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The human orbitofrontal cortex monitors outcomes even when no reward is at stake

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Abstract

The orbitofrontal cortex (OFC) processes the occurrence or omission of anticipated rewards, but clinical evidence suggests that it might serve as a generic outcome monitoring system, independent of tangible reward. In this positron emission tomography (PET) study, normal human subjects performed a series of tasks in which they simply had to predict behind which one of two colored rectangles a drawing of an object was hidden. While all tasks involved anticipation in that they had an expectation phase between the subject's prediction and the presentation of the outcome, they varied with regards to the uncertainty of outcome. No comment on the correctness of the prediction, no record of ongoing performance, and no reward, not even a score, was provided. Nonetheless, we found strong activation of the OFC: in comparison with a baseline task, the left anterior medial OFC showed activation in all conditions, indicating a basic role in anticipation; the left posterior OFC was activated in all tasks with some uncertainty of outcome, suggesting a role in the monitoring of outcomes; the right medial OFC showed activation exclusively during guessing. The data indicate a generic role of the human OFC, with some topical specificity, in the generation of hypotheses and processing of outcomes, independent of the presence of explicit reward.

Keywords: Human orbitofrontal cortex; Reality monitoring; Anticipation; Reward; Functional imaging; PET

1. Introduction

Animal studies with non-human primates have established that the orbitofrontal cortex (OFC) contributes to the anticipation of reward, and processes the appearance or absence of predicted rewards (Rosenkilde, Bauer, & Fuster, 1981; Thorpe, Rolls, & Maddison, 1983; Tremblay & Schultz, 1999, 2000). Patients with anterior OFC lesions tend to make decisions aiming at short-term gains while disregarding long-term consequences (Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Bechara, Damasio, & Damasio, 2000; Damasio, 1994; Eslinger & Damasio, 1985; Eslinger, Grattan, Damasio, & Damasio, 1992; Price, Daffner, Stowe, & Mesulam, 1990). Imaging studies with healthy human subjects obtained activation of the OFC when subjects received anticipated food reward (O'Doherty, Deichmann, Critchley, & Dolan, 2002) or imagined good meals (Arana et al., 2003), but also in gambling or guessing tasks associated with monetary reward or punishment (Critchley, Mathias, & Dolan, 2001; Elliott, Friston, & Dolan, 2000; Elliott, Frith, & Dolan, 1997; Elliott, Rees, & Dolan, 1999; O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001; Pochon et al., 2002; Rogers et al., 1999; Thut et al., 1997). An implicit conclusion from these studies is that the OFC evaluates outcomes when some form of explicit reward—pleasant food or stimulation, money, some score—or at least the thrill of a correct guess is at stake. Indeed, several studies specifically explored the impact of the magnitude of reward on brain activation (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001; O'Doherty et al., 2001; Rogers et al., 1999).

However, clinical studies indicate that the OFC keeps track of ongoing reality in thought and behavior, irrespective of wins or losses: patients with posterior OFC lesions often fail

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to adapt their behavior to ongoing reality and act on the basis of currently irrelevant memories, a syndrome called spontaneous confabulation (Schnider, 2003). We have demonstrated that this failure is based on deficient suppression of mental associations that do not pertain to now (Schnider & Ptak, 1999; Schnider, von Däniken, & Gutbrod, 1996); the patients appear to fail to adapt their behavior to the non-occurrence of (implicitly) anticipated outcomes (Schnider, 2003). This observation indicates that the OFC may constitute a generic system monitoring the occurrence or absence of an anticipated outcome (true reality), irrespective of the notion of reward.

In the present study, we tested the possibility that the OFC is indeed activated by the mere anticipation and confirmation, or negation, of predicted outcomes, even when any notion of reward (gain) or punishment is avoided as completely as possible. Healthy subjects performed a series of tasks of anticipation, in which they saw whether their predictions were correct or wrong, but which provided no reward for their performance; correct predictions would not yield any gain or benefit, would not even be commented, incorrect predictions did not induce any penalty. Brain activity was monitored using positron emission tomography (PET) with [^{15}O]H_2O.

2. Materials and methods

2.1. Subjects

Eight healthy men (19–26, 22.4 ± 2.8, years old) were paid to participate in the study. The study was approved by the Ethical Committee of the University Hospital of Zürich and the Swiss Federal Bureau of Radiation Protection.

2.2. Experimental task

Subjects performed four tasks presented in a counterbalanced order (Fig. 1), each of them probing distinct components of anticipation and processing of outcomes (Table 1). In all conditions, subjects saw a red and a green rectangle, which were randomly positioned on the right and left side,

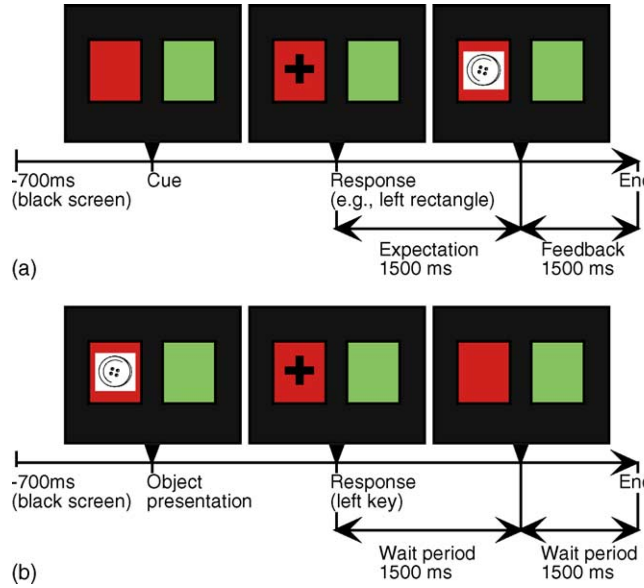

Fig. 1. Experimental design: (a) design of the four tasks and (b) design of the baseline task (see Section 2 for explanation).

and had to indicate by pressing a button on the corresponding side, behind which one of the two rectangles an "object" (line drawing of an object) was hidden (Fig. 1a). As soon as they had pressed the response key, a cross appeared in the middle of that rectangle and remained there for 1500 ms (expectation phase). Immediately after this phase, feedback was provided by presentation of a design of an object (correct choice) or a grid (error) within the chosen rectangle for 1500 ms. No other feedback was given; no sound, comment or score. Then, the screen turned black for 700 ms till the start of the next trial. "Objects" were simple line drawings (Snodgrass & Vanderwart, 1980) with no obvious "reward" value, e.g., clip, butterfly, tree, tie, flower, fountain, umbrella, kettle, mushroom, snail, etc. Different designs were used in the different tasks and among the subjects.

2.3. Main tasks

Common to all tasks was that subjects had to make a choice, followed by an expectation phase and presentation of

Table 1
Task conditions and their cognitive components

Condition	Component							
	Anticipation	Relevant feedback	Uncertainty	Guessing	Extinction	Planning	Reaction time (±S.D.)	Hit rate (±S.D.)
AlwaysSame	+	+	+	–	–	–	467 ± 118 ms	99 ± 1.8%
Extinction	+	+	+	–	+	–	520 ± 135 ms	64 ± 2.8%
Guess	+	–	++	+	+	+	673 ± 365 ms	56 ± 7.6%
PlaceIt	+	–	–	–	–	+	527 ± 213 ms	100 ± 0%

Anticipation indicates whether the subject anticipates an outcome; relevant feedback indicates that the outcome is useful to guide the next prediction; uncertainty indicates whether the outcome has an uncertainty or not; guessing indicates that the subject is asked to guess rather than to base predictions on the last feedback; extinction indicates the presence of trials with absence of the predicted outcome; planning indicates that the subject has to make decisions which cannot be based on experience. Reactions times are means ± standard deviations of each subject's median reaction time over all stimuli of the condition; hit rate indicates the percentage of trials with the outcome corresponding to the prediction, irrespective of whether the outcome was predictable or not.

the outcome. Subjects made four tasks (conditions) in which we varied the type of decision they had to make and the uncertainty of the outcome. In 3 of the 4 conditions (Table 1), the object's position was determined by the presentation program and subjects had to find out the rectangle "hiding the object". In 2 of these 3 conditions, subjects were asked to respond according to the last feedback and to restrain from guessing. They were informed that the "object" might change position from time to time. Unknown to them, these two conditions had a distinct difference: in one condition (AlwaysSame) the same object always appeared behind the same rectangle. In the second condition (Extinction), the object changed position every 1–4 trials. Thus, if a subject adhered to the rules of the task and based decisions on the previous trial, their prediction would be wrong on every 1st to 4th trial. We called this condition "Extinction" as it demanded the ability to abandon a previously successful choice. An electrophysiological study using this condition yielded specifically different electrocortical responses from confirmed trials only in trials with absence of the predicted outcome, but not in trials with a new color–object association. The critical difference between the AlwaysSame and Extinction condition thus appears to be the extinction, rather than the object alternation capacity (Mohr et al., submitted). Because instructions were the same in both the AlwaysSame and Extinction condition, the uncertainty of outcome was similar in both conditions; even in the AlwaysSame condition, subjects did not know that the object would actually always appear behind the same rectangle. Thus, the main difference between these tasks was the different number of positive and negative outcomes.

The third condition (Guess) had precisely the same design as the Extinction condition, but the subjects were told that the object position would be completely random and that they should guess. In the final fourth condition (PlaceIt), the sequence of events within a trial was exactly the same as in the other conditions, but subjects were asked to determine themselves, where the object should appear. Thus, this condition was the only one having no uncertainty of outcome, but—similar to the Guess condition—demanded a decision which could not be based on previous experience. In the Guess and PlaceIt conditions, subjects were explicitly asked to make a choice in each individual trial. Observation of their behavior showed that all subjects varied the chosen side and color.

Each condition had 44 trials composed of four blocks with 11 trials each. Each block with changes of object positions had, in random order, one trial sequence of 0, 1, 2, 3, and 4 repetitions of the same trial type (same object position).

The sequence of conditions, including the base line task, was counterbalanced across subjects.

2.4. Baseline task

The baseline task contained the same phases as the main task but in inverted order, that is, with initial presentation of the "outcome". A trial started with the presentation of the two rectangles with one of them containing the "object" (similar layout as the presentation of the outcome in the main tasks). Subjects simply had to press the key corresponding to the side of the rectangle containing the object (similar motor demand as the indication of the prediction in the main tasks). As soon as the subject responded, the object was replaced by a cross in the center of the respective rectangle, which remained there for 1500 ms (similar layout as the expectation phase in the main tasks). Then, the cross disappeared, and the two empty colored rectangles remained on the screen for another 1500 ms (similar layout as the initial screen in the main tasks). Then, the screen turned black for 700 ms until the start of the next trial. This sequence gave the impression that, after indicating the side with the object and appearance of the triangle that the trial was simply over; it did not arouse a feeling of anticipation, as confirmed by the subjects. Thus, the baseline task had all visual and motor components of the main tasks but implied no anticipation, provided no feedback, and demanded no memory. Forty-four trials were made.

2.5. Imaging procedures

PET scans were acquired on a whole-body scanner (Advance GE Medical Systems, Waukesha, WI) in three-dimensional mode with a 15 cm axial field of view. Subjects had 5 scans (4 main tasks, 1 baseline task). For each scan, 400–450 MBq $[^{15}O]H_2O$ were administered as a slow bolus with a remotely controlled injection device. PET counts were recorded in 3D mode over 60 s after the arrival of the bolus in the brain. A 10-min transmission scan was performed to correct for photon attenuation. Image reconstruction and preprocessing using SPM99 (Friston et al., 1995) was the same as used in a previous study (Schnider, Treyer, & Buck, 2000).

All conditions were analyzed in reference to the baseline condition. The only direct comparison was made between the Extinction and Guess conditions as they had exactly the same design and produced a comparable rate of hits (correctly predicted outcomes) and errors (incorrectly predicted outcomes) (see results). Thus, they only, but clearly, differed with regards to the task instruction and, therefore, the basis of the choice and the behavioral significance of the outcome. These differences were evaluated voxel by voxel in a PET multi-subject design. We accepted significance in the a priori defined region (orbitofrontal cortex) when $T > 3.2$, $P < 0.001$ was reached, uncorrected for multiple comparisons. The results were overlaid on a T1-weighted magnetic resonance image of eight subjects.

In order to determine whether OFC activations appearing in the comparison of the main tasks with the baseline condition also reflected significant differences between the main tasks, region-of-interest (ROI) analyses were performed. As will be described below, the Guess condition induced activation of all four OFC clusters that—to variable extent—also showed activation in the other main tasks. Therefore, the ROI analysis was performed by first selecting the four OFC areas activated in the comparison between the

Guess and baseline condition. In order to cover the whole area of those clusters, all voxels activated in any of the four main conditions around these clusters (as compared with the baseline), were then included in the final clusters entering the ROI analysis. The analysis was performed with PMOD (www.pmod.com) (Mikolajczyk, Szabatin, Rudnicki, Grodzki, & Burger, 1998) on the spatially and globally normalized images of each subject.

3. Results

3.1. Behavioral data

The tasks proved to be very easy (Table 1). Subjects made virtually no error except in the two conditions which intentionally provided negative feedback (Extinction and Guess). Behavioral data show that the subjects did indeed respect the differing task instructions in the Extinction and Guess conditions, although they had exactly the same design: whereas in the Extinction condition, their choice of the correct rectangle was correct in 97 ± 4% of trials in which the position was correctly predicted by the previous trial (yielding a total hit rate of 64 ± 2.8%), they chose the correct rectangle only in 59 ± 13% of such trials in the Guess condition (yielding, together with the correctly guessed, unpredictable trials, a total hit rate of 56 ± 7.8%) ($t = 7.0$; $P = 0.0002$). There was no significant response bias in the Guess condition: subjects chose the left rectangle in 55 ± 9% and the green rectangle in 45 ± 7% of trials.

Reaction times varied moderately between the conditions (repeated-measures ANOVA, $F(3, 7) = 2.95$; $P = 0.057$) with the Guess condition having the longest and AlwaysSame inducing the shortest reaction times (Table 1).

3.2. Activation in the four tasks versus baseline

When comparing the four tasks with the baseline task, three main results emerged (Table 2, Fig. 2a): first, all main tasks induced OFC activation; second, there was highly homogeneous activation, with little variance between the tasks, of the left OFC; third, the right OFC was exclusively activated in the Guess condition.

The pattern of OFC activation was amazingly consistent, but precise foci of activation varied among conditions. In essence, four distinct regions of OFC activation were

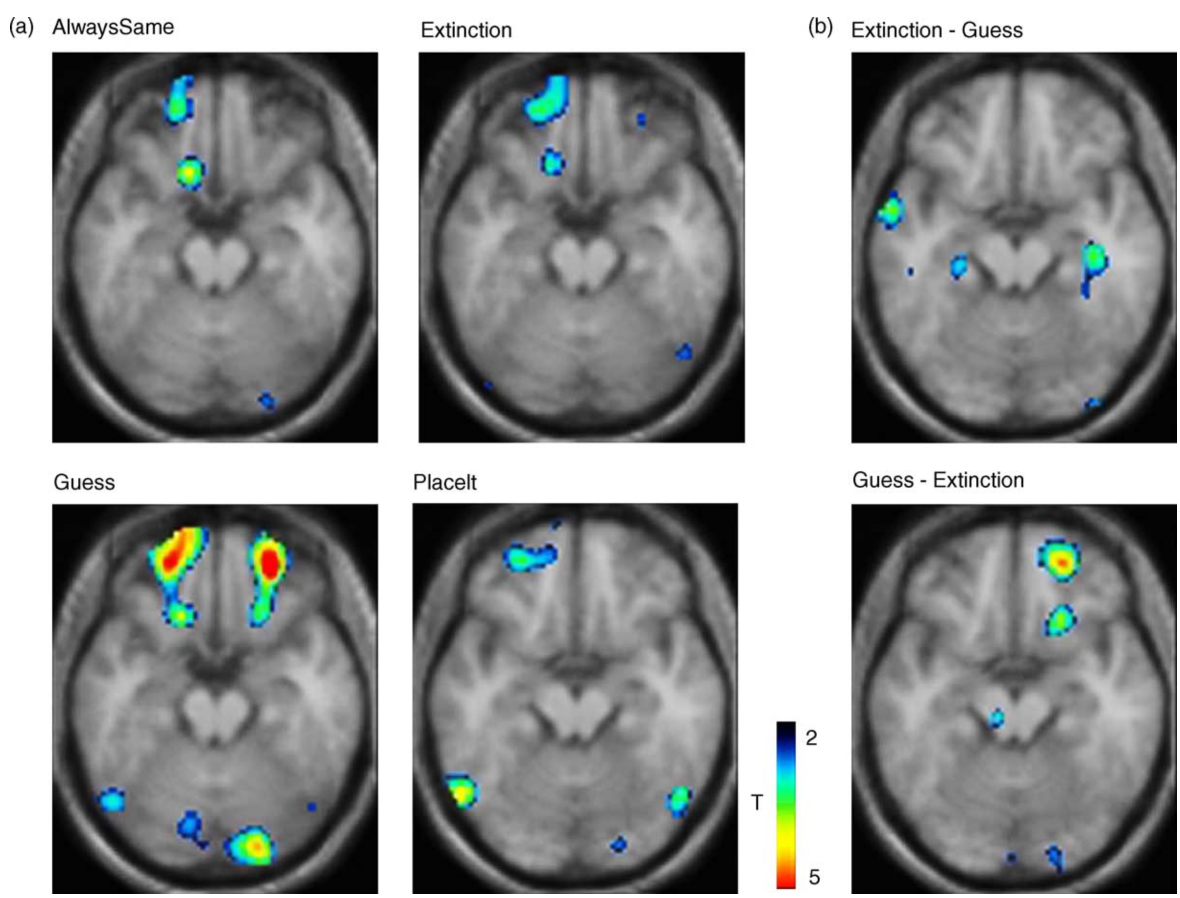

Fig. 2. Areas of activation in the OFC. Activation of the orbitofrontal cortex induced by: (a) the four tasks (subtraction of task—baseline) and (b) the direct comparison between the two conditions: Extinction and Guess, which had the same structure but differed in task instruction. The slices correspond to MNI z-coordinate levels −24 (AlwaysSame, Extinction, Guess) and −20 (PlaceIt; Extinction–Guess, Guess–Extinction).

Table 2
Areas of significant activation in the four task conditions (subtraction of task—baseline) and in the direct comparison between the two conditions Extinction and Guess

Region	AlwaysSame		Extinction		Guess		PlaceIt		Extinction–Guess		Guess–Extinction	
	Coordinates	*T*	Coordinates	*T*	Coordinates	*T*	Coordinates	*T*	Coordinates	*T*	Coordinates	*T*
Left anterior OFC (BA 11 anterior/10)	−18, 52, −28	4.18	−20, 50, −24	3.40	−26, 48, −16	5.24	−26, 48, −16	3.90				
	−12, 68, −16	4.60										
Left posterior OFC (area 13/posterior 25)	−12, 18, −24	4.03	−14, 22, −24	3.29	−16, 22, −24	3.99						
Right anterior OFC (BA 11)					28, 46, −24	6.53					24, 48, −20	4.66
Right posterior OFC, anterior insula (BA 13/47)					24, 24, −16	4.40					22, 20, −20	3.77
Left lateral prefrontal (BA 44)							−52, 16, 28	4.22				
Right lateral prefrontal					52, 38, 20	5.17	50, 22, 40	4.45			32, 28, 32	4.17
Right frontal pole	10, 38, 52	4.19	08, 34, 52	3.60	10, 26, 36	4.41	06, 32, 56	3.82				
Right lateral temporal (BA 20)			64, −30, −12	4.75								
Left perirhinal (BA 38)									−32, −24, −12	3.61		
Left hippocampal area (BA 28/35)									−34, 10, −32	4.25		
Right hippocampal area									34, −42, −08	4.06		
Left mesencephalon											−4, −22, −4	3.63

The *x*, *y*, and *z* values indicate the MNI coordinates of the clusters' maximal activity.

observed: an anterior (rostral Brodmann's area, BA, 11, and partly 10) and a posterior (posterior area 13 towards area 25) blob on the right and the left side (Table 2, Fig. 2).

The left anterior OFC (rostral area 10 and 11) was activated by all four tasks, irrespective of whether the feedback was always confirmatory (AlwaysSame), approximately 30% false (Extinction, Guess), or irrelevant (Guess, PlaceIt). A ROI analysis directly comparing the activation in this cluster across all main tasks did not yield significant differences of activation.

A discretely different pattern of activation was observed in the left posterior OFC (posterior BA 13), in that significant activation was obtained in all tasks except the only one having no uncertainty of outcome, condition PlaceIt. This difference between the tasks was discrete and only indicated by the result of the comparison of the main tasks with the baseline. A direct comparison of this cluster of activity across all main tasks using a ROI analysis did not reveal significant variations.

A strikingly different activation pattern was observed in the right OFC. In contrast to the left side, the right OFC was activated exclusively in the Guess condition (comparison with the baseline task). The activation was particularly strong in the anterior OFC (rostral area 11/10). A region-of-interest (ROI) analysis confirmed that this area was significantly more activated by Guess than any other condition ($F(3, 7) = 8.0$; $P = 0.0009$; Tukey post-hoc test significant for the comparisons of Guess with all other conditions). Similarly, activation of the right posterior OFC (posterior lateral area 13), which extended laterally into the anterior inferior insula, was obtained exclusively in the Guess condition (comparison with the baseline task). In contrast to the anterior activation, a ROI analysis did not confirm significant differences between the four main conditions for this posterior cluster.

The Guess condition activated other areas than the right OFC. Apart from the left OFC, which was activated in virtually all tasks, Guess induced marked activation of the dorsolateral prefrontal cortex bilaterally (right area 46 and left area 8). Similar activation was obtained in the PlaceIt condition, which shares with Guess the requirement to take a prospective decision (planning) which cannot be based on previous experience.

3.3. Extinction versus Guess

Of particular interest was the direct comparison of the conditions Extinction and Guess, which had precisely the same design but differed with regard to task instruction (Table 1). Both tasks activated the left anterior and posterior OFC (Fig. 2a). Guess, in direct comparison with Extinction, additionally activated the right anterior OFC and right dorsolateral prefrontal cortex (Fig. 2b, Table 2). Discrete additional activation was also seen in the left mesencephalon in an area compatible with the substantia nigra (Fig. 2b). By contrast, Extinction, in comparison with Guess, more strongly activated medial temporal structures (perihippocampal cortex on both sides and left perirhinal cortex) and left lateral temporal cortex. Thus, anticipation based on previous experience relatively more strongly activated the medial temporal lobe, whereas the generation of hypotheses which cannot be based on previous experience (guessing), more strongly activates the right OFC.

4. Discussion

It is well known that the OFC processes expected rewards, signals deviations from the expected reward, and processes the magnitude of an expected reward (Breiter et al., 2001; Elliott et al., 2000; O'Doherty et al., 2001; Rogers et al., 1999; Thut et al., 1997; Tremblay & Schultz, 2000). The rewards used in these studies were either concrete (primary taste enforcer like chocolate or fruit juice) or abstract (money, score, positive comment). In the present study, we explored whether the OFC is also involved in anticipation and processing of outcomes that provide no tangible reward. Whereas the task conditions varied with regards to the type of choice to be made as well as uncertainty and behavioral significance of the outcome, the outcomes themselves had no intrinsic value and provided no perspective of a gain—no money, no score, not even a comment on the performance could be obtained. Nonetheless, we found consistent activation of the OFC, whose precise location varied with specific task conditions. The result confirms our hypothesis that the human OFC participates in anticipation and processing of outcomes even when the outcome does not provide any tangible reward. Depending on one's view, one may prefer the alternative interpretation stating that any anticipated outcome, even if it has no concrete value and does not provide the slightest gain, represents sufficient "reward" (or "punishment" in the case of an incorrect response) for the OFC to become activated. Both views support the idea that the human OFC constitutes a core reality monitoring system comparing hypotheses (anticipated outcomes) with real outcomes, whose role transcends the common notion of reward as an outcome with an positive value.

Although the results are particularly impressive by the consistency of the OFC activation, the study also suggests that different compartments of the OFC contribute to different aspects of anticipation and outcome processing. The precise distribution of OFC activation, in particular the side of activation, and the interplay with medial temporal structures appeared to depend on the relevance of the feedback and the degree of uncertainty of the prediction.

There was highly consistent activation of the left medial OFC. The frontal pole (rostral area 11/10) was activated in all tasks, suggesting a role in anticipation per se. In comparison with the baseline task, all main tasks induced activation of the left posterior OFC (posterior area 13), except when there was no uncertainty of outcome (PlaceIt). Although this difference did not reach statistical significance in a direct comparison between the main tasks (ROI analysis), the finding suggests that the posterior OFC might have a particular role in detecting disparity between hypotheses and real outcomes, a disparity which was a priori excluded in condition PlaceIt where the subjects themselves defined the outcome. This interpretation, albeit tentative with respect to the present results, is clearly supported by clinical studies. Indeed, lesions of the human posterior OFC are most likely to produce prolonged confusion of personal past (memories relating to the past) with ongoing reality (Schnider, Ptak, von Däniken, & Remonda, 2000). The patients act on the basis of memories which do not pertain to ongoing reality, as if their currently inappropriate action plans (anticipations) failed to be adapted by incompatible outcomes, that is, true ongoing reality (Schnider, 2003). When healthy subjects performed a memory selection task in which such patients failed, we found activation of precisely the same left posterior medial OFC area as in the present study (Schnider, Treyer, et al., 2000). In any case, these studies indicate that the human OFC monitors disparity between hypotheses (anticipated outcomes) and real outcomes even when the anticipated outcomes have no tangible reward value.

Whereas we know of no study using designs similar to our AlwaysSame and Extinction condition, the brain activity associated with guessing has repeatedly been explored. Our study indicates that the right OFC, in particular its polar portion, becomes particularly strongly activated when the outcome of a decision is completely unpredictable, that is, during guessing. Indeed, the right anterior OFC was the only area of OFC that had—as determined with a ROI analysis—significantly stronger activation during one specific condition (guessing) than all other task conditions. It is important to note that this activation apparently depends on the (declared) unpredictability of the outcome, rather than the structure of the task or the type of feedback; condition Extinction, which differed only in the task instruction (whereas it had exactly the same design and a comparable number of negative outcomes), did not activate the right OFC. Again, this difference also turned out to be statistically significant in the direct comparison between the two conditions (Fig. 2b). Thus, the right anterior OFC activation observed in this study appears to reflect specifically the act of guessing.

A comparable activation involving the right inferior frontal gyrus and anterolateral frontal convexity was previously observed in a PET study using a computerized gambling task with varying probabilities of monetary gains or losses (Rogers et al., 1999). Similarly, an earlier PET study comparing activation in a guessing task with a planning task, none of them involving concrete reward, also obtained right orbitofrontal activation (Elliott et al., 1997). A comparison of our results with fMRI studies on guessing is difficult because most fMRI sequences have strong artifacts in the area of our primary interest, the OFC (Ojemann et al., 1997). Some authors therefore explicitly excluded this area from analysis (Cools, Clark, Owen, & Robbins, 2002). Nonetheless, when OFC activation was reported, it appeared to preferentially, but not exclusively, involve the right OFC (Elliott et al., 2000; O'Doherty et al., 2001).

The activation of the right posterior OFC is more difficult to interpret. In comparison to the baseline task, only the Guess condition induced significant activation in this area (Fig. 2a). In addition, the activation was also significant in the direct comparison with the Extinction condition (Fig. 2b). Thus, within the context of this study, right posterior OFC activation, too, appeared to be specific for guessing. Activation of the right posterior lateral area 13 was previously described when subjects memorized a series of meaningless designs (Frey & Petrides, 2000, 2002), and in particular when some of the designs deviated in an obvious manner from the pattern of most designs and thus violated the expectation of a typical pattern of designs (Petrides, Alivisatos, & Frey, 2002). A study comparing a guessing condition providing feedback with a condition providing no feedback, also demonstrated activation of this area (Elliott et al., 1997). These findings thus suggest that the right posterior OFC, similarly to the left posterior OFC, might be more important for the processing of the feedback than for the formation of hypotheses.

Our study focused on the OFC's role in anticipation and processing of outcomes. This is not to suggest that the OFC is the only brain area involved in this activity. Indeed, we found marked activation of the dorsolateral frontal cortex (areas 8 and 46) when subjects made predictions which could not be based on previous experience, that is, in conditions Guess and PlaceIt (Table 2). Activation in this area was previously described in card playing tasks (Critchley et al., 2001; Elliott et al., 1999), but also in working memory tasks (Kammer et al., 1997; Pochon et al., 2002; Sakai, Rowe, & Passingham, 2002). It is possible that activation of this area, known to be eminently involved in higher-order planning (Fuster, 1997; Miller & Cohen, 2001), reflects the counterbalancing of opposing possibilities, when no decision is a priori more advantageous than the other.

A final aspect of interest is the apparent dichotomy between the (right) anterior OFC and the medial temporal lobe observed in the direct comparison between the Extinction and the Guess condition, which had exactly the same design (Fig. 2b). Both conditions activated the left anterior and posterior OFC. However, Guess, in which feedback was not helpful for the next prediction, significantly more activated the right frontal pole, whereas Extinction, in which predictions were guided by the last feedback, significantly more activated the parahippocampal area on both sides. In a simplified model, this finding would be compatible with a prevalent role of the (right) polar OFC in the formation of new hypotheses, of the medial temporal lobes in the storage of recent experience, and—as discussed above—of the posterior OFC in the comparison of anticipated outcomes (hypotheses) with real outcomes (experiences).

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