Nonlinear Responses Within the Medial Prefrontal Cortex Reveal When Specific Implicit Information Influences Economic Decision Making

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ABSTRACT

Background and Purpose. The authors used functional magnetic resonance imaging (fMRI) to investigate how individual economic decisions are influenced by implicit memory contributions. *Methods*. Twenty-two participants were asked to make binary decisions between different brands of sensorily nearly undistinguishable consumer goods. Changes of brain activity comparing decisions in the presence or absence of a specific target brand were detected by fMRI. *Results*. Only when the target brand was the participant's favorite one did the authors find reduced activation in the dorsolateral prefrontal, posterior parietal, and occipital cortices and the left premotor area (Brodmann areas [BA] 9, 46, 7/19, and 6). Simultaneously, activity was increased in the inferior precuneus and posterior cingulate (BA 7), right superior frontal gyrus (BA 10), right supramarginal gyrus (BA 40), and, most pronounced, in the ventromedial prefrontal cortex (BA 10). *Conclusions*. For products mainly distinguishable by brand information, the authors revealed a nonlinear winner-take-all effect for a participant's favorite brand characterized, on one hand, by reduced activation in brain areas associated with working memory and reasoning and, on the other hand, increased activation in areas involved in processing of emotions and self-reflections during decision making.

Key words: Behavior, economics, decision making, fMRI, neuroeconomics.

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In economically relevant siuations, judgments depend not only on explicit knowledge such as prices and object attributes but also on implicit ("intuitive") processes biasing the evaluation.[1,2] Implicit information can help to select relevant objects by constraining the decision space and reducing uncertainty. Consequently, a person can act quickly and efficiently, especially if the decision process is complex and explicit information is lacking. Implicit evaluation processes not only play an important role in obviously intuitive decisions also but can influence all kinds of seemingly rational decision-making processes. Psychology and economics had synergistically been combined by the 2002 Nobel laureates Kahneman and Smith, who created the new scientific field of behavioral economics in the 1970s.[3,4] Until recently, however, studying the neurobiological basis of how emotions influence behavior was confined to methods measuring epiphenomenal physiological parameters such as the skin conductance response (SCR). The SCR, however, does not specifically reflect the underlying brain activity and is unspecific in terms of the emotional direction (negative vs positive). Correlations between SCR and cortical activation appear not only in reward-based decision making but also during working memory tasks and even spontaneously during rest.[5]

With the present approach, we combined economical research and neuroscience to answer the following question: Is the selection process during buying decisions modulated by brand information, and, if so, what are the underlying brain mechanisms? Recent advances in functional magnetic resonance imaging (fMRI) allow the investigation of the neurobiological mechanisms of emotion-modulated behavior more directly by visualizing brain activity changes (see Dolan[6] for review).

We applied high-field fMRI to detect brand-dependent changes in brain activation in a simulated buying decision task between sensorily nearly indistinguishable commodity products.

Methods

Participants

Two separate cohorts of 12 male (median age = 23 years) and 10 female (median age = 22 years) right-handed, healthy students of economics participated in the present study. Standard exclusion criteria for MR examinations, such as metal implants, were applied. As we used visual stimuli, participants with strong myopia or other relevant constraints of vision were also excluded. All participants provided written informed consent prior to the scanning sessions.

Stimulation Paradigm

The binary decision-making task was simulated by visual presentation of brand pairs during fMRI. This paradigm was designed to detect systematic differences of cortical processing during buying decisions in the presence or absence of a specific target brand (T). As product types, we used coffee for the female participants and beer for the male group. All these commodity goods have among each other similar ingredients as well as sensory qualities defined, for instance, by tradition or legislation (eg, German purity law for beer, *Reinheitsgebot*), causing that the brand itself functions as the major selection criterion. For each decision, 2 different brands were combined in a pseudo-randomized manner from a pool of 20 beer or 15 coffee brands, respectively. For each single decision trial, participants were requested to decide mentally which of the 2 displayed products they would buy. One of the respective market leaders for each product type was defined as the target brand (T_{coffee}, T_{beer}). The selection of the target brand T was performed a priori and identically for all participants within the male and female group without knowing the personal brand preferences of the participants. The other brands (N_{coffee} = 14, N_{beer} = 19) were classified as diverse (D_1, D_2 . . . D_N). This means that participants had to make either a binary TD or a DD decision (TD decision = target brand vs various diverse other brands; DD decision = diverse vs other diverse brands). Here, a D without index indicates that the diverse brands were selected from the pool by chance. The sequence of the 2 employed decision types is illustrated in Figure 1. The order of DD and TD decisions was pseudo-randomized within 10 blocks of 10 decisions each, so that these blocks consisted either of 8 DD and 2 TD or 2 DD and 8 TD decisions. While this arrangement allowed evaluating the data as a block design with blocks of 20% and 80% TD decisions, respectively, the block structure was not apparent for the participants. We implemented no resting condition to avoid the problem of ambiguous baseline conditions.[7] The 100 decision trials (1 run) were presented twice for each participant to assess reproducibility and habituation effects.[8] To avoid response-related brain activations and movement artifacts, we did not ask for any feedback during the measurements. We hypothesized an approximately linear relationship between cortical activity differences between TD and DD decisions and the individual rating of the target brand T.

Visual Presentation

A dedicated shielded fMRI projection system (Covilex, Magdeburg, Germany) provided high-quality image presentation. Controlled by a personal computer in the MR control room, images were projected onto an approximately 50 cm $\times$ 50 cm field on a screen fixed at the rear opening of the MR bore. A participant lying in the bore could see the screen via a 45° mirror fixed at the top of the head coil. As the images nearly covered the participant's whole field of view, even small details of all product labels could be recognized easily. Triggered by the scanner, all images were presented by the neuropsychological stimulation software ShowPics.[9] Stimulus duration and interstimulus interval were 3 seconds. Care was taken to present the different products with equal size, position, background, and luminance, to prevent confounding visual stimulation.

Instructions Given to the Participants

All participants were informed prior to the experiment in exactly the same way by reading the instructions clearly and slowly to them. The participants were requested to imagine that they have to buy coffee (women) or beer (men) in a shop. For each trial, they have the option of 2 different brands of the same product type (coffee or beer), which will be presented on the screen. The decision should be taken during the presentation of the object pairs (3 second) and must be finished purely mentally after the thought process by mentally speaking the selected brand name. The participants were informed about the course of events of the whole experiment and the sequence and repetition.

MR Image Acquisition

All data were acquired on a 3.0-T whole-body scanner (Intera T30, Philips, Best, NL) equipped with master gradients (nominal gradient strength 30 mT/m, maximal

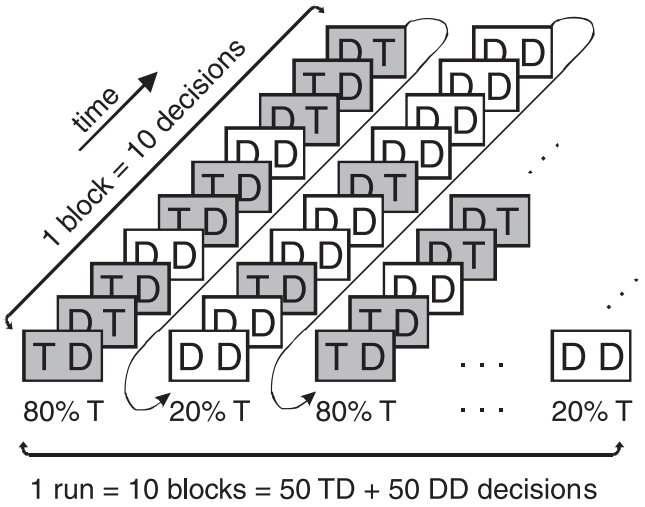

Fig 1. Buying decision-making task. The letter *T* represents the respective target brand (T_{coffee}, T_{beer}) and *D* 1 of the 19 or 14 diverse other beer or coffee brands in pseudo-randomized order, respectively. For details, see text.

slew rate 150 mT/m/ms). For spin excitation and resonance signal acquisition, a circularly polarized transmit/receive birdcage head coil with an HF reflecting screen at the cranial end was used. Coil diameter was 275 mm; coil length was 230 mm.

Following a survey, a T1w data set of the whole head with isotropic voxels of 1.0 mm edge length was acquired for anatomical identification and coregistration into the Talairach space[10] using a turbo field echo technique in sagittal slice orientation with 3-dimensional acquisition, that is, phase encoding in 2 directions (ap and slice encoding direction lr); FOV 256 × 205 × 160 mm (frequency encoding × phase encoding × slice encoding in fh/ap/lr direction), measured matrix 256 ,≅ 0180 205 × 160, reconstructed after zero filling to 512 × 410 × 320, that is, reconstructed edge length 0.5 mm; contrast was defined by TR = 7.4 mm, TE = 3.4 ms, FA = 9°, an inversion recovery prepulse every 805 ms = every 102 acquisitions, 1 saturation slab caudal to the acquired volume. Acquisition bandwidth (BW) per pixel was 217.1 Hz, total BW 55.578 kHz. With 2 signal averages, the total acquisition time was 11:01 minutes.

For functional images, blood oxygenation level–dependent contrast images were acquired using a T2*-weighted single-shot gradient echo-planar imaging (EPI) sequence that covered nearly the whole brain. The data set consisted of 36 transversal slices of 3.6 mm thickness without gap, FOV 230 × 230 mm, acquired matrix 63 × 64 (ap/lr direction), reconstructed matrix 64 × 64, that is, reconstructed isotropic voxels with 3.6 mm edge length, with phase encoding in ap direction. Slices were oriented parallel to the ac-pc-line. Contrast parameters were TR = 3000 ms, TE = 50 ms, FW = 90°, EPI-factor (echo train length) 63, frequency selective fat suppression by a preceding inversion pulse (SPIR-technique), BW per pixel in frequency encoding direction 2452.8 Hz, total BW 156.98 kHz, BW per pixel in phase encoding direction 23.3 Hz, and the total acquisition time per set of 25 slices was 3 seconds. Prior to each fMRI run, 10 dummy scans were acquired to allow for equilibration of magnetization. The total acquisition time without dummy scans was 5:00 minutes for each run.

Postscan Interview

Two weeks after the fMRI measurements, participants were asked to rank the presented beer or coffee brands according to their preference. For the later statistical analysis, participants were grouped according to the rank they assigned to the target brand.

Image Preprocessing

Data analysis was performed using Statistical Parametric Mapping (SPM99; Wellcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm)[11-13] to correct for head movements and allow functional data sets to be entered into group analyses. All functional volumes of each participant were realigned to the first volume acquired using a 6-parameter affine rigid-body transformation. The calculated mean volume was saved for coregistration with the participant's T1-weighted structural scan. The transformation parameters were applied to all volumes during spatial normalization and resampling of 2 mm × 2 mm × 2 mm resolution[14] to the Montreal Neurological Institute (MNI) EPI standard template of 152 averaged brains. All normalized functional volumes were smoothed with an isotropic Gaussian kernel (4 mm full width at half maximum). Global changes in fMRI response from scan to scan were removed by proportional scaling to have a common global mean voxel value. Grand mean scaling was session (participant) specific. The hemodynamic responses without temporal derivatives were modeled into the statistical design.

Statistical Data Analysis

We employed three types of analysis of the fMRI data based on the general linear model:

i. a linear regression concerning the target ranking order,
ii. a 1-level fixed effects design to estimate the volunteers' individual representation of the target brands according to their personal ranking order of the target, and
iii. a 2-level random effects model to assess group differences.

For the first model (i), a linear regression based on the 22 contrast images and the individual ranking order of the target brand was performed.

Second (ii), we used the fixed factor participant number and the factor target occurrence probability (levels 20% and 80%). For the fixed effects analysis, we employed separate design matrices for the beer (male) and the coffee (female) group. Basically, 2 contrasts were used to create SPM(t)s for the brand effect: (1) TD-DD and (2) DD-TD. All inference tests were calculated employing the a priori error probability of $P < .05$, corrected for multiple comparisons and a minimum cluster size of 20 voxels. For the group analysis (iii), contrast images (TD-DD) for all participants were calculated at the first level. Three male and 5 female participants ranked the respective target (T_{beer} or T_{coffee}) as their "first-choice brand" (FCB) above all other beer or coffee brands. For the second level (random effects analysis), the contrast images were divided into 2 groups, 1 representing the data of the participants who rated the target brand first (FCB group, n = 8) and 1 for all other volunteers (non-FCB group, n = 14). A *t* test for independent samples was applied to assess general population-based differences between the FCB and non-FCB groups.

Coordinate Assignment

Because the SPM99 MNI space uses a coordinate system that is not exactly congruent with the one introduced by Talairach and Tournoux, all SPM99 coordinates were automatically transformed to the Talairach and Tournoux space and assigned to cortical regions with the T2T-database Java applet (http://neurologie.uni-muenster.de/T2T/).[15] The coordinates presented in the following correspond to the MNI space.

Results

The target brand rankings of the participants are given in Tables 1 to 4. The fMRI data sets recorded during the simulated decision tasks were analyzed using 3 statistical approaches. At an inference level of $P < .05$, the linear regression analysis showed no significant linear correlation between the ranking order and cortical activation patterns (analysis part (i)).

Individual effects of the target brand were analyzed by applying SPM's fixed effects model[16] (analysis part (ii)). We found that significant differences in cortical activations between TD decisions and DD decisions occurred in both gender groups. *t* tests were calculated by contrasting the factors TD-DD and DD-TD separately for each ranking group for the assessment of increased and reduced activations during TD decisions in relation to DD decisions. The *t* tests revealed that only the 3 male and 5 female participants in the respective FCB groups were responsible for the main effects of the fixed effects analysis. No significant effect could be detected when the target brand was ranked second by a participant, although this condition reduces the number of decisions in favor of the target brand only slightly. Rather than a graded response depending on the ranking order according to our initial hypothesis, we found an all-or-nothing effect, which was solely determined by the presence of the FCB during buying decisions (Fig 2; Tables 1-4). Even when the critical cluster size was reduced from the a priori value of 20 to 1 voxel (the theoretical minimum), this amounted to a total of only 73 voxels modulated by the target in some non-FCB groups. For completeness, the corresponding clusters were added to Tables 1 to 4. However, this effect is negligible (1.4%) in relation to the FCB-induced activity change (total sum = 5252 voxels). A second analysis on the level of the individual participants revealed highly significant and congruent differences in cortical activation between TD and DD decisions for each single FCB participant. Moreover, looking at the location of the induced FCB-specific cortical activity changes (tagged by circles and identification numbers [IDs] in Fig 2; ↑ = increased, ↓ = decreased activations), this effect occurred congruently in both gender (product type) groups and in all reproducibility measurements.

The random effects analysis (iii) provided evidence that significant differences in cortical activations occurred between the FCB and the non-FCB group. On a very liberal significance level ($P < .01$, uncorrected), the activation patterns were comparable with those of Figure 2 (see Fig 3A). A more conservative level ($P < .05$, corrected for multiple comparisons, minimum cluster size 50 voxels) showed that the most prominent differences between the 8 participants that rated the target as their FCB and the other 14 volunteers occurred within the medial prefrontal cortex (Fig 3B).

Brain areas where we found reduced activations for FCB decisions (target = FCB) as compared to DD decisions were the dorsolateral prefrontal cortex (DLPFC; bilateral Brodmann area [BA] 9 = IDs 5↓, 6↓; bilateral BA 46 = IDs 8↓, 9↓), the left premotor area (BA 6 = ID 4↓), and the posterior parietal and occipital cortices (bilateral BA 7/19 = IDs 1↓, 2↓). Increased activations during FCB decisions were detected in the inferior precuneus and posterior cingulate cortex (ID 10↑), the right superior frontal gyrus (ID 7↑), the right supramarginal gyrus (SMG; ID 3↑), and the anterior medial prefrontal cortex (ID 11↑).

Table 1. Reduced (↓) Activations (Contrast DD-TD) of the Male Participants

Group (Ranking of Target Brand)	Number of Participants in Group	Cortical Region	Side	BA	MNI Coordinate (x,y,z)	*t*	*P* (Corrected)	Cluster Size (Voxel)	ID
First (FCB)	3	Inferior/middle frontal gyrus	R	46	52,36,18	9.18	.000	90	9↓
		Middle frontal gyrus	R	9	52,30,34	6.30	.000		5↓
		Occipital lobe, cuneus	R	19	30,–90,24	7.51	.000	91	1↓
		Superior parietal lobule	R	7	36,–70,48	6.13	.000	70	1↓
		Superior temporal gyrus	R	21/22	58,–12,–2	6.00	.000	197	na
		Inferior frontal gyrus	L	46	–48,40,8	7.98	.000	79	8↓
		Middle frontal gyrus	L	9	–50,26,34	7.93	.000	427	6↓
		Inferior frontal gyrus	L	6	–42,4,28	7.77	.000	117	4↓
		Parietal lobe precuneus	L	7/19	–24,–86,42	7.36	.000	257	2
		Occipital lobe, cuneus	L	19	–24,–82,32	6.45	.000		2↓
		Middle frontal gyrus	L	10	–42,52,–4	6.27	.012	24	na
Second	1					ns			
Third	2					ns			
Fourth	3					ns			
Fifth	1					ns			
Ninth	1					ns			
20th	1	Superior temporal gyrus/inferior frontal gyrus/limbic lobe	L	38/47/28	–32,8,–22	6.04	.026	18	

Only cluster sizes >20 for the first-choice brand (FCB) group (rank = first), all clusters for the non-FCB groups (rank ≥ second). The localizations of these deactivations are illustrated in Figure 2A as green regions. BA = Brodmann area, MNI = Montreal Neurological Institute, ID = common identification numbers of Figures 2A and 2B, na = not assigned, ns = not significant.

Table 2. Increased (↑) Activations (Contrast TD-DD) of the Male Participants

Group (Ranking of Target Brand)	Number of Participants in Group	Cortical Region	Side	BA	MNI Coordinate (x,y,z)	*t*	*P* (Corrected)	Cluster Size (Voxel)	ID
First (FCB)	3	Parietal/temporal lobe, supramarginal gyrus	R	40	60,–50,28	8.28	.000	273	3↑
		Frontal lobe, inferior frontal gyrus (Broca's area)	L	45	–52,24,6	7.69	.000	200	na
		Frontal lobe, inferior frontal gyrus	R	45	52,26,–4	7.63	.000	220	na
		Temporal lobe, middle temporal gyrus	L	21/39	–56,–60,4	6.92	.000	80	na
		Frontal lobe, superior frontal gyrus	R	9	20,44,40	6.65	.000	111	7↑
		Frontal lobe, medial frontal gyrus	L	9	–8,50,26	6.61	.000	175	11↑
		Frontal lobe, medial frontal gyrus	R	9	4,46,28	5.92	.000		11↑
		Frontal lobe, medial frontal gyrus	R	10	4,54,8	5.91	.000		11↑
		parietal lobe, precuneus/postcingulate	L	7	–10,–56,36	6.38	.000	222	10↑
		Parietal lobe, precuneus/postcingulate	R	7	2,–58,34	5.71	.000		10↑
		Frontal lobe, inferior frontal gyrus	R	44/45	60,18,18	6.32	.000	47	na
		Parietal lobe, inferior parietal lobule	L	40	–64,–38,30	6.34	.000	83	na
		Frontal lobe, middle frontal gyrus	L	6/WM	–40,8,48	6.31	.000	64	na
		Temporal lobe, middle temporal gyrus	R	39/22	56,–56,6	6.26	.000	102	na
		Parietal lobe, supramarginal gyrus	L	40	–60,–56,28	6.05	.000	41	na
		Frontal lobe, middle frontal gyrus	R	11	42,50,–10	5.77	.000	59	
Second	1					ns			
Third	2					ns			
Fourth	3	Parietal/temporal lobe, supramarginal gyrus	R	40	54,–46,28	5.35	.002	15	3↑
		Parietal lobe, precuneus	R	7	2,–62,48	5.16		17	na
Fifth	1					ns			
Ninth	1					ns			
20th	1					ns			

Only cluster sizes >20 for the first-choice brand (FCB) group (rank = first), all clusters for the non-FCB groups (rank ≥ second). The localizations of these activations are illustrated in Figure 2A as red regions. BA = Brodmann area, MNI = Montreal Neurological Institute, ID = common identification numbers of Figures 2A and 2B, na = not assigned, WM = working memory, ns = not significant.

Table 3. Reduced (↓) Activations (Contrast DD-TD) of the Female Participants

Group (Ranking of Target Brand)	Number of Participants in Group	Cortical Region	Side	BA	MNI Coordinate (x,y,z)	*t*	*P* (Corrected)	Cluster Size (Voxel)	ID
First (FCB)	5	Frontal lobe, precentral gyrus	L	6	–42,–2,30	8.92	.000	561	4↓
		Frontal lobe, middle frontal gyrus	L	9	–48,30,34	8.47	.000	33	6↓
		Parietal lobe, inferior parietal lobule	L	40	–54,–36,48	7.94	.000	168	na
		Parietal lobe, precuneus	L	7	–24,–66,34	7.90	.000	744	2↓.
		Parietal lobe, postcentral gyrus	R	40	46,–32,52	6.59	.000	78	na
		Frontal lobe, middle frontal gyrus	L	46	–50,32,18	6.39	.000	39	8↓
		Parietal lobe, precuneus	R	7	30,–78,50	6.30	.000	47	1↓
		Frontal lobe, inferior/middle frontal gyrus	R	46	46,28,10	6.22	.000	112	9↓
		Middle frontal gyrus	R	9	50,32,28	5.66	.000		5↓
		Occipital lobe, superior occipital gyrus	R	19	30,–82,26	6.18	.000	49	1↓
		Occipital/parietal lobe, precuneus	R	7/31	12,–68,28	5.87	.000	36	1↓
		Occipital lobe/lingual gyrus	R	17	18,–84,0	5.46	.000	38	na
Second	2					ns			
Third	3	Frontal lobe, precentral gyrus	L	6	–52,–2,48	6.24	.003	23	na

Only cluster sizes >20 for the first-choice brand (FCB) group (rank = first), all clusters for the non-FCB groups (rank ≥ second). The localizations of these deactivations are illustrated in Figure 2B as green regions. BA = Brodmann area, MNI = Montreal Neurological Institute, ID = common identification numbers of Figures 2A and 2B, na = not assigned, ns = not significant.

Table 4. Increased (↑) Activations (Contrast TD-DD) of the Female Participants

Group (Ranking of Target Brand)	Number of Participants in Group	Cortical Region	Side	BA	MNI Coordinate (x,y,z)	*t*	*P* (Corrected)	Cluster Size (Voxel)	ID
First (FCB)	5	Parietal lobe, inferior parietal lobule	R	40	58,–44,20	7.12	.000	90	3↑
		Temporal lobe, superior temporal gyrus	R	22	58,–46,6	6.78	.000		3↑
		Frontal lobe, middle frontal gyrus	R	6	42,–2,48	6.89	.000	69	na
		Frontal lobe, medial frontal gyrus/ limbic lobe, anterior cingulate	L	10/32	–6,44,10	6.06	.000	55	11↑
		Parietal lobe, precuneus	L	7	–2,–52,50	5.83	.000	27	10↑
		Temporal lobe, supramarginal gyrus	R	40	56,–58,20	5.77	.000	30	3↑
		Frontal lobe, superior frontal gyrus	R	10	34,54,20	5.49	.000	31	7↑
		Frontal lobe, medial frontal gyrus/ anterior cingulate	R	10	8,52,2	5.30	.000	16	11↑
Second	2					ns			
Third	3					ns			

Only cluster sizes >20 for the first-choice brand (FCB) group (rank = first), all clusters for the non-FCB groups (rank ≥ second). The extensions of these activations are illustrated in Figure 2B as red regions. BA = Brodmann area, MNI = Montreal Neurological Institute, ID = common identification numbers of Figures 2A and 2B, na = not assigned, ns = not significant.

Discussion

Methodical Considerations

The imbalance of the number of target versus nontarget brand presentations could in principle have biased responses to the target brands (target brands occurred in 50% of the trials, compared to an average of 7.5 [male group] or 10% [female group] for non-target brands). However, the present results exclude any significant bias because all participants were stimulated with exactly the same presentation paradigm, but only participants belonging to the 2 FCB groups showed significantly different cortical responses between TD and DD decisions in the fixed effects analysis. In addition, the absence of relevant significant effects in the non-FCB groups also rules out further relevant confounders associated with the stimulation design, for example, visual properties of the presentation.

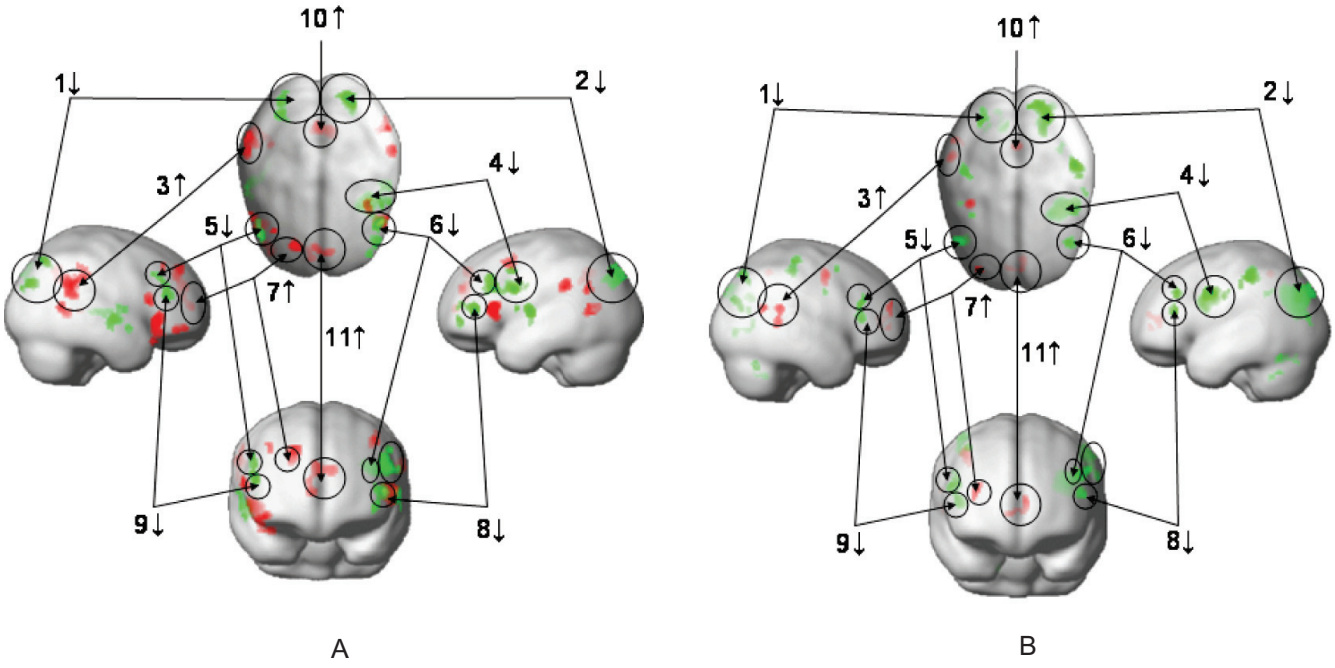

Fig 2. Regions (only) modulated by the favorite brand. (A) Male first-choice brand (FCB) group of 3 participants. (B) Female FCB group of 5 participants (contrasts TD-DD = red, DD-TD = green). Red represents cortical areas with significantly increased (↑) activation and green represents areas with significantly reduced (↓) activity during FCB decisions as compared to decisions between non-FCB brands. The numbered regions, corresponding to the identification numbers (IDs) of Tables 1 to 5 and Figure 3, were found consistently and significantly modulated by the FCB in both gender groups and in reproducibility measurements. The sequence of numbering was arbitrarily selected. In contrast to this, no significant changes ($P < .05$, corrected; cluster size >20) were found in those groups in which the participants ranked the target brand second or lower.

The selection of a blocked design was motivated by our aim to visualize both shortly occurring, event-related, item-driven effects and more sustained activations.[17,18] The latter have to be taken into consideration in the context of emotion processing. Preliminary experiments, employing a stimulation paradigm that simultaneously allowed event-related and block design analyses, clearly indicated that the parametric block design was more sensitive to the activations within the median prefrontal cortex.

As the 2 major statistical approaches, we employed a 1-level fixed effects analysis and a 2-level random effects group analysis. The first approach was motivated by the fact that the original objective of this study was not to investigate systematic differences between 2 (or more) groups of participants with a priori differences in buying behavior. At the time the fMRI experiments were carried out, we did not have any knowledge of grouping factors, as none of the participants were asked about buying behavior or brand preferences prior to the fMRI examinations. We considered this point very important because an interview before the participants' definite decision making could potentially have confounded the participants' expectancy. The 2-week interval after the fMRI scan was chosen (1) short enough after the scans to avoid shifts in brand preferences and (2) long enough afterward to prevent a bias by the presentation itself. By the selection of the respective market leaders as the target brands T, the probability was high that the selected target brand was the FCB for a participant. The distribution of FCB (n = 8) versus non-FCB (n = 14) participants was close to the ideal distribution (11 vs 11) for later statistical random effects group analyses, even though the brand preference was unknown before the experiments.

The random effects analysis was employed to account for the interesting fact that the fixed effects analysis revealed a clearly distinct cortical processing for the favorite brands as compared to the other, less preferred ones. The random effects analysis gives evidence that the FCB effect can be generalized to the population represented by the participants. Thus, the activity changes shown in Figures 2 and 3 must reflect a specific mode of cortical processing as long as a favorite brand is involved in the buying decisions. A generalization of the results is supported by their reproducibility, the largely congruent activation patterns in both gender/product groups and the results of the random effects group analysis. A comparison of the results for intraindividual differences between TD and DD deci-

Table 5. Significant Differences Between the First-Choice Brand (FCB) Group and the Non-FCB Group of Cortical Activations During TD Decisions Compared to DD Decisions as Estimated by the Random Effects Analysis

ID	Cortical Region	Side	BA	T	Representative MNI Coordinate (x,y,z)
1↓	Occipital lobe, superior occipital lobe	R	18/31	4.96	22,–74,16
	Occipital lobe, cuneus	R	19	3.00	18,–92,22
	Parietal lobe, precuneus	R	7	4.06	2,–78,36
	Occipital lobe/parietal lobe, precuneus/precuneus	R	7/31	3.91	10,–76,26
2↓	Occipital lobe, cuneus	L	19	2.93	–14,–86,28
	Parietal lobe, superior parietal lobule/precuneus	L	7	2.84	–18,–64,60
3↑	parietal/temporal lobe, supramarginal gyrus	R	40	ns	
4↓	Frontal lobe, inferior frontal gyrus	L	6	4.17	–32,–18,42
5↓	Frontal lobe, middle frontal gyrus	R	9	2.60	50,22,36
6↓	Frontal lobe, middle frontal gyrus	L	9	2.74	–46,32,34
7↑	Frontal lobe, superior frontal gyrus	R	10	4.10	20,50,18
8↓	Frontal lobe, inferior/middle frontal gyrus	L	46	ns	
9↓	Frontal lobe, inferior/middle frontal gyrus	R	46	3.36	46,28,16
10↑	Parietal lobe, precuneus	L	7	ns	
		R	7	ns	
11	Frontal lobe, medial frontal gyrus	L	10	3.91	–10,50,12
		R	10/11	3.33	18,58,–8
		R	10	3.10	12,54,2
12↓	Temporal lobe, middle temporal gyrus	L	22	3.95	–54,–42,4
	Temporal lobe, superior temporal gyrus	L	22/42	2.67	–60,–36,10
13↑	Frontal lobe, middle frontal gyrus	L	8	4.15	–28,30,48
		L	9	4.10	–32,38,36
(na)↓	Parietal lobe, inferior parietal lobule	R	40	3.19	42,–42,54
(na)↓	Frontal lobe, medial frontal gyrus	R	6	3.27	4,–10,60
		R	6	2.74	0,–26,50
(na)↑	Frontal lobe, precentral gyrus	R	6	4.07	44,–6,46
(na)↑	Temporal lobe, superior temporal gyrus	L	38	3.94	–44,18,–22
	Frontal lobe, inferior frontal gyrus	L	47	3.91	–38,26,–18
		R	47	3.34	34,32,–14
(na)↑	Frontal lobe, precentral/inferior frontal gyrus, gray matter	R	44/45	2.98	48,14,8

Random factor = participant, contrast on the first level: TD-DD. Relatively increased and reduced activations are denoted by ↑ and ↓, respectively. ID = identification numbers of Figures 2A, 2B, and 3A, BA = Brodmann area, MNI = Montreal Neurological Institute, ns = not significant, na = not assigned.

sions of specific FCB participants (fixed effects analysis, Figs 2A, 2B), and the results of the group analysis (Fig 3A) show that most of the activations numbered by the IDs in the figures above occurred consistently as interindividual group differences. Only activity changes within the regions 3↑, 8↓, and 10↑ could not be proven as brand-specific cortical activity modulations induced by the presence of the FCB during the decision. This could have the following explanations: region 3↑ could be moderately activated during TD decisions compared to DD decisions for (at least some) non-FCB participants due to its ability to respond to patterns (in this case, triggered by the higher presentation rate of the target T). Some evidence for this can be found by the results presented in Table 2 for group 4.

A key to understand this seemingly distinct decision mode triggered only by the presence of the favorite brand may be identified by a detailed analysis of the involved brain regions.

Functionally Modulated Cortical Regions

Reduced Activations

The areas with reduced activations have been reported to be involved in the neural network associated with working memory, planning, and reasoning-based decision making.[19-29] Our finding that FCB decisions caused reduced activations in these areas supports the hypothesis that during FCB decisions, strategy-based reasoning and judgment is reduced as compared to non-FCB decisions. Although the prefrontal cortex is a key region in many aspects of human decision making, the frontal lobe is not the only structure involved in the FCB effect. Fuster has emphasized the cortical dynamics between the posterior and frontal pathways of the perception-action cycle.[30,31] The results illustrated in Figure 2 demonstrate that frontal cortical regions do not work autonomously in carrying out decision processes but rather interact with posterior areas.

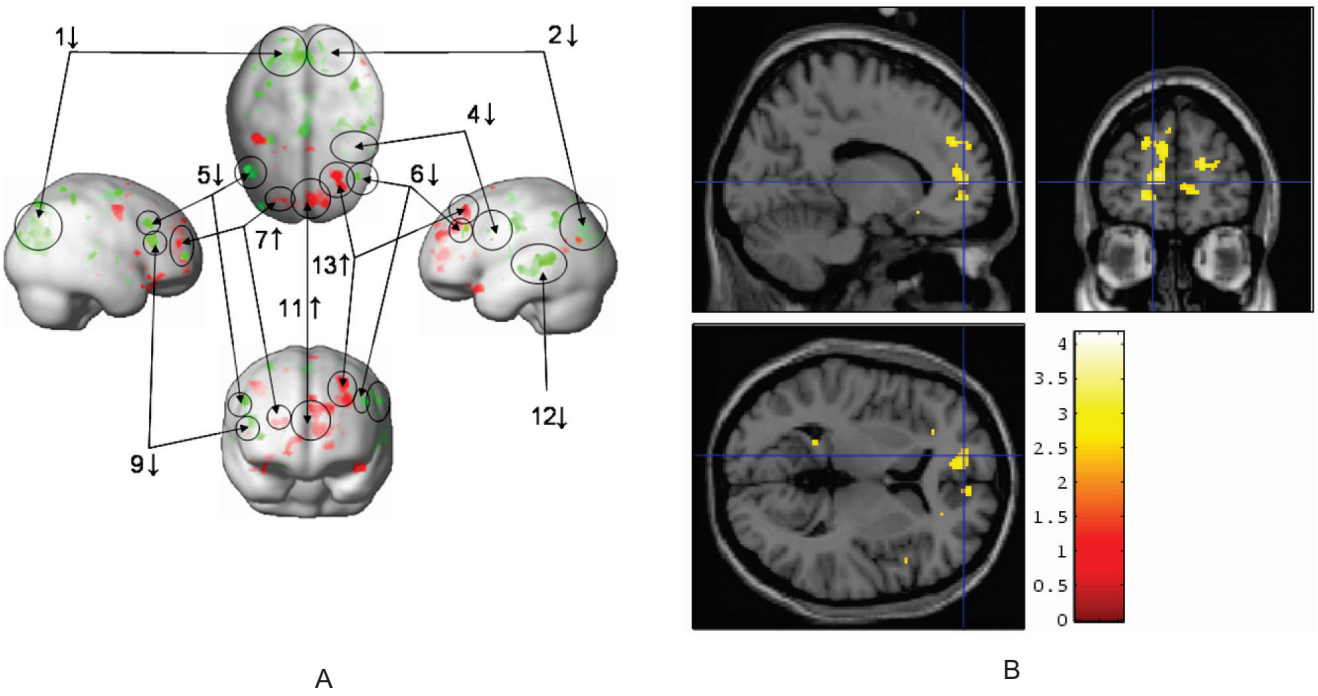

Fig 3. Results from the random effects group analysis (A) Three-dimensional overview of all significantly different activation patterns between the first-choice brand (FCB; n = 8) and the non-FCB group (n = 14; $P < .01$, degrees of freedom = 20, height threshold $t_{crit} = 2.5$). Red represents cortical areas with significantly increased (↑) activation and green areas with significantly reduced (↓) activity during decisions in the presence of the target as compared to DD-decisions (target not for choice). Locations and anatomical assignments of all significant regions are given in Table 5. (B) Anatomical assignment of the most pronounced activity differences ($P < .05$, corrected, $t = 3.9$) within the left and right medial prefrontal cortex between the FCB than in the non-FCB group. The 3 orthogonal sections represent planes of the Montreal Neurological Institute space at ($x = –13$ mm, $y = 52$ mm, $z = 6$ mm). This region corresponds to ID 11↑ and was found significantly activated only in participants belonging to the FCB group by the fixed effects analysis.

Increased Activations

The anterior medial prefrontal cortex (ID 11↑) and the inferior precuneus and posterior cingulate cortex (ID 10↑) have been identified as multimodal association areas that are important for integrating current inputs with background knowledge,[32,33] episodic memory retrieval,[34] and self-reflection.[35] Hence, the activity increases within these areas, which were also present in the random effect analysis, can be interpreted as a specially pronounced, self-referential process during FCB decisions. Maddock et al found the posterior cingulate cortex specifically activated during the presentation of emotional words as compared to neutral words.[36] The right superior frontal gyrus (ID 7), where we found increased activity during FCB decisions, has been identified as specialized in maintaining working memory representations that integrate verbal and spatial (geometrical) information.[37] Specific activations in the right SMG (ID 3↑) have been described only in a small number of studies. H. Damasio et al reported a significantly increased engagement of the right SMG during a spatial task using abstract shapes in comparison to concrete objects.[38] Lesions of the right SMG often lead to visuospatial neglect and impaired generation of SCRs.[39] Downar and coworkers described a specific role of the right SMG as part of a network in detecting behaviorally relevant events in the sensory environment.[40,41] Hence, the right SMG seems to be an important multimodal node of the network responsible for evaluating the relevance of the sensory characteristics of the FCB (eg, its logo) and the immediate integration with self-referential and emotion-related information.

The right and left ventromedial parts of the prefrontal cortex (VMPFC; ID 11↑, BA 10) are essential for the integration of emotions into decision making.[42] Damage to the VMPFC disrupts social behavior; the patients become unable to observe social conventions and show abnormalities in their processing of emotions and feelings.[43,44] Thus, FCB decisions seem to be particularly influenced by emotions. Recent fMRI studies describe that specific VMPFC regions correlated with monetary rewards associated with abstract visual stim-

uli.[45-47] For a rewarding outcome of a decision task, O'Doherty and coworkers found bilateral but predominantly left-sided medial activations within the prefrontal cortex. In our study, activations occurred exactly in the same positions (ID 11↑; Fig 3A) with consistently more activated voxels in the left hemisphere in agreement with the findings of O'Doherty et al. Thus, the presented FCBs represent a reward situation; that is, they seem to be associated with positive emotions.

A Concept of Buying Decision Making

The interdependence of emotions and body states and their important impact on behavior was realized already in the 19th century by the American philosopher and psychologist William James.[48] A system-level neuroanatomical and cognitive framework for the influence of emotions on decision making has been proposed by Antonio R. Damasio in his somatic marker hypothesis.[49] The central idea of this hypothesis is that decision making is a process influenced by marker signals arising in (somatic) bioregulatory processes, especially those underlying emotions. This influence can occur consciously and nonconsciously. Damasio and coworkers concluded from lesion studies that the VMPFC is part of a system that stores information about past rewards and punishments.[42,50,51] The comparison of cognitive deficits of patients with lesions either in the VMPFC or in the DLPFC revealed evidence for a cognitive and anatomic double dissociation between deficits in decision making and working memory.[52] Investigations of emotional participation of moral judgments have shown that areas associated with working memory (BA 7, 40, bilateral parietal lobe, and right BA 46) were less active during emotional as compared to cognitive processing.[53] In the context of our study, this means that the regions with decreased and increased activity may reflect more or less dissociated neuronal networks with specific roles in working memory and emotional information processing, respectively. Besides the VMPFC, the amygdala is also regarded as a component of a neural system necessary for advantageous decision making.[51,54] Unfortunately, increased susceptibility artifacts at the higher magnetic field prevented a reliable detection of activation changes in the amygdala.

A more integrated view of the FCB-induced changes with reduced cortical activity within areas associated with rule, strategy, and memory processing, on one hand, and increased activity of structures storing and processing emotional experience of a stimulus, on the other hand, can be deduced from the work of Bechara et al.[50] For advantageous decision making, they suggest 2 largely parallel but interacting chains of cortical and subcortical processing events, dependent on the sensory representation of the stimulus. The authors suggest one chain involving emotional experience, abbreviated here as "emotional chain" and another one based on reasoning strategies in case no sufficiently strong emotional information biases the decision ("reasoning chain"). Their flow diagram of proposed interactions was adapted and modified for the present purpose (Fig 4). Thus, the FCB-specific increase in cortical activation within the VMPFC can be interpreted as the fMRI correlate of brain activations involved in this emotional chain, that is, the integration of previous emotional experience with a brand into the ongoing decision process. In combination with the reduced activations in regions associated with reasoning strategies (reasoning chain), this supports the hypothesis that in the competitive situation of buying decisions, only an FCB has the specific power to switch between the 2 cortical processing chains whereas a second-rated brand already has not. This winner-take-all effect rejects our original hypothesis of a cortical representation of a ranking list as the underlying decision criterion. In this case, one would expect only small and graded differences in cortical processing between different brands, especially between the first- and second-rated ones. Ranking orders can be established only by multiple, time and neuronal resource-consuming brand-to-brand comparisons. From a neuroeconomical and evolutionary point of view, reasoning-based rating scales are ineffective in the sense of *periculum in mora* (danger in delay).

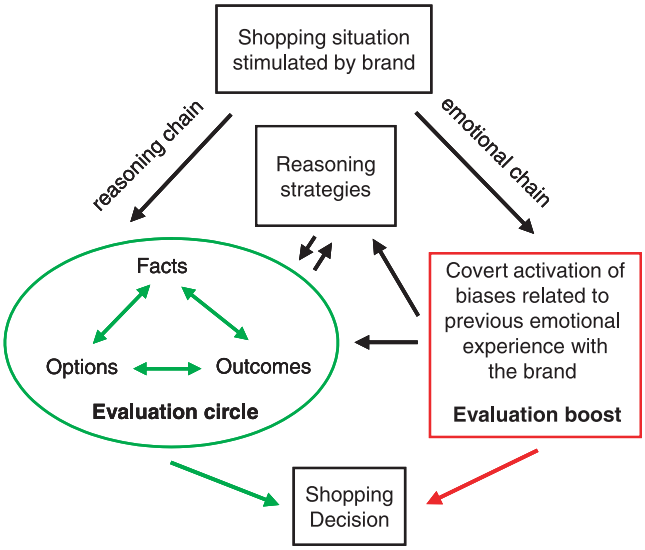

Fig 4. Diagram of the hypothesized interactions involved in buying decisions (based on suggestions of Bechara et al[50]).

The winner-take-all effect was shown for very similar commodity products, for which brand information is the prevailing, 1-dimensional decision criterion. For other goods, however, there will probably be competing explicit characteristics such as price, usefulness, availability, the associated status symbol, and so forth. Our described approach, however, can be adapted to differentiate the influence of these multidimensional characteristics in future studies.

Conclusion

Our results provide evidence for 2 different pathways in economically relevant decision making including the steps proposed by Bechara et al[50] (Fig 4). Based on the somatic marker hypothesis, an FCB can be regarded as a stimulus, evoking a somatic state that either "forces attention on the negative outcome of the decision" and immediately rejects the negative course of action, that is, not to choose the FCB, or, if the marker is positive, it becomes a "beacon of incentive" to select the FCB.[49] For our selection of the particular brand, implicit memory contents and experienced emotions are causative, usually stored a long time before the actual decision. In a more general and social view, the concept "brand" is not limited to consumer goods but can possibly be expanded to other eligible objects or persons, for example, politicians or our social partners.

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