkin, & Knutson, 2009, for further behavioral evidence suggesting that perceived future self-continuity promotes savings behavior).

These variations in the degree of CMS activity as a function of temporal perspective fit nicely with behavioral data showing that processes involved in distinguishing representations of self from representations of others are also used for distinguishing selves from different time periods (Libby & Eibach, 2002; Pronin & Ross, 2006; Wilson & Ross, 2003). We have suggested that by processing degrees of self-relatedness, CMS might sustain the process of identifying oneself with current self-representations, which are therefore regarded as ''me'' (D'Argembeau et al., 2008). In the current study, we aimed to extend this work on the effects of temporal perspective in two important ways. First, we sought to investigate whether reflecting on the present self versus a temporally distant self modulates activity in CMS in the same way for the past and the future. Although the two studies described above both reported modulation of CMS activity as a function of temporal perspective, the medial prefrontal region that differentiated between present and past selves in the D'Argembeau et al. study (MNI coordinates of the peak voxel: $-6, 54, -2$) was somewhat rostral to the region that differentiated between present and future selves in the Ersner-Hershfield et al. study (which was located in the rACC; MNI coordinates of the peak voxel: 3, 38, 2).[1] Adopting a distant perspective on the self might therefore modulate slightly different brain regions for the past and the future. Cross-study comparisons of brain activation foci are obscured by various factors, however (e.g., individual differences in functional brain anatomy and differences in methods used to spatially normalize and analyze data), so present, past, and future selves conditions should be directly compared within the same study to investigate this possibility in a more rigorous way. Furthermore, even if adopting a distant perspective on the self modulates the same brain region(s) for the past and the future, there might still be differences in the magnitude of this effect. In the current study, we addressed these issues by including self-judgments regarding both past and future

time periods (in addition to judgments regarding the current self), and investigated whether differences in CMS activity when reflecting on the present self versus a temporally distant self are qualitatively and quantitatively the same for the past and the future.

Some behavioral studies have also reported asymmetries between past and future selves in terms of the positivity of self-representations. For example, people tend to systematically devalue their former selves to create the illusion that they have improved over time (Wilson & Ross, 2001), whereas representations of future selves are overwhelmingly positive (Markus & Nurius, 1986). These findings led us to the second aim of the current study, which was to explore possible differences in the neural basis of temporal perspective as a function of trait valence. Prior functional neuroimaging studies suggest that the MPFC and PCC are engaged during self-referential processing regardless of trait valence (Fossati et al., 2003; Gutchess, Kensinger, & Schacter, 2007; Moran et al., 2006; Yoshimura et al., 2009). For example, Moran et al. (2006) found that the MPFC and PCC responded more to traits that were self-descriptive than to traits that were not self-descriptive for both positive and negative traits. These studies only investigated the neural correlates of judgments regarding the current self, however, and trait valence might have different effects when reflecting on temporally distant selves. There is abundant evidence that most people process information in ways that maintain or increase the positivity of their current self-concept (for recent reviews, see Leary, 2007; Sedikides & Gregg, 2008). As mentioned above, one strategy used to fulfill such self-enhancement goals is to derogate past selves, such that the current self is viewed more positively in comparison (Ross & Wilson, 2002; Wilson & Ross, 2001). By contrast, far from being devalued, future selves are overwhelmingly viewed through rose-colored glasses (Markus & Nurius, 1986; Taylor & Brown, 1988). On the basis of these findings, it might be hypothesized that the neural correlates of self-judgments are influenced by trait valence to a greater extent when considering past and future selves than when considering present self. We investigated this possibility in the current functional magnetic resonance imaging (fMRI) study by using a factorial design in which both temporal perspective and trait valence were manipulated. Participants were asked to make judgments regarding present, past, and future

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[1] The coordinates reported by Ersner-Hershfield et al. have been transformed to the MNI space using a nonlinear transformation (http://imaging.mrc-cbu.cam.ac.uk/imaging/MniTalairach).

selves in response to positive traits and negative traits. To investigate whether thinking about past versus future selves showed similar or different patterns of activity in CMS and to explore whether these patterns of activity were modulated by trait valence, we looked at the brain regions that correlated with the main effect of temporal perspective, the main effect of trait valence, and their interaction.

METHODS

Participants

Twenty-one right-handed undergraduate or first-year graduate students (11 women) aged between 18 and 28 years (mean age = 23 years) participated in the experiment. They all gave their written informed consent to take part in the study, which was approved by the Ethics Committee of the Medical School of the University of Liège. None of the participants had any history of neurological or psychiatric disorder.

Self-reference task

Stimuli consisted of 20 adjectives designating positive traits (e.g. sincere, reliable) and 20 adjectives designating negative traits (e.g., selfish, lazy) selected from a published database (Anderson, 1968) and translated into French. Mean valence was 4.92 for positive traits (SD = 0.42) and 1.30 for negative traits (SD = 0.40), on a seven-point rating scale anchored at 0 (least desirable) and 6 (most desirable). Positive and negative traits were matched for length (number of letters and syllables) and frequency of use (New, Pallier, Brysbaert, & Ferrand, 2004). The task consisted of making different types of judgments on these adjectives. More specifically, participants were asked to assess whether or not the adjectives described their current character traits (present self), the character traits they had 5 years ago (past self), and the character traits they might have 5 years from now (future self). A temporal distance of 5 years was chosen to locate past and future selves in order to induce sufficient levels of perceived personal changes between present and distant selves. For college students, a 5-year temporal distance targets life periods that are clearly distinct from the current life period (i.e., high school years for the past, work

period for the future) and behavioral studies have confirmed that such a temporal distance induces significant differences in self-attributions (Pronin & Ross, 2006). A control condition was also included (judging whether or not the adjectives designated a positive trait), which involved semantic processing but did not require one to reflect on one's own character traits.

Ten blocks of four trials were presented for each condition (i.e., present self, past self, future self, control). Before the start of each block, an instruction cue appeared on the screen (for a variable duration: random normal distribution with a mean duration of 3000 ms and standard deviation of 500 ms) to inform participants about the type of judgment they had to make for the adjectives presented subsequently (present self: *At present, I am*; past self: *Five years ago, I was*; future self: *In five years from now, I will be*; control: *Positive trait*). The four trials were then presented sequentially. Each trial consisted of the presentation of an adjective for 3500 ms, during which participants made a yes/no decision by pressing one of two buttons, followed by a variable inter-stimulus interval (random normal distribution with a mean duration of 1250 ms and standard deviation of 350 ms). Each block consisted of two positive and two negative adjectives presented in random order. Between each pair of blocks, a fixation cross was presented for a variable duration between 5000 and 6000 ms. Blocks were presented in a pseudo-random order such that all four conditions were presented once before being repeated. In addition, blocks of a particular condition could not be repeated immediately and could not be separated by more than six intervening blocks of a different condition.

Before the fMRI session, participants were asked to take a few minutes to think about their life circumstances 5 years ago, to imagine their life circumstances 5 years from now, and to think about their present life circumstances (for each time period, the experimenter helped participants to bring to mind representations of that period by asking them questions about their situation at school/work, their familial and social conditions, and so forth). Participants were instructed to keep in mind the past, present, or future time period when making the corresponding judgments. Then they made a series of practice trials (with a different set of adjectives) in order to familiarize them with the four types of judgments. After the fMRI session, participants were asked to rate the

overall ease/difficulty with which they made each type of judgment in the scanner (using a 10-point rating scale: $1 =$ not at all difficult, $10 =$ very difficult) and the frequency with which some specific events (e.g., memories of specific episodes) came to their mind while making each type of judgments (using a 10-point rating scale: $1 =$ not at all, $10 =$ very frequently).

MRI acquisition

Data were acquired on a 3 T scanner (Siemens, Allegra, Erlangen, Germany) using a T2* sensitive gradient echo EPI sequence (TR $= 2130$ ms, TE $= 40$ ms, FA $90°$, matrix size $64 \times 64 \times 32$, voxel size $3.4 \times 3.4 \times 3.4$ mm^3). Thirty-two 3-mm thick transverse slices (FOV 22×22 cm^2) were acquired, with a distance factor of 30%, covering the whole brain. Five hundred and sixteen functional volumes were acquired. The first three volumes were discarded to account for T1 saturation. A structural MR scan was obtained at the end of the session (T1-weighted 3D MP-RAGE sequence, TR $= 1960$ ms, TE $= 4.4$ ms, FOV 23×23 cm^2, matrix size $256 \times 256 \times 176$, voxel size $0.9 \times 0.9 \times 0.9$ mm). Head movement was minimized by restraining the subject's head using a vacuum cushion. Stimuli were displayed on a screen positioned at the rear of the scanner, which the subject could comfortably see through a mirror mounted on the standard head coil.

fMRI analyses

fMRI data were preprocessed and analyzed using SPM5 (Wellcome Department of Imaging Neuroscience, http://www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB (Mathworks, Sherborn, MA). Functional scans were realigned using iterative rigid body transformations that minimize the residual sum of squares between the first and subsequent images. They were normalized to the MNI EPI template (voxel size: $2 \times 2 \times 2$ mm) and spatially smoothed with a Gaussian kernel with full-width at half maximum (FWHM) of 8 mm.

For each participant, BOLD responses were modeled at each voxel, using a general linear model. Responses to positive and negative traits were modeled separately for the four judgment conditions (present self, past self, future self, control) and were modeled as event-related responses. The design matrix also included the realignment parameters to account for any residual movement-related effect. The canonical HRF was used. A high pass filter was implemented using a cut-off period of 128 s in order to remove the low-frequency drifts from the time series. Serial autocorrelations were estimated with a restricted maximum likelihood algorithm with an autoregressive model of order 1 (+ white noise). Six linear contrasts were performed, looking at the effect of each self-referential task relative to the control task (present self – control; past self – control; future self – control) separately for positive traits and negative traits. The corresponding contrast images were smoothed (6-mm FWHM Gaussian kernel) in order to reduce remaining noise due to intersubject differences in anatomical variability in the individual contrast images. They were then entered in a second-level analysis, corresponding to a random-effects model.

We first looked at the brain regions that were commonly engaged by the three self-referential conditions (relative to the control condition) for positive traits and the brain regions that were commonly engaged by the three self-referential conditions (relative to the control condition) for negative traits, using null conjunction analyses (Friston, Penny, & Glaser, 2005) with the three respective contrast images. Next, in order to identify brain regions that showed differential activity as a function of temporal perspective (i.e., judgments targeting the present self, past self, or future self) and trait valence (positive or negative), the six contrast images were entered in a 3 (temporal perspective) $\times$ 2 (trait valence) whole-brain voxel-wise repeated-measures analysis of variance (ANOVA). For a priori regions of interest, statistical inferences were corrected for multiple comparisons using Gaussian random field theory at the voxel level in a small spherical volume (radius 10 mm) around coordinates selected from previous work on self-referential processing that has used similar tasks (D'Argembeau et al., 2008; Ersner-Hershfield et al., 2009). These a priori regions of interest concerned areas in the ventral MPFC (-6, 54, -2; 0, 54, -12), the dorsal MPFC (-2, 54, 24) (in this study, we refer to ventral MPFC for z coordinate ≤ 10 mm and to dorsal MPFC for z coordinate >10 mm), the rACC (3, 38, 2), and the PCC (-6, -54, 28). Other regions are reported if they survived a threshold of $p < .05$ corrected for multiple comparisons over the entire volume. For completeness, the tables also list regions that survived a threshold of $p < .001$ uncorrected for multiple

comparisons with a minimum cluster size of 30 voxels, but these regions are not discussed further.

RESULTS

Behavioral results

Table 1 shows the mean response times (RTs) for positive and negative traits in each judgment condition. A repeated-measures ANOVA with judgment condition (present self, past self, future self, control) and trait valence (positive, negative) as within-participants factors yielded a main effect of judgment condition, $F(3, 60) = 14.92$, $p < .001$, and an interaction between judgment condition and valence, $F(3, 60) = 5.56$, $p = .002$. The main effect of valence was not significant, $F(1, 20) < 1$. To further investigate the interaction, we conducted separate one-way ANOVAs (with judgment condition as within-participants factor) for positive and negative traits. For positive traits, RTs differed significantly between judgment conditions, $F(3, 60) = 18.23$, $p < .001$, and post-hoc comparisons (Tukey's HSD test) showed that RTs were faster for the control task relative to each self-reference task (all $p < .05$) and that RTs were faster in the future self condition than in the past self condition ($p < .05$); no other comparison reached statistical significance (all $p > .19$). RTs for negative traits also different significantly between judgment conditions, $F(3, 60) = 6.60$, $p < .001$, and post-hoc comparisons showed that RTs were faster in the control task than in the past self and future self conditions (all $p < .05$) and that RTs were faster in the present self condition than in the past self condition ($p < .05$); no other comparison reached statistical significance (all $p > .40$).

Table 1 also shows the mean proportion of "yes" responses given for positive and negative traits in each judgment condition. A repeated-measures ANOVA with judgment condition and trait valence as within-participants factors yielded a main effect of judgment condition, $F(3, 60) = 3.58$, $p < .05$, a main effect of valence, $F(1, 20) = 522.31$, $p < .001$, and an interaction between judgment condition and valence, $F(3, 60) = 37.45$, $p < .001$. To further investigate the interaction, we conducted separate one-way ANOVAs (with judgment condition as within-participants factor) for positive and negative traits. For positive traits, proportions of "yes" responses differed significantly between judgment conditions, $F(3, 60) = 20.05$, $p < .001$, and post-hoc comparisons showed that "yes" responses were more frequent for the future self and control conditions than for the present and past self conditions (all $p < .05$) and tended to be more frequent for the present self than for the past self ($p = .06$); there was no difference between the future self and control conditions ($p = .90$). Proportions of "yes" responses for negative traits also differed significantly between judgment conditions, $F(3, 60) = 45.31$, $p < .001$, and post-hoc comparisons showed that "yes" responses were less frequent in the control condition than in the three self-reference conditions, were less frequent in the future self condition than in the present self and past self conditions, and were less frequent in the present self condition than in the past self condition (all $p < .05$). Overall, these findings suggest that the future self is seen more positively than present and past selves and that the present self is seen more positively than the past self.

We also estimated perceived differences in personal characteristics across time, by computing the percentages of adjectives for which participants

TABLE 1
Behavioral measures as a function of judgment condition

	Present self	Past self	Future self	Control
Response times (ms)				
Positive traits	1618 (281)	1726 (294)	1545 (338)	1340 (226)
Negative traits	1500 (328)	1646 (314)	1585 (316)	1420 (284)
Proportion of "yes" responses				
Positive traits	0.81 (0.17)	0.70 (0.23)	0.95 (0.08)	0.99 (0.04)
Negative traits	0.25 (0.14)	0.37 (0.17)	0.16 (0.09)	0.02 (0.03)
Perceived judgment difficulty	2.86 (1.98)	3.05 (1.32)	6.04 (2.36)	1.76 (1.73)
Frequency of specific events	5.29 (2.39)	5.86 (2.46)	3.33 (1.62)	3.00 (2.53)

Notes: Standard deviations are shown in parentheses.

gave a different answer between the present self condition and the past or future self condition. There was a substantial level of differences for both present versus past judgments ($M = 26\%$, $SD = 14\%$) and present versus future judgments ($M = 20\%$, $SD = 11\%$). Although differences were slightly higher for the past than for the future, the difference failed to reach statistical significance, $t(20) = 1.91$, $p = 0.07$.

Finally, Table 1 shows mean ratings of judgment difficulty and mean ratings of the frequency with which specific events came to mind while making the judgments. Ratings of judgment difficulty differed significantly between conditions, $F(3, 60) = 20.34$, $p < .001$, and post-hoc comparisons showed that the future self condition was perceived as more difficult than the three other conditions (all $p < .05$); no other comparison reached statistical significance (all $p > .12$). Ratings of the frequency of specific events also differed between conditions, $F(3, 60) = 12.31$, $p < .001$, and post-hoc comparisons showed that the present and past self conditions were associated with more specific events than the future self and control conditions (all $p < .05$); there was no difference between the present and past self conditions, nor between the future self and control conditions (all $p > .74$).

fMRI results

We first examined the brain regions that were commonly activated by the three self-reference tasks (relative to the control task) for positive traits and the brain regions that were commonly activated by the three self-reference tasks (relative to the control task) for negative traits, using null conjunction analyses. With regard to positive traits, self-referential processing was associated with activations in the MPFC (in both ventral and dorsal portions of the MPFC) and the PCC (Table 2, Figure 1A). Similar activations were observed for negative traits, although activation in the MPFC was restricted to the ventral MPFC (Table 2, Figure 1B).

Next, we investigated the brain regions that showed differential activity as a function of the type of self-referential task (i.e., judgments about the present self, past self, or future self) and trait valence (i.e., positive or negative), using a two-way (temporal perspective × trait valence) whole-brain repeated-measures ANOVA. The main effect of temporal perspective was asso-

ciated with differential activity in a large portion of the MPFC (including the rACC and ventral and dorsal portions of MPFC; see Table 3, Figure 2). Differential activity was also detected in the right inferior parietal cortex (Table 3, Figure 2). No brain region was associated with the main effect of valence or with the temporal perspective by valence interaction, even at a lower statistical threshold ($p < .001$, uncorrected).

To further explore patterns of activation within the brain regions that were associated with the main effect of temporal perspective, we used a region-of-interest (ROI) analysis. For each participant, parameter estimates (mean beta weights) were derived from the MPFC/rACC (averaged over all voxels within an 8 mm radius of the peak voxel: $-2, 36, 10$) and the right inferior parietal cortex (averaged over all voxels within an 8 mm radius of the peak voxel: $46, -68, 40$) for each self-referential condition (relative to the control condition). A two-way repeated-measures ANOVA with temporal perspective (present, past, future) and ROI (MPFC/rACC, inferior parietal cortex) was performed. The ANOVA yielded a significant temporal perspective by ROI interaction, $F(2, 40) = 79.62$, $p < .001$. As can be seen from Figure 2 (right panels), mean activation level in the MPFC/rACC was significantly higher when thinking about the present self than when thinking about past and future selves (all $p < .05$, using Tukey's HSD tests); the difference between past and future selves was not significant ($p = 0.95$). With regard to the right inferior parietal cortex, mean activation level was significantly higher for past and future selves than for the present self (all $p < .05$); the difference between past and future selves was not significant ($p = .13$). On the participant-by-participant level, parameter estimates in the MPFC/rACC ROI were higher for the present self than for both past and future selves in 18 of 21 participants, whereas parameter estimates in the right inferior parietal cortex ROI were higher for both past and future selves than for the present self in 18 of 21 participants, $\chi^2(1) = 21.43$, $p < .001$.

Finally, we also performed a similar ROI analysis using an a priori defined ROI in the ventral MPFC ($-2, 54, -2$) based on our previous research (D'Argembeau et al., 2008), and similar results were obtained. Specifically, there was a significant temporal perspective by ROI interaction, $F(2, 40) = 34.94$, $p < .001$, and mean activation level in the ventral MPFC was significantly higher for the present self condition

Brain regions that were commonly activated when reflecting on present, past, and future selves (relative to valence judgments) for positive traits and for negative traits

| | MNI coordinates | | | | |
	x	y	z	Voxels	Z-score
Positive traits					
Ventral MPFC	−4	56	−10	269	3.84[a]
Dorsal MPFC	4	56	20	396	3.69[a]
Posterior cingulate cortex	4	−50	30	1949	5.65[a]
Left inferior parietal cortex	−44	−66	32	216	4.35[b]
Left supplementary motor area	−8	20	66	245	4.23[b]
Left middle/inferior temporal gyrus	−56	−6	−26	103	4.09[b]
Negative traits					
Ventral MPFC	4	54	−10	129	3.45[a]
Posterior cingulate cortex	6	−52	30	1345	4.25[a]
Left inferior parietal cortex	−50	−68	32	247	4.40[b]

Notes: MPFC = medial prefrontal cortex. Ventral MPFC refers to z coordinate ≤ 10 mm and dorsal MPFC to z coordinate > 10 mm. [a]Significant at $p < .05$ corrected for multiple comparisons at the voxel level over small volumes of interest (see "Methods" for details). [b]Significant at $p < .001$ uncorrected for multiple comparisons with a minimum cluster size of 30 voxels.

than for the past self and the future self conditions (all $p < .05$); the difference between past and future selves was not significant ($p = .63$).

DISCUSSION

In line with earlier studies (e.g., D'Argembeau et al., 2008; Fossati et al., 2003; S. C. Johnson et al., 2002; Kelley et al., 2002; Schmitz et al., 2004), we found that self-referential processing (whatever temporal perspective) was associated with higher activity in CMS compared to the control task (valence judgments), for both positive traits and negative traits. More important for our purpose, however, was the finding that the degree of activity in anterior CMS varied significantly as a function of temporal perspective. Specifically, the MPFC/rACC showed higher activity when reflecting on the present self than when reflecting on past and future selves; the past and future self conditions did not differ from each other. Temporal perspective also modulated activity in the right inferior parietal cortex but in the opposite direction, activity in this brain region being higher when reflecting on past and future selves than when reflecting on the present self (again with no differences between past and future selves). These effects of temporal perspective were not modulated by trait valence.

As already mentioned, the medial prefrontal region that differentiated present from past selves

in our previous study (D'Argembeau et al., 2008) was somewhat rostral to the region that differentiated present from future selves in the Ersner-Hershfield et al. (2009) study, raising the possibility that adopting a distant perspective on the self modulates brain activity in slightly different regions for the past and the future. The present findings do not support this hypothesis,
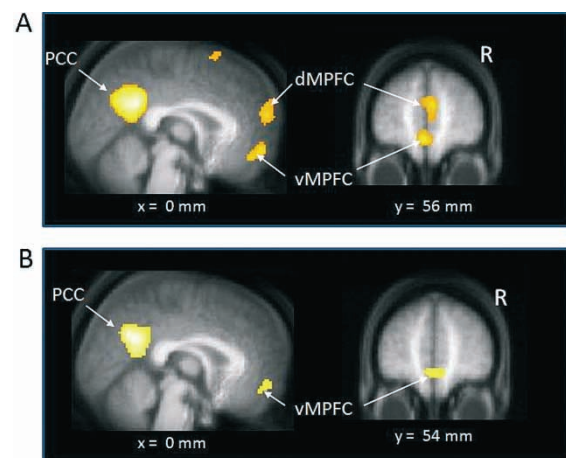
Figure 1. Brain regions commonly activated by the three self-referential tasks (present self, past self, future self) relative to the control task (valence judgments). (A) Brain regions activated for positive traits. (B) Brain regions activated for negative traits. Displayed at $p < .001$ (uncorrected) on the mean structural MRI of all participants. Abbreviations: PCC, posterior cingulate cortex; vMPFC, ventral medial prefrontal cortex; dMPFC, dorsal medial prefrontal cortex.

TABLE 3
Brain regions associated with the main effect of temporal perspective (present, past, future) in the full factorial (temporal perspective × valence) ANOVA

	MNI coordinates				
	x	*y*	*z*	*Voxels*	*Z-score*
rACC	−2	36	10	3769	6.43[a]
Ventral MPFC/rACC	−6	46	4		6.04[a]
	4	50	−4		3.94[a]
Dorsal MPFC/rACC	−2	48	16		5.58[a]
Right inferior parietal cortex	46	−68	40	1162	4.79[b]
Left inferior parietal cortex	−56	−48	48	415	3.92[c]
Calcarine fissure	−12	−52	6	498	4.55[c]
	−6	−88	0	548	4.54[c]
Right precuneus	16	−52	18	103	4.02[c]
Middle cingulate gyrus	−2	−16	40	165	3.81[c]
Left inferior frontal gyrus	−42	24	28	243	3.79[c]
Right inferior frontal gyrus	56	24	36	67	3.62[c]
Right middle frontal gyrus	38	12	60	90	3.76[c]
Right supperior temporal gyrus	62	−28	14	239	3.61[c]
Right middle temporal gyrus	52	−50	12	110	3.56[c]
Right supramarginal gyrus	64	−28	34	69	3.36[c]

Notes: MPFC = medial prefrontal cortex. rACC = rostral anterior cingulate cortex. Ventral MPFC refers to *z* coordinate ≤10 mm and dorsal MPFC to *z* coordinate >10 mm. [a]Significant at $p < .05$ corrected for multiple comparisons at the voxel level over small volumes of interest (see "Methods" for details). [b]Significant at $p < .05$ corrected for multiple comparisons at the voxel level over the entire volume. [c]Significant at $p < .001$ uncorrected for multiple comparisons with a minimum cluster size of 30 voxels.

however, but rather suggest that differences in cortical midline activations when reflecting on the current self versus temporally distant selves are symmetrical between the past and the future. In the current study, the effect of temporal perspective was associated with a large cluster of activation that encompassed both the MPFC and the rACC. The peak of activation fell in the rACC, in
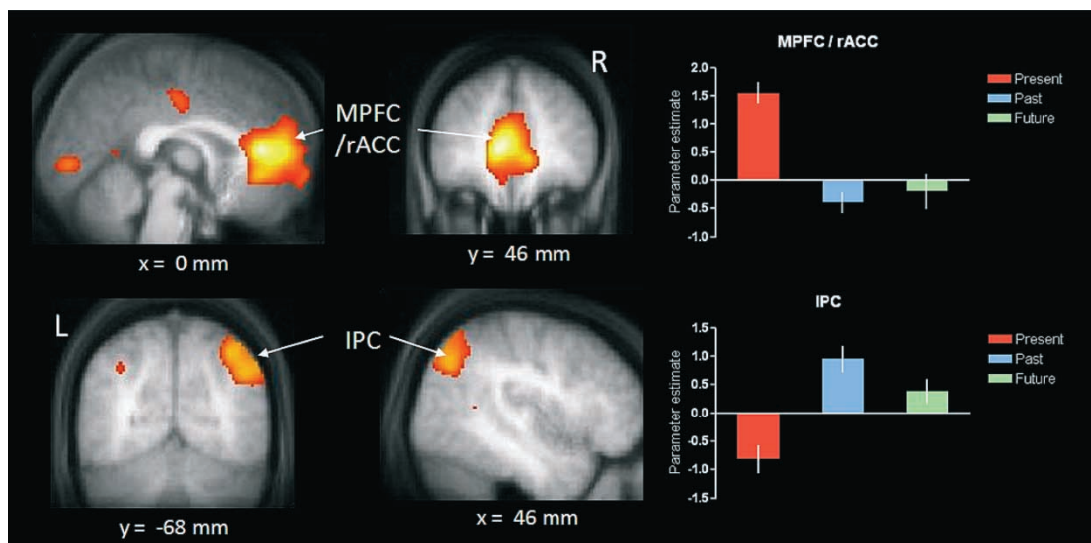
Figure 2.   Brain regions showing differential activity as a function of temporal perspective. As shown in left and middle panels, the MPFC/rACC and the right IPC were associated with the main effect of temporal perspective in the two-way ANOVA. Displayed at $p < .001$ (uncorrected) on the mean structural MRI of all participants. Right panels show mean parameter estimates (averaged over all voxels within an 8 mm radius of the peak voxel) for each self-referential condition (relative to the control condition) in the MPFC/rACC (−2, 36, 10) and the right IPC (46, −68, 40). Error bars represent the standard error of the mean. Abbreviations: MPFC, medial prefrontal cortex; rACC, rostral anterior cingulate cortex; IPC, inferior parietal cortex.

a region close to the region identified by Ersner-Hershfield et al. Notably, however, the ROI analysis using an a priori defined ROI in the MPFC (BA10) based on our previous research (D'Argembeau et al., 2008) showed that activity in this region was also higher in the present self condition than in past and future selves conditions (with no difference between past and future selves). Thus, in the current study, temporal perspective modulated brain activity in both the MPFC and the rACC.

Behavioral data have revealed important symmetries in attributions regarding distant past and future selves (Pronin & Ross, 2006). For example, people feel less psychologically connected to distant past and future selves and, as a consequence, tend to treat them as ''different persons'' (Libby & Eibach, 2002; Pronin & Ross, 2006; Wilson & Ross, 2003). The current findings are consistent with these studies and suggest that the critical factor that correlates with differences in MPFC/rACC activity relates to this reduced sense of connectedness, whatever the specific temporal direction considered (i.e., past versus future). From this perspective, it should be noted that the effect of temporal perspective may not be related to objective temporal distance *per se*, but rather to the perception of personal changes between the current self and past or future selves (Libby & Eibach, 2002; Libby, Eibach, & Gilovich, 2005). For college students, a temporal distance of five years targets life periods that are clearly distinct from the current life period (i.e., high school years for the past, work period for the future). In the current study, behavioral data confirmed that a substantial level of personal changes was perceived for both the past and the future time periods. Later in life, however, people may perceive fewer differences between their present self and their self five years ago or five years from now (unless they encountered or expect important changes in their life circumstances), such that the processing of present versus past and future selves may be more similar to each other. It would be interesting to investigate this issue further in future studies, by manipulating the subjective temporal distance of past or future selves while holding objective temporal distance constant (cf. Wilson & Ross, 2001).

Although many researchers believe that the MPFC plays some specific roles in self-referential processing (e.g., D'Argembeau et al., 2008; Moran et al., 2006; Northoff & Bermpohl, 2004;

Northoff et al., 2006; Schmitz & Johnson, 2007), this issue remains highly debated (Gillihan & Farah, 2005; Legrand & Ruby, 2009). For example, Legrand and Ruby (2009) have recently argued that the brain regions that have been associated with self-referential trait judgments are not self-specific and that activity in these regions can be explained by the involvement of reasoning processes and the retrieval of past episodes from memory. Although self-referential judgments undoubtedly engage reasoning and memory processes, we do not think that the differential activity detected in the MPFC when comparing self- versus other-judgments (D'Argembeau et al., 2007, 2008; Heatherton et al., 2006; Zhu et al., 2007) or when manipulating temporal perspectives on the self (D'Argembeau et al., 2008; Ersner-Hershfield et al., 2009) can be entirely explained by differential involvements of reasoning and memory processes. In the current study, judgments regarding the future self were rated as more difficult than judgments regarding present and past selves, suggesting that reflecting on the future self may involve a greater number of reasoning processes, yet activity in the MPFC was higher for the present self than for both past and future selves. With regard to the possible involvement of past event recall, it should first be noted that there is evidence that episodic memory is not necessary for making trait self-referential judgments (Klein, Robertson, Gangi, & Loftus, 2008; Klein, Rozendal, & Cosmides, 2002). Yet, it is possible that some specific events spontaneously come to mind when making such judgments. Ratings obtained in this study suggest that this was indeed the case and that specific event recall was more frequent when making judgments regarding present and past selves than when making judgments regarding the future self. However, ratings of specific event recall were not different between the present self and past self conditions, and yet making judgments on the present self was associated with more activity in the MPFC/rACC than making judgments on the past self. Thus, the pattern of activity in the MPFC/rACC that was detected in the current study when making judgments regarding present, past, and future selves is difficult to explain in terms of our behavioral measures of task difficulty and memory retrieval.

It is also important to emphasize again that the MPFC may not be involved in making fixed and rigid self/non-self distinctions, but may instead mediate dynamic processes that locate

information on a continuum of self-relatedness: The more activity a particular stimulus or mental content elicits in the MPFC, the more strongly it would be related to the self (Moran et al., 2006; Northoff et al., 2006; Schmitz & Johnson, 2007). At the upper end of this continuum of self-relatedness, the MPFC might sustain the process of identifying oneself with particular mental representations, which are therefore regarded as "me" (D'Argembeau et al., 2008). This view allows for the self to be somewhat fluctuating and, in particular, to vary as a function of a series of contextual factors (Markus & Wurf, 1987). We sometimes treat ourselves as "others" when making self-judgments (Libby & Eibach, 2002; Pronin & Ross, 2006), which, as the current study illustrates, is reflected in differential activity within the MPFC. Conversely, we often use information about ourselves when we reflect on others, especially when considering people who are perceived to be like ourselves (Van Boven & Loewenstein, 2005). Thus, reflecting on similar others engages the MPFC more than reflecting on dissimilar others (Mitchell, Banaji, & Macrae, 2005; Mitchell, Macrae, & Banaji, 2006). The relative malleability of the boundaries of the self-concept is also well illustrated by recent studies that have explored cultural differences in the neural correlates of self-processing. People who have more individualistic self-concepts show increased activations in the MPFC when thinking about the self versus a close other, whereas there is no difference between self and close other for people with more collectivistic self-concepts (i.e., whose self-concept overlaps more with intimate others; Zhu et al., 2007). Furthermore, priming cultural values of individualism versus collectivism in bicultural individuals induces increased activity in the MPFC for culturally congruent self-judgments (Chiao et al., in press). Overall, then, what is regarded as the "self" may depend on what information one identifies with on a particular occasion (i.e., what one includes in the currently activated self-concept; Markus & Wurf, 1987), and the MPFC may play a key role in implementing this process.

Another interesting finding of this study was that the right inferior parietal cortex showed greater activity when considering past and future selves than when considering the present self. Although we did not initially expect to observe differential activity in this brain region as a function of temporal perspective, the finding fits well with the proposed role of this region in social cognition. The inferior parietal cortex (especially in the right hemisphere) is thought to allow the distinction between self-generated actions and actions generated by others (Blakemore & Frith, 2003; Farrer et al., 2008; Jackson & Decety, 2004). This region has also been implicated in studies of empathy as well as studies of conceptual perspective-taking (for review, see Decety & Moriguchi, 2007; Decety & Sommerville, 2003). For example, the right inferior parietal cortex shows higher activity when making semantic judgments (i.e., judging the truthfulness of a series of propositions dealing with medical and health issues) according to another person's perspective than when making the same judgments according to one's own perspective (Ruby & Decety, 2003). On the basis of these and similar findings, Decety and colleagues have suggested that the right inferior parietal cortex may implement domain-general mechanisms that play a key role in distinguishing self from others (Decety & Moriguchi, 2007; Decety & Sommerville, 2003). The current data further suggest that the same region may also be involved in distinguishing the present self from temporally distant selves. Again, this finding fits well with the idea that processes involved in distinguishing self from others are also used for distinguishing selves from different time periods (Libby & Eibach, 2002; Pronin & Ross, 2006; Wilson & Ross, 2003). The precise mechanisms that are implemented by the inferior parietal cortex remain to be determined, however (Decety & Lamm, 2007). Interestingly, it has been recently found that processing spatial distance and computing the social distance of others in reference to the self were associated with activations in similar regions of the parietal cortex (Yamakawa, Kanai, Matsumura, & Naito, 2009). The investigators suggested that the parietal cortex may support a multipurpose module for computing abstract distances in different domains (e.g., spatial, social, numerical). From this perspective, the increased activation of the right inferior parietal cortex that was observed in the current study when participants thought about past and future selves might reflect the involvement of processes that computed distances in the temporal domain (i.e., distances of past and future selves relative to the present self). This interpretation is still tentative, however, and requires further investigation.

Finally, we did not find clear effects of trait valence on the neural correlates of self-judgments in the current study. The behavioral data indicated

that participants perceived themselves in a positive way, particularly in the future, which is consistent with studies of self-enhancement (for reviews, see Leary, 2007; Sedikides & Gregg, 2008). Yet we did not find any brain regions associated with the main effect of valence or with the interaction between valence and temporal perspective in the two-way ANOVA. When looking at the conjunction analysis for positive traits and the conjunction analysis for negative traits, one can see that activation in the MPFC for self-judgments versus the control task was more extended for positive traits than for negative traits (see Figure 1). However, this difference in extent of activation might be due to self-relevance rather than valence *per se*. Indeed, self-relevance and valence were not independent in the current study, as participants judged positive traits as more self-descriptive than negative traits. Unfortunately, we did not have a sufficient number of trials in each condition to examine the influence of valence independently of self-descriptiveness (e.g., the mean number of negative adjectives that were judged descriptive of the future self was only 3.2). Future studies should therefore be conducted to examine possible interaction between valence and temporal perspective in more detail (see Moran et al., 2006, for a successful attempt at disentangling the effects of self-relevance and valence on the neural correlates of current self-judgments).

In conclusion, the current study extends previous work that has examined the effects of temporal perspective on the neural correlates of self-referential processing by showing that differences in brain activity when thinking about current versus temporally distant selves are symmetrical between the past and the future. This finding suggests that the critical factor that underlies the effects of temporal perspective relates to feelings of connectedness to self-representations, whatever the specific temporal direction considered (i.e., past vs. future). We have suggested that by processing degrees of self-relatedness, the MPFC might sustain the process of identifying oneself with current representations of the self, whereas the right inferior parietal cortex might be involved in distinguishing the present self from temporally distant selves. We speculate that these processes play key roles in the organization of self-knowledge from different time periods and thereby in the construction of our sense of who we currently are.

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