

The importance of actions and the worth of an object: dissociable neural systems representing core value and economic value

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Neuroeconomic research has delineated neural regions involved in the computation of value, referring to a currency for concrete choices and decisions ('economic value'). Research in psychology and sociology, on the other hand, uses the term 'value' to describe motivational constructs that guide choices and behaviors across situations ('core value'). As a first step towards an integration of these literatures, we compared the neural regions computing economic value and core value. Replicating previous work, economic value computations activated a network centered on medial orbitofrontal cortex. Core value computations activated medial prefrontal cortex, a region involved in the processing of self-relevant information and dorsal striatum, involved in action selection. Core value ratings correlated with activity in precuneus and anterior prefrontal cortex, potentially reflecting the degree to which a core value is perceived as internalized part of one's self-concept. Distributed activation pattern in insula and ACC allowed differentiating individual core value types. These patterns may represent evaluation profiles reflecting prototypical fundamental concerns expressed in the core value types. Our findings suggest mechanisms by which core values, as motivationally important long-term goals anchored in the self-schema, may have the behavioral power to drive decisions and behaviors in the absence of immediately rewarding behavioral options.

Keywords: core value; economic value; emotion; decision-making; MPFC; insula

INTRODUCTION

Research in psychology and sociology has long investigated the structure of values and their effects on choices and behaviors (see e.g. Rohan, 2000; Hitlin and Piliavin, 2004 for reviews). More recently, research in the field of neuroeconomics has begun to elucidate the neurobiological and computational basis of value-based decision-making (Montague *et al.*, 2006; Rangel *et al.*, 2008; Peters and Buchel, 2010). However, a similar use of the term 'value' in these disciplines does not mean that the same underlying construct is considered. Indeed, while psychologists, sociologists and neuroeconomists all use the term 'value', there are different ways in which the term is understood, used and operationalized. 'Value', in its broadest sense, refers to the worth or the importance of something. Philosopher-economists like Adam Smith (1776/1994) considered value as 'the worth of an object', which was determined by how much people would work for it or would be willing to give to obtain it. Moral philosophers such as Immanuel Kant (1785/2000) used the term in a different, vastly expanded sense. Here, 'value' refers to the 'importance of actions', in the context of ethical questions such as 'What is the right thing to do?' or

'What is the good way to live?' These two different conceptualizations of the term value are reflected in the different definitions used in current research in neuroeconomics and psychology.

Neuroeconomists typically are interested in understanding the computation of object value in concrete situations, and how this computation allows predicting decisions between several different options. For example, a person may be facing the choice between drinking a coke or a pepsi or between buying a sports car or a family car. To make the decision, the brain needs to compute the anticipated reward value—in terms of the 'worth of an object'—of each of the options, possibly by establishing a common currency between options of different natures (Montague and Berns, 2002). These computations involve regions such as the orbitofrontal cortex (OFC)/ventromedial prefrontal cortex (VMPFC), the ventral striatum and the insula, a network activated by many different types of rewarding stimuli such as food, juice, money or attractiveness (Knutson *et al.*, 2003; Kawabata and Zeki, 2004; O'Doherty, 2004; Kim *et al.*, 2011). When comparing the effects of different rewarding stimuli in the same subjects, overlapping activations were observed in VMPFC and insula, suggesting that these regions represent the common currency for different types of rewarding stimuli (Kim *et al.*, 2011). The activation of value-related regions reflects individual preferences and, therefore, choices, i.e. it allows predicting both how much an

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individual likes an item and which of two items he/she will choose (FitzGerald *et al.*, 2009; Lebreton *et al.*, 2009). The term ‘value’ as used in neuroeconomics thus typically refers to an estimate about how much reward will result from a concrete behavioral decision, reflecting how much a person will prefer one stimulus to another in a given choice situation. We will refer to this conceptualization of the term value as ‘economic value’.

In contrast to the situation-specific economic value concept, research in psychology and sociology typically defines value as ‘motivational construct about desirable end states that transcends specific situations and guides the selection or evaluation of behaviors and events’ (Rohan, 2000). This value concept, which is more closely related to the philosophical notion of the ‘importance of actions’, refers to a broad, stable, trait-like construct that influences behavioral choices across time points and situations. Typical research investigates, for example, how the behavior of a person who considers ‘honoring traditions’ to be an important value differs from a person without this value priority (Bardi and Schwartz, 2003). In value-relevant situations, the value construct modulates attention, perception, stimulus interpretation and evaluation of the behavioral options (Bruner and Goodman, 1947; Schwartz, 2004). As a consequence, the person will frequently choose behaviors that are congruent with this value, such as ‘showing respect for the elderly’ or ‘observing traditional customs on holidays’ (Bardi and Schwartz, 2003). These values are constructs or schemata that people use to guide and give coherent meaning to their actions. They are intrinsically linked to the self by providing organization for one’s self-schema (Roccas and Brewer, 2002). It has even been suggested that they form the core of one’s identity (Hitlin, 2003). We will thus refer to this conceptualization of the term value as ‘core value’. Core values are similar to personality traits, in that they are relatively stable constructs that predetermine behavior. However, whereas traits represent enduring behavioral dispositions, core values represent enduring goals (Roccas *et al.*, 2002). Cross-cultural research has shown that the overall structure of human core values is universal and that people in many different cultures use and recognize a set of core values reflecting different types of basic human requirements, which can be grouped into core values expressing ‘anxiety-free self-expansion’ (‘growth-type core values’: self-direction, universalism, benevolence, stimulation and hedonism) and core values expressing ‘anxiety-based self-protection’ (‘protection-type core values’: security, power, achievement, conformity and tradition; Schwartz, 2006). The concept of core values differs from the concept of ‘moral values’ or ‘moral judgments’ (Moll *et al.*, 2005), which are internalized abstract social norms or rules against which the appropriateness of one’s behavior is evaluated. Core values, in contrast, are not norm-based representations that one can choose to obey or violate, but are integral parts of the self-schema and thus have the behavioral

power to drive decisions and to guide goal-directed behavior.

The concepts of economic value and of core value thus both refer to evaluative representations that guide decisions and behaviors, but are conceptualized at different levels of concreteness, economic value referring to a currency for concrete immediate choices and decisions, and core value representing abstract motivational constructs that guide choices and behaviors across many situations. However, the two value concepts can be linked to each other by assuming that core value determines on a meta-level how much economic value is given to each option in a concrete choice situation, consequently influencing behavioral decisions. In reverse, the behavioral effects of core values may be implemented via mechanisms that underlie the computation of economic value. Notwithstanding the conceptual similarities and the potential for synergistic theoretical integration, the concept of core value has not yet found its way into recent theorizing and research in decision-making, nor does core value research take into account neurobiological or computational findings delineating the neural valuation network.

In a first step toward an integration of the psychological and sociological core value research and the neuroimaging literature on economic value, we recently demonstrated that individuals reporting high self-interest related core values show stronger activation of the ventral striatum, a region central to the computation of economic value, when allocating money to themselves in a donation paradigm (Brosch *et al.*, 2011). In the current study, we investigated which neural structures are involved in the explicit processing of core value and economic value. In our task, participants were presented with examples of actions reflecting core value (as identified by Schwartz, 1992; such as ‘correcting injustice’, ‘respecting traditions’ and ‘having freedom’) and examples of potentially rewarding concrete activities (such as ‘eating an apple’, ‘listening to blues’ and ‘playing tennis’). Depending on the stimulus that was presented, participants then reflected on (i) how important the core value is for them (core value condition) or (ii) how much they like the activity (economic value condition).

We could thus investigate which brain regions were preferentially involved in the computations of core value and economic value, respectively, within the same task and the same individuals. As outlined above, the neural regions underlying the processing of economic value have been mapped in previous research (see, e.g. Montague *et al.*, 2006, for a review). Core values are critically involved in the organization of one’s self-schema (Hitlin, 2003), thus we hypothesized that core value processing would more strongly involve regions previously implicated in the processing of self-relevant information (such as medial prefrontal cortex, MPFC; D’Argembeau *et al.*, 2005). Critically, our experimental design also allowed us to investigate which brain regions would show variations of neural activation that correlate with the subjective ratings in the core value

condition and the economic value condition, respectively. Economic value has previously been shown to be parametrically reflected by the strength of neural activation of the OFC (Plassmann *et al.*, 2007; FitzGerald *et al.*, 2009). No empirical evidence exists with regards to core value. Given the similarity of the two rating tasks, core value may also be tracked by the OFC. Alternatively, considering the very different nature of concrete economic value and abstract core value, different neural regions may be tracking subjective core value. As outlined above, cross-cultural research has revealed a universal set of core values grouped in protection-type values and growth-type values (Schwartz, 2006). In an additional, more explorative analysis, we investigated whether types of universal core values are associated with identifiable patterns of brain activation. Using both standard univariate fMRI analysis and searchlight multivariate pattern classification (Kriegeskorte *et al.*, 2006), we looked for brain regions in which the local pattern of activation during core value processing would allow to correctly classify the type of core value the participant was currently reflecting upon.

METHODS

Subjects

Eighteen participants (8 males, 10 females, mean age = 28.8 years, s.d. = 4.8) participated in the experiment after giving informed consent according to the ethics regulation of the University of Geneva. All participants were right-handed, had normal or corrected-to-normal vision and had no history of psychiatric or neurological diseases.

Stimuli and procedure

Participants read examples of actions reflecting core values as identified by Schwartz (1992; such as 'correcting injustice', 'respecting traditions' and 'having freedom') and examples of potentially rewarding activities (such as 'eating an apple', 'listening to blues' and 'playing tennis'). Individual items were presented on screen for 6 s. After each item, a question mark was presented for 2 s. Depending on the stimulus that appeared on the screen, participants were to reflect on either (i) how important the core value is for them as guiding principle in their life (core value condition) or (ii) how much they like performing the activity (economic value condition). Participants were asked to respond while the question mark was presented on the screen. For both ratings, participants used a four-button response box with responses from 1 (not at all) to 4 (very much). The items were presented in 39 blocks of 3 items per block, one block thus lasted a total of 24 s. Between blocks, a fixation cross was shown for 12 s. In total, participants rated 117 items, 45 items for each universal core value type (Schwartz, 2006) and 27 items reflecting potentially rewarding activities (as the multivoxel pattern analysis investigated differences between different types of core value, we included more

trials for core value than for economic value to increase the power for this analysis).

Data acquisition

MRI data were acquired on a 3 T whole-body TIM system (Siemens, Germany) using an eight-channel head coil. For each participant, functional images were acquired with a gradient-echo EPI sequence [repetition time (TR)/echo time (TE)/flip angle = 2150 ms/30 ms/80°, field of view (FOV) = 192 mm, matrix = 64 × 64 × 36, voxel-size: 3 × 3 × 3 mm]. Each functional image was composed of 36 contiguous axial slices-oriented parallel to the AC-PC line. A total of 496 functional images were acquired. A structural image was also acquired with a T1-weighted sequence (192 contiguous sagittal slices, TR/TE/flip angle = 1900 ms/2.32 ms/9°, FOV = 230 mm, matrix = 246 × 256 × 192, voxel-size = 0.9 × 0.9 × 0.9 mm).

Data analysis

Functional images were analyzed using the general linear model (GLM) for event-related designs in SPM8 (Wellcome Department of Imaging Neuroscience, London, UK; <http://www.fil.ion.ucl.ac.uk/spm>). All images were first realigned, corrected for slice timing, normalized to an EPI template (resampled voxel-size of 3 mm), spatially smoothed (8 mm FWHM Gaussian kernel) and high pass-filtered (cutoff 120 s). Statistical analyses were performed on a voxel-wise basis across the whole brain. Individual events were modeled by a standard synthetic hemodynamic response function (HRF). Two event types were defined, including each of the experimental trial types (core value, economic value). We included parametric modulators for each of the two regressors of interest, reflecting the individual ratings for core value and economic value, respectively. Number of letters for each stimulus was covariate of no interest to control for any potential effect of basic visual differences due to different text length. To account for residual movement artifacts after realignment, movement parameters derived from realignment corrections (three translations, three rotations) were entered as additional covariates of no interest. The GLM was then used to generate parameter estimates of activity at each voxel, for each condition and each participant. Statistical parametric maps were generated from linear contrasts between the HRF parameter estimates for the different conditions and for the parametric modulators of interest. We performed random-effect group analyses on the contrast images from the individual analyses, using one-sample *t*-tests. Activation results are reported at uncorrected $P < 0.0001$, $k = 20$ for peak voxels in a whole-brain analysis of the contrasts (core value > economic value and economic value > core value) and uncorrected $P < 0.001$, $k = 20$ for peak voxels in a whole-brain analysis of the two parametric modulators of interest (core value rating, economic value rating).

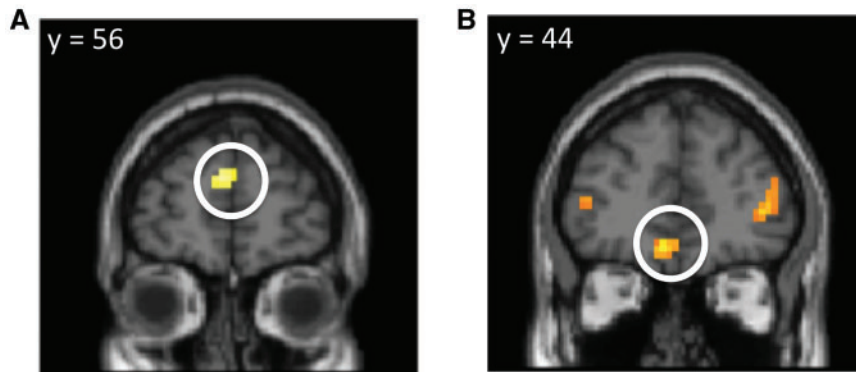


Fig. 1 Dissociation in prefrontal cortex for the processing of core value and economic value. (A) Increased activation during computation of abstract core value (e.g. ‘correcting injustice’, ‘respecting traditions’, ‘having freedom’) in MPFC (peak coordinates $x = -3$, $y = 56$, $z = 22$, $t = 5.76$, $P < 0.0001$), (B) Increased activation during computation of concrete economic value (e.g. ‘eating an apple’, ‘listening to blues’, ‘playing tennis’) in mOFC (peak coordinates $x = -6$, $y = 44$, $z = -14$, $t = 7.48$, $P < 0.0001$).

Searchlight classification analysis

In order to investigate which cortical regions carry additional information about different types of core value, we assessed whether it was possible to decode the core value type the subject was evaluating in a given trial (growth-type core value or protection-type core value) from the local spatial pattern of signals in each region of the cortex.¹ We applied multivariate pattern classification to spatial patterns of neural responses to the different core value types, using a searchlight approach (Kriegeskorte *et al.*, 2006) which examines the information in the local spatial patterns surrounding each voxel in an unbiased fashion. This analysis was performed on the normalized, unsmoothed data, using the searchlight functions of the Princeton MVPA toolbox implemented in MATLAB (<http://code.google.com/p/princeton-mvpa-toolbox/>). The functional data were divided into four subsets of 124 scans each. A spherical searchlight centered on one voxel was used to define a local neighborhood with a three-voxel radius. For each subset, the spatial response pattern in this local spherical cluster was extracted during the trials where subjects evaluated protection-type core values and the trials where subjects evaluated growth-type core values, yielding specific activation vectors for each core value type and each subset. Next, we assigned the pattern vector for three out of the four subsets to a ‘training’ data set that was used to train a linear support vector pattern classifier to correctly classify response patterns in the remaining independent fourth subset. If the classifier predicts the core value type evaluated by the subject in a given trial above chance, this implies that the local cluster of voxels spatially encodes information about the core value type. In total, the training and test procedure was repeated four times, each with a different subset assigned as test data set, yielding an average decoding accuracy in the local environment of the central voxel (4-fold crossvalidation). Then,

the procedure was repeated for the next spatial position. The average decoding accuracy for each voxel was then used to create a three-dimensional spatial map of decoding accuracy for each voxel in a gray-matter mask of the cortex. Because the subjects’ images had previously been normalized to a common stereotactic template, it was possible to perform a second-level analysis where we computed on a voxel-by-voxel basis how well decoding could be performed on average across all subjects from each position in the brain (see Haynes *et al.*, 2007). This yielded a spatial map of average decoding accuracy across subjects.

RESULTS

Analysis of the individual ratings showed that participants used the whole range of available responses for both the core value and the economic value condition. Overall the ratings for the core value condition (mean = 3.02, s.d. = 0.20) were slightly higher than for the economic value condition [mean = 2.68, s.d. = 0.35, $t(17) = 4.02$, $P = 0.001$].

GLM analysis of the brain imaging data revealed that different regions are involved in the processing of core value and economic value, respectively (Figure 1; see Table 1 for a complete list of activations). In the core value condition, we observed a relative increase in activation in MPFC (Figure 1A, peak coordinates $x = -3$, $y = 56$, $z = 22$, $t = 5.76$, $P < 0.0001$) and the left caudate ($x = -18$, $y = 17$, $z = 16$, $t = 6.61$, $P < 0.0001$). In the economic value condition, we observed a relative increase in a network including medial OFC (Figure 1B, peak coordinates $x = -6$, $y = 44$, $z = -14$, $t = 7.48$, $P < 0.0001$), lateral OFC, dorsolateral prefrontal cortex (DLPFC), precuneus and posterior cingulate.

We then examined which brain regions parametrically tracked the subjects’ individual subjective ratings during the core value and the economic value conditions, respectively (see Table 2 for a complete list of activations). During core value rating, lower subjective ratings were associated with increased activation in precuneus (Figure 2A), inferior frontal gyrus and anterior prefrontal cortex, whereas during

¹We also performed a univariate analysis comparing protection-type core values and growth-type core values. However, this analysis did not reveal any activation differences.

economic value rating, higher subjective ratings were associated with increased activation in mOFC (Figure 2B). No other regions were positively or negatively associated with individual ratings of core value or economic value.

Using multivariate pattern analysis, we then investigated which brain regions carry information that allows

Table 1 Main effects of condition

Region	Hemisphere	BA	Peak coordinates	N Voxel	t-value
Core value > economic value					
MPFC	L	9	-3, 56, 22	20	5.76
Caudate	L	-	-18, 17, 16	59	6.61
Economic value > core value					
mOFC	L	11	-6, 44, -14	35	7.48
IOFC	L	47	-30, 32, -14	67	7.96
DLPFC	R	46	48, 38, 22	78	9.07
	L	46	-42, 38, 10	27	6.23
Inferior parietal lobule	R	7	33, -67, 46	294	7.10
	L	7	-30, -58, 40	321	10.81
Inferior temporal gyrus	R	21	60, -40, -17	24	7.94
Precuneus	L	23	-3, -58, 13	78	7.25
Superior frontal gyrus	R	8	33, 20, 55	33	7.08
Posterior cingulate	R	31	3, -34, 37	32	6.58

Results are thresholded at $P < 0.0001$ uncorrected with an extended threshold of 20 voxels.

Table 2 Regions tracking the individual ratings for the core value and the economic value conditions

Region	Hemisphere	BA	Peak coordinates	N Voxel	t-value
Brain areas tracking individual ratings in core value condition					
Precuneus	R	19	12, -64, 58	89	-5.58
Anterior prefrontal cortex	R	10	21, 56, 1	23	-4.40
Inferior frontal gyrus	R	45	54, 26, 4	30	-5.37
Brain areas tracking individual ratings in economic value condition					
mOFC	R	11	9, 41, -5	81	5.73

Results are thresholded at $P < 0.001$ uncorrected with an extended threshold of 20 voxels.

distinguishing between the different types of core values (growth-type core values and protection-type core values). Searchlight multivoxel pattern classification analysis (Kriegeskorte *et al.*, 2006; Haynes *et al.*, 2007) yielded a spatial map of average decoding accuracy (Figure 3).

The analysis revealed a cluster in the left posterior insula (peak coordinates $x = -36$, $y = -13$, $z = 16$), where the pattern of local activation allowed to reliably differentiate between protection-type core values and growth-type core values [correct classification performance at peak coordinates 54%, statistical test against chance performance of 50%, $t(17) = 6.06$, $P < 0.001$]. A second, albeit smaller, cluster was observed in the anterior cingulate cortex [ACC, peak coordinates $x = -9$, $y = 38$, $z = 16$, correct classification performance at peak coordinates 53%, statistical test against chance performance, $t(17) = 3.04$, $P = 0.07$].

DISCUSSION

In this study, we set out to compare the neural representations underlying the computation of two different value concepts: economic value, referring to a currency for concrete immediate choices and decisions, as often used in neuroeconomic research and core value, referring to abstract motivational constructs that guide choices and behaviors across many situations, as often used in sociological and psychological research.

Computations of core value led to increased activation in MPFC and left caudate. MPFC has been frequently linked to processes involving self-reflection (Macrae *et al.*, 2004; Northoff and Bermphohl, 2004; D'Argembeau *et al.*, 2005; Mitchell *et al.*, 2005; see Lieberman, 2010 for review), both when explicitly reflecting on one's self-schema and when implicitly processing schema-related information (Rameson *et al.*, 2010). MPFC has furthermore been shown to be activated when thinking about one's future goals, which are closely tied to one's core values (D'Argembeau *et al.*, 2009). The observed MPFC activation during computations of core value is thus consistent with the conceptualization of core value as motivational information that forms an

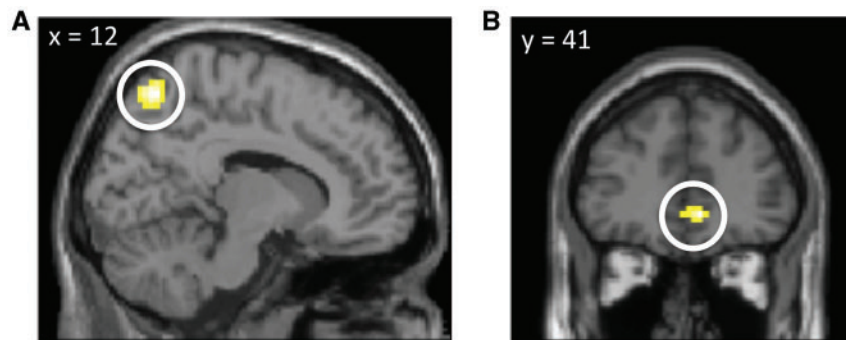


Fig. 2 Different regions tracking the individual ratings in the core value and the economic value condition. (A) Lower individual subjective core value ratings were associated with increased activation in precuneus, peak coordinates $x = 12$, $y = -64$, $z = 58$, $t = -5.58$, $P < 0.001$. (B) Higher individual economic value ratings were associated with increased activation in mOFC (peak coordinates $x = 9$, $y = 41$, $z = -5$, $t = 5.73$, $P < 0.001$).

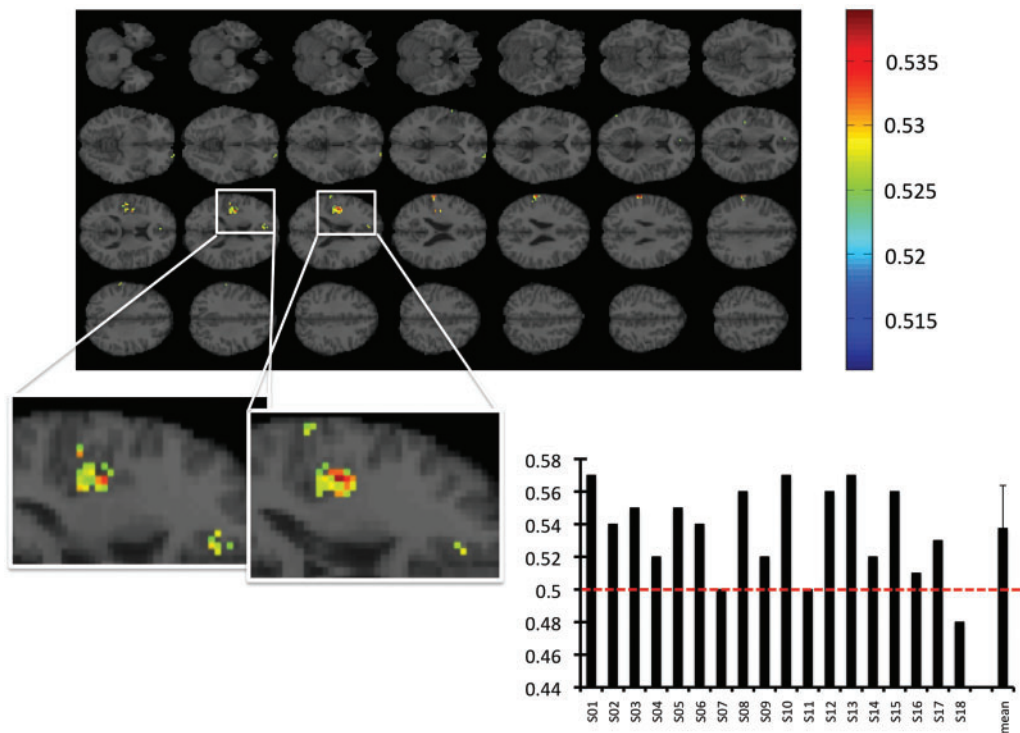


Fig. 3 Results of the multivariate searchlight analysis. Top panel: spatial map of average decoding accuracy across all subjects. Bottom left panel: Magnification of the cluster in the left posterior insula (peak coordinates $x = -36$, $y = -13$, $z = 16$), where the local classifier was able to decode significantly above chance what core value type the subject was currently evaluating [correct classification performance at peak coordinates 54%, statistical test against chance performance (50%), $t(17) = 6.06$, $P < 0.001$]. Bottom right panel: individual classifier performance for each subject for the insula peak coordinates.

integral part of the self-schema (Hitlin, 2003). Furthermore, we observed increased activation in the dorsal striatum, in particular in the left caudate. Whereas the ventral striatum is crucially involved in the processing of the economic value of a stimulus (Delgado, 2007), the dorsal striatum has been linked to the representation of ‘action value’ (Kim *et al.*, 2009) and is involved in action selection through the integration of cognitive, motivational/emotional and sensorimotor information (Balleine *et al.*, 2007). Self-schema-related core value information may thus be one form of cognitive–motivational information that is integrated in the dorsal striatum during action selection and decision-making processes.

In contrast, computations of economic value activated a network including medial and lateral OFC, PCC and DLPFC. Neuroeconomic research has established OFC as a central part of a valuation network that estimates immediate reward value and predicts preferences and choices (Montague *et al.*, 2006; Peters and Buchel, 2010). DLPFC has been shown to reflect, together with mOFC, participants’ willingness to pay money for rewarding objects such as food (Plassmann *et al.*, 2007). Likewise, PCC has been linked to the assignment of subjective value to stimuli of both financial (Kable and Glimcher, 2007) and social (Schiller *et al.*, 2009) nature. These results suggest that our experimental design could effectively combine the computation of both core value and economic value within the same design and

participants. Note however that even though we dissociated brain regions that are selectively involved in the processing of core value and economic value, respectively, this does not rule out that in addition common neural substrates may be involved in the processing of both value types.

By definition, core value is a more abstract construct than economic value. Core value rating may thus be more difficult than economic value rating, which may potentially account for some of the differences in brain activation. To evaluate this possibility, we assessed the impact of task difficulty on our results using individual differences in response times (RTs) during the fMRI experiment as a proxy for task difficulty. When comparing participants’ RTs for core value ratings and economic value ratings, we found indeed longer RTs for the core value condition (579 ms) compared to the economic value condition [517 ms, $t(17) = 5.94$, $P < 0.001$]. To investigate whether this difference can account for our brain imaging results, we ran an additional analysis of our fMRI data adding individual RTs for each trial as a parametric covariate. No brain region correlated with differences in RTs and most importantly, controlling for these differences did not change the pattern of results. Thus, we can conclude that differences of task difficulty (as operationalized by RTs) do not account for the reported activation differences.

We then investigated which brain regions code for individual variations in core value and economic value rating, respectively. Individual variations in economic value rating

were reflected in mOFC activity, replicating previous work (FitzGerald *et al.*, 2009). Variations in core value ratings, on the other hand, were tracked by precuneus, anterior prefrontal cortex and right inferior frontal gyrus.

Precuneus has been shown to be involved in self-reflective processing and the processing of autobiographic memories based on episodic memory retrieval and mental imagery strategies (Macrae *et al.*, 2004; Northoff and Bermpohl, 2004; D'Argembeau *et al.*, 2005; Mitchell *et al.*, 2005; Cavanna and Trimble, 2006; Johnson *et al.*, 2006). Anterior prefrontal cortex is thought to integrate the outcome of multiple separate cognitive operations in the pursuit of a higher behavioral goal (Ramnani and Owen, 2004). Note that the correlations were negative, in that the neural activation decreased with increased subjective core value ratings. In a series of studies on self-reflective processing, precuneus was more active when people were adopting the third-person perspective compared to the first-person perspective (Ruby and Decety, 2001; Farrer and Frith, 2002; Vogeley *et al.*, 2004). This has been interpreted as being due to the creation of a particularly vivid representation of the self in order to be able to imagine/simulate another person with the same neural resources as the self (Ruby and Decety, 2001). In a similar vein, increased precuneus activation in our study for core values that are not endorsed or perceived as internalized part of one's self-concept may be due to the simulation of a third person who endorses these core values or to an increased retrieval of episodic memories related to this value, on which participants based their decisions.

Core value was associated with higher ratings than economic value. This is not surprising, as all types of universal core value are positive constructs, even though individuals differ in their rank order of the values. On the other hand, a concrete object or activity may be positive for one person, but negative for another. Thus, activation differences may partly be due to these differences in rating. This does not seem likely, as there was very few overlap between brain regions showing activation differences depending on the type of rating task and brain regions parametrically tracking the ratings, but cannot completely be excluded.

In an additional analysis, we used searchlight multivoxel pattern classification to investigate which brain regions carry information that allows distinguishing between different types of core value. This whole-brain analysis revealed that the local activation pattern in the left insula and in the anterior cingulate cortex allowed the classifier to correctly predict whether a subject in a given trial was thinking about growth-type core values (expressing self-expansion) *vs* protection-type core values (expressing self-protection, Schwartz, 2006). The insula, which is frequently co-activated with the ACC, has been suggested to play an important role in the re-representation of interoception and to substantialize subjective feelings arising from bodily feedback (Craig, 2002, 2009). Neural representations of bodily feedback as they occur in the insula have long been assumed to play

an important role in emotional processing (James, 1884, see also Harrison *et al.*, 2010) and the insula has been demonstrated to be crucial for emotion-based decision processes (Damasio, 1994; Clark *et al.*, 2008; Weller *et al.*, 2009). In previous work, increased neural connectivity between insula and MPFC during the processing of self-relevant information has been shown, (Schmitz and Johnson, 2006), which may represent the pathway by which self-schema-based core value information is integrated into evaluative representations in the insula. However, up to now, brain imaging studies have not been able to reveal how the insula represents emotional and value-related information, as insula activation does not show linear increases or hemispheric asymmetries according to stimulus valence (Lamm and Singer, 2010, but see Kim *et al.*, 2011). It was recently suggested that different neuronal ensembles lying in close proximity in the insula may code for negative and positive affect, and that standard coarse-grained fMRI analysis techniques may therefore not be able to separate the information (Lamm and Singer, 2010). Multivoxel pattern analysis, however, allows for a readout of fine-tuned representations (Kamitani and Tong, 2005) and could thus pick up differences in the pattern of insula activation. The successful classification of different core value types may thus be based on changes in fine-grained activation patterns in neuronal ensembles in the insula, based on the integration of bodily feedback and other types of cognitive and motivational information (Craig, 2009). Core values are universal motivational themes reflecting requirements of human existence that are crucial for survival (Schwartz, 1992), thus representing prototypical fundamental concerns. One may speculate that activating different types of fundamental concerns may lead to systematical changes in the pattern of insula activation, potentially reflecting different evaluative profiles that may inform decisions and behaviors. However, given the relatively small effect size, this analysis should be considered exploratory and needs to be replicated.

To sum up, in this article, we describe the neural mechanisms underlying the processing of core value, referring to motivational constructs that coherently influence choices and behaviors across multiple situations and time-points, and furthermore suggest possible pathways for theoretically integrating the concept of core value and the concept of economic value as used in current research in neuroeconomics. We demonstrate that explicit processing of core value implicates medial prefrontal regions which are involved in the processing of self-relevant information, consistent with the notion that core values provide organization for one's self-schema (Roccas and Brewer, 2002). Individual variations in core value ratings are tracked by precuneus, potentially reflecting the degree to which a value is perceived as internalized part of one's self-concept, and the anterior prefrontal cortex, which tracks and integrates multiple outcomes in the pursuit of higher behavioral goals. Distributed activation pattern in the insula and ACC allowed to

differentiate and predict the core value type an individual was reflecting upon. We speculate that activation pattern in the insula represent evaluation profiles reflecting responses to prototypical fundamental concerns expressed in the core value types. These activation patterns may enter awareness and thus inform decisions and behaviors ('gut feelings'). By representing motivationally important long-term goals, core values may thus have the behavioral power to drive decisions even in the absence of immediately rewarding behavioral options.

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Conflict of Interest

None declared.

REFERENCES

- Balleine, B.W., Delgado, M.R., Hikosaka, O. (2007). The role of the dorsal striatum in reward and decision-making. *Journal of Neuroscience*, 27, 8161–5.
- Bardi, A., Schwartz, S.H. (2003). Values and behavior: strength and structure of relations. *Personality and Social Psychology Bulletin*, 29, 1207–20.
- Brosch, T., Coppin, G., Scherer, K.R., Schwartz, S., Sander, D. (2011). Generating value(s): psychological value hierarchies reflect context-dependent sensitivity of the reward system. *Social Neuroscience*, 6, 198–208.
- Bruner, J.S., Goodman, C.C. (1947). Value and need as organizing factors in perception. *Journal of Abnormal and Social Psychology*, 42, 33–44.
- Cavanna, A.E., Trimble, M.R. (2006). The precuneus: a review of its functional anatomy and behavioural correlates. *Brain*, 129, 564–83.
- Clark, L., Bechara, A., Damasio, H., Aitken, M.R., Sahakian, B.J., Robbins, T.W. (2008). Differential effects of insular and ventromedial prefrontal cortex lesions on risky decision-making. *Brain*, 131, 1311–22.
- Craig, A.D. (2002). How do you feel? Interoception: the sense of the physiological condition of the body. *Nature Reviews Neuroscience*, 3, 655–66.
- Craig, A.D. (2009). How do you feel—now? The anterior insula and human awareness. *Nature Reviews Neuroscience*, 10, 59–70.
- D'Argembeau, A., Collette, F., Van der Linden, M., et al. (2005). Self-referential reflective activity and its relationship with rest: a PET study. *Neuroimage*, 25, 616–24.
- D'Argembeau, A., Stawarczyk, D., Majerus, S., et al. (2009). The neural basis of personal goal processing when envisioning future events. *Journal of Cognitive Neuroscience*, 22, 1701–13.
- Damasio, A.R. (1994). *Descartes' Error: Emotion, Reason, and the Human Brain* (1994/10/01 ed.). New York: Putnam Publishing.
- Delgado, M.R. (2007). Reward-related responses in the human striatum. *Annals of the New York Academy of Sciences*, 1104, 70–88.
- Farrer, C., Frith, C.D. (2002). Experiencing oneself vs another person as being the cause of an action: the neural correlates of the experience of agency. *Neuroimage*, 15, 596–603.
- FitzGerald, T.H., Seymour, B., Dolan, R.J. (2009). The role of human orbitofrontal cortex in value comparison for incommensurable objects. *Journal of Neuroscience*, 29, 8388–95.
- Harrison, N.A., Gray, M.A., Gianaros, P.J., Critchley, H.D. (2010). The embodiment of emotional feelings in the brain. *Journal of Neuroscience*, 30, 12878–84.
- Haynes, J.D., Sakai, K., Rees, G., Gilbert, S., Frith, C., Passingham, R.E. (2007). Reading hidden intentions in the human brain. *Current Biology*, 17, 323–8.
- Hitlin, S. (2003). Values as the core of personal identity: drawing links between two theories of self. *Social Psychology Quarterly*, 66, 118–37.
- Hitlin, S., Piliavin, J.A. (2004). Values: reviving a dormant concept. *Annual Review of Sociology*, 30, 359–93.
- James, W. (1884). What is an Emotion? *Mind*, 9, 188–205.
- Johnson, M.K., Raye, C.L., Mitchell, K.J., et al. (2006). Dissociating medial frontal and posterior cingulate activity during self-reflection. *Social Cognitive and Affective Neuroscience*, 1, 56–64.
- Kable, J.W., Glimcher, P.W. (2007). The neural correlates of subjective value during intertemporal choice. *Nature Neuroscience*, 10, 1625–33.
- Kamitani, Y., Tong, F. (2005). Decoding the visual and subjective contents of the human brain. *Nature Neuroscience*, 8, 679–85.
- Kant, I. (1785/2000). *Grundlegung zur Metaphysik der Sitten*. Berlin: Suhrkamp.
- Kawabata, H., Zeki, S. (2004). Neural correlates of beauty. *Journal of Neurophysiology*, 91, 1699–705.
- Kim, H., Shimojo, S., O'Doherty, J.P. (2011). Overlapping responses for the expectation of juice and money rewards in human ventromedial prefrontal cortex. *Cerebral Cortex*, 21, 769–76.
- Kim, H., Sul, J.H., Huh, N., Lee, D., Jung, M.W. (2009). Role of striatum in updating values of chosen actions. *Journal of Neuroscience*, 29, 14701–12.
- Knutson, B., Fong, G.W., Bennett, S.M., Adams, C.M., Hommer, D. (2003). A region of mesial prefrontal cortex tracks monetarily rewarding outcomes: characterization with rapid event-related fMRI. *Neuroimage*, 18, 263–72.
- Kriegeskorte, N., Goebel, R., Bandettini, P. (2006). Information-based functional brain mapping. *Proceedings of the National Academy of Sciences*, 103, 3863–8.
- Lamm, C., Singer, T. (2010). The role of anterior insular cortex in social emotions. *Brain Structure and Function*, 214, 579–91.
- Lebreton, M., Jorge, S., Michel, V., Thirion, B., Pessiglione, M. (2009). An automatic valuation system in the human brain: evidence from functional neuroimaging. *Neuron*, 64, 431–9.
- Lieberman, M.D. (2010). Social cognitive neuroscience. In: Fiske, S.T., Gilbert, D.T., Lindzey, G., editors. *Handbook of Social Psychology* 5th edn. New York: McGraw-Hill, pp. 143–93.
- Macrae, C.N., Moran, J.M., Heatherton, T.F., Banfield, J.F., Kelley, W.M. (2004). Medial prefrontal activity predicts memory for self. *Cerebral Cortex*, 14, 647–54.
- Mitchell, J.P., Banaji, M.R., Macrae, C.N. (2005). The link between social cognition and self-referential thought in the medial prefrontal cortex. *Journal of Cognitive Neuroscience*, 17, 1306–15.
- Moll, J., Zahn, R., de Oliveira-Souza, R., Krueger, F., Grafman, J. (2005). Opinion: the neural basis of human moral cognition. *Nature Reviews Neuroscience*, 6, 799–809.
- Montague, P.R., Berns, G.S. (2002). Neural economics and the biological substrates of valuation. *Neuron*, 36, 265–84.
- Montague, P.R., King-Casas, B., Cohen, J.D. (2006). Imaging valuation models in human choice. *Annual Review of Neuroscience*, 29, 417–48.
- Northoff, G., Bermpohl, F. (2004). Cortical midline structures and the self. *Trends in Cognitive Sciences*, 8, 102–7.
- O'Doherty, J.P. (2004). Reward representations and reward-related learning in the human brain: insights from neuroimaging. *Current Opinions in Neurobiology*, 14, 769–76.
- Peters, J., Buchel, C. (2010). Neural representations of subjective reward value. *Behavioral Brain Research*, 213, 135–41.
- Plassmann, H., O'Doherty, J., Rangel, A. (2007). Orbitofrontal cortex encodes willingness to pay in everyday economic transactions. *Journal of Neuroscience*, 27, 9984–8.

- Rameson, L.T., Satpute, A.B., Lieberman, M.D. (2010). The neural correlates of implicit and explicit self-relevant processing. *Neuroimage*, 50, 701–8.
- Ramnani, N., Owen, A.M. (2004). Anterior prefrontal cortex: insights into function from anatomy and neuroimaging. *Nature Reviews Neuroscience*, 5, 184–94.
- Rangel, A., Camerer, C., Montague, P.R. (2008). A framework for studying the neurobiology of value-based decision making. *Nature Reviews Neuroscience*, 9, 545–56.
- Roccas, S., Brewer, M.B. (2002). Social identity complexity. *Personality and Social Psychology Review*, 6, 88–106.
- Roccas, S., Sagiv, L., Schwartz, S.H., Knafo, A. (2002). The big five personality factors and personal values. *Personality and Social Psychology Bulletin*, 28, 789–801.
- Rohan, M.J. (2000). A rose by any name? The values construct. *Personality and Social Psychology Review*, 4, 255–77.
- Ruby, P., Decety, J. (2001). Effect of subjective perspective taking during simulation of action: a PET investigation of agency. *Nature Neuroscience*, 4, 546–50.
- Schiller, D., Freeman, J.B., Mitchell, J.P., Uleman, J.S., Phelps, E.A. (2009). A neural mechanism of first impressions. *Nature Neuroscience*, 12, 508–14.
- Schmitz, T.W., Johnson, S.C. (2006). Self-appraisal decisions evoke dissociated dorsal-ventral aMPFC networks. *Neuroimage*, 30, 1050–8.
- Schwartz, S.H. (1992). Universals in the content and structure of values: theoretical advances and empirical tests in 20 countries. In: Zanna, M.P., editor. *Advances in experimental social psychology*, Vol. 25, San Diego, CA: Academic Press, pp. 1–65.
- Schwartz, S.H. (2004). Mapping and interpreting cultural differences around the world. In: Vinken, H., Soeters, J., Ester, P., editors. *Comparing Cultures: Dimensions of Culture in a Comparative Perspective*. Leiden: Brill.
- Schwartz, S.H. (2006). Les valeurs de base de la personne: théorie, mesures et applications [Basic human values: theory, measurement, and applications]. *Revue Française de Sociologie*, 45, 929–68.
- Smith, A. (1776/1994). *The Wealth of Nations*. New York: Modern Library.
- Vogeley, K., May, M., Ritzl, A., Falkai, P., Zilles, K., Fink, G.R. (2004). Neural correlates of first-person perspective as one constituent of human self-consciousness. *Journal of Cognitive Neuroscience*, 16, 817–27.
- Weller, J.A., Levin, I.P., Shiv, B., Bechara, A. (2009). The effects of insula damage on decision-making for risky gains and losses. *Social Neuroscience*, 4, 347–58.