“FMRI studies in neuro-fuzzy and behavioural finance: a case based approach”

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fMRI studies in neuro-fuzzy and behavioral finance: a case based approach

Abstract

Financial decision making mechanisms have not been identified. Using event-related fMRI without MR compatible switch which can be performed by all MRI system which has only Echo Planar Imaging (EPI) feature, we examined financial decision-making task with three risk levels in two participants. We saw activation regions differences between risk-seeking and risk-aversion selection in addition to larger activated regions in selection funding in comparison with no selection. Thus, consideration of anticipatory neural mechanisms may add predictive power for economic decision-making.

Keywords: fMRI, financial markets, behavioural finance, neural mechanism, echo planar imaging, decision making.
JEL Classification: C02, C45, C61, D53, D81.

Introduction

Individual investors systematically deviate from optimal behavior, which could influence asset valuation (Daniel et al., 2002; Hirshleifer, 2001; Odean, 1998). The causes of these deviations have not been established, but emotion may have some influence. While some research has examined the role of emotion in decision making (Camerer et al., 2005; Loewenstein et al., 2001) and economists have begun to incorporate emotion into models of individual choice (Bernheim and Rangel, 2004; Caplin and Leahy, 2001), scientists still lack a mechanistic account of how emotion might influence choice. Understanding such mechanisms might help theorists to specify more accurate models of individual decision making, which could ultimately improve the design of economic institutions so as to facilitate optimal investor behavior. Here, we sought to examine whether neural activation linked to anticipatory affect would predict financial choices. At least two hypotheses have been put forth regarding the role of affect in decision-making. According to one account, undifferentiated arousal might be related to both risk seeking and risk aversion (Lo and Repin, 2002). However, according to a second account, positive aroused feelings associated with anticipation of gain (e.g., "excitement") may promote risk taking, whereas negative aroused feelings associated with anticipation of loss (e.g., "anxiety") may promote risk aversion (Knutson et al., 2005; Paulus et al., 2003).

Recent evidence from human brain imaging implies that affect evoked by the anticipation of gain and loss may carry distinct neural signatures. Specifically, the nucleus accumbens (NAcc) of the ventral striatum shows proportional activation during anticipation of monetary gains (Breiter et al., 2001; Knutson et al., 2001), and this activation correlates with positive aroused affect (Bjork et al., 2004; Knutson et al., 2005; Martinez et al., 2003). Neural markers of anticipatory negative affect have not been as clearly delineated, but the anterior insula provides a candidate substrate for a number of reasons. First, brain imaging studies have consistently reported activation of the anterior insula during anticipation of physical pain, which correlates with selfreported state anxiety (Buchel and Dolan, 2000; Chua et al., 1999; Ploghaus et al., 1999). Second, the anterior insula shows activation during anticipation of aversive visual stimuli (Simmons et al., 2004). Third, the anterior insula shows activation during risky choice in games involving nonmonetary incentives, which correlates with subsequent risk-aversion and trait measures of negative aroused affect (Paulus et al., 2003). Although the anterior insula is also sensitive to attentional and other demands (Phan et al., 2002), a recent review suggests that activation in this region is more common under negative than positive affective circumstances (Wager et al., 2003).

1. Materials & methods

1.1. Subjects. Two healthy female volunteers (21, 23 years, right handed) participated in the study and underwent the same task and replied by flexion/extension of wrist. Due to nonexistence of MR compatible switch the volunteers replied through flexes/extends right one for "yes" and left one for "no". Their IQs were 110 and 125 respectively. The question asked from subjects after fMRI study to confirm reply was acquired from fMRI data analysis.

1.2. Task timing. Task consisted of block design as one 12s rest block at first and six 15s question and rest blocks sequentially. In rest block the "?" was shown to subjects. In activation block the questions were shown and the subjects were asked to reply silently (Table 1).

We thank Miss N. Rabiee from Research center for science and technology in medicine, Tehran, Iran for assistance in collecting data.

Table 1. Three task questions with 3 risk degrees used for fMRI study

Mode	Question
A	Do you fund on newly established company with 30% purchase?
B	Do you fund on private company with 20% purchase?
C	Do you fund on governmental company with 15% purchase?

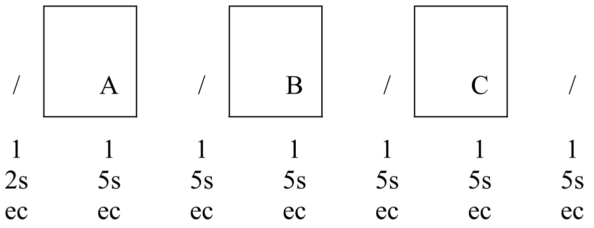


Fig. 1. Task diagram

1.3. fMRI acquisition. Images were acquired with a 1.5T General Electric MRI scanner using a standard birdcage quadrature head coil. Fifteen 7 mm thick slices (in-plane resolution 4 x 4 mm) extended axially from the mid-pons to the top of the skull. Functional scans of the whole brain were acquired every 3 s (TR = 3s) with TE = 60ms, FA = 90 for 34 times. High-resolution structural scan was subsequently acquired using a standard T1-weighted spin echo sequence (TR = 500ms, TE = 15ms) facilitating subsequent localization and coregistration of functional data.

1.4. fMRI analysis methods. Analysis was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.63, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). The following pre-statistics processing was applied: motion correction using MCFLIRT (Jenkinson, 2002); non-brain removal using BET (Smith, 2002); spatial smoothing using a Gaussian kernel of FWHM 5mm; global (volumetric) multiplicative mean intensity renormalization; highpass temporal filtering (Gaussian-weighted least-squares straight line fitting, with sigma = 17.0s). Time-series statistical analysis was carried out using FILM with local autocorrelation correction (Woolrich, 2001). Z (Gaussianised T/F) statistic images were thresholded using clusters determined by $Z > 2.3$ and a (corrected) cluster significance threshold of $P = 0.05$ (Worsley, 1992). Registration to high resolution and/or standard images was carried out using FLIRT (Jenkinson, 2001, 2002). We eliminate first 4 volumes of fMRI acquisition and used 30 volumes (90sec) of each fMRI study. The design matrix for determination of motor activation side for determination of yes/no consists of 3 separate ones as 5 volumes on (15sec) and 25 volumes off (75sec) for every mode (Fig. 2).

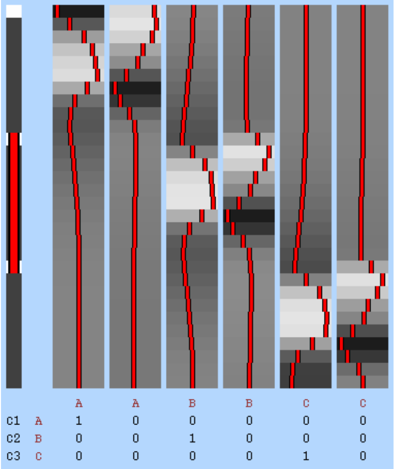


Fig. 2. Design matrix for determination of motor activation side for determination of Yes/No

Since the activation side of motor cortex in brain relates to yes/no reply we design matrix for activation areas for each yes/no consists of 2 separate ones for yes and no separately regarding subject reply (Fig. 3, 4).

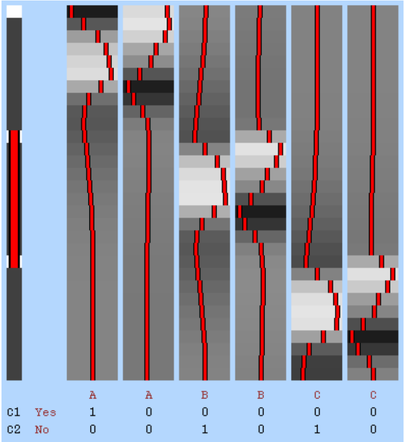


Fig. 3. The design matrix for activation areas regarding subject 1 reply as Yes-No-No

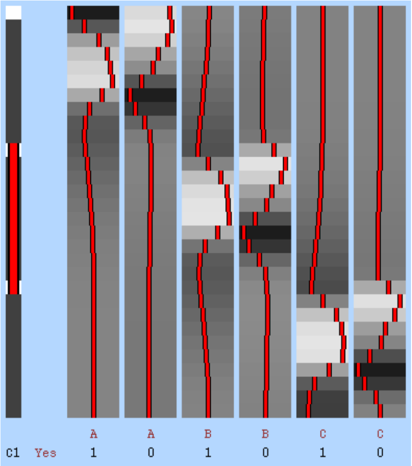


Fig. 4. The design matrix for activation areas regarding subject 2 reply as Yes-Yes-Yes

1.5. Results. Subject 1 replied to questions as Yes, No & No respectively and subject 2 replied as Yes, Yes & Yes.

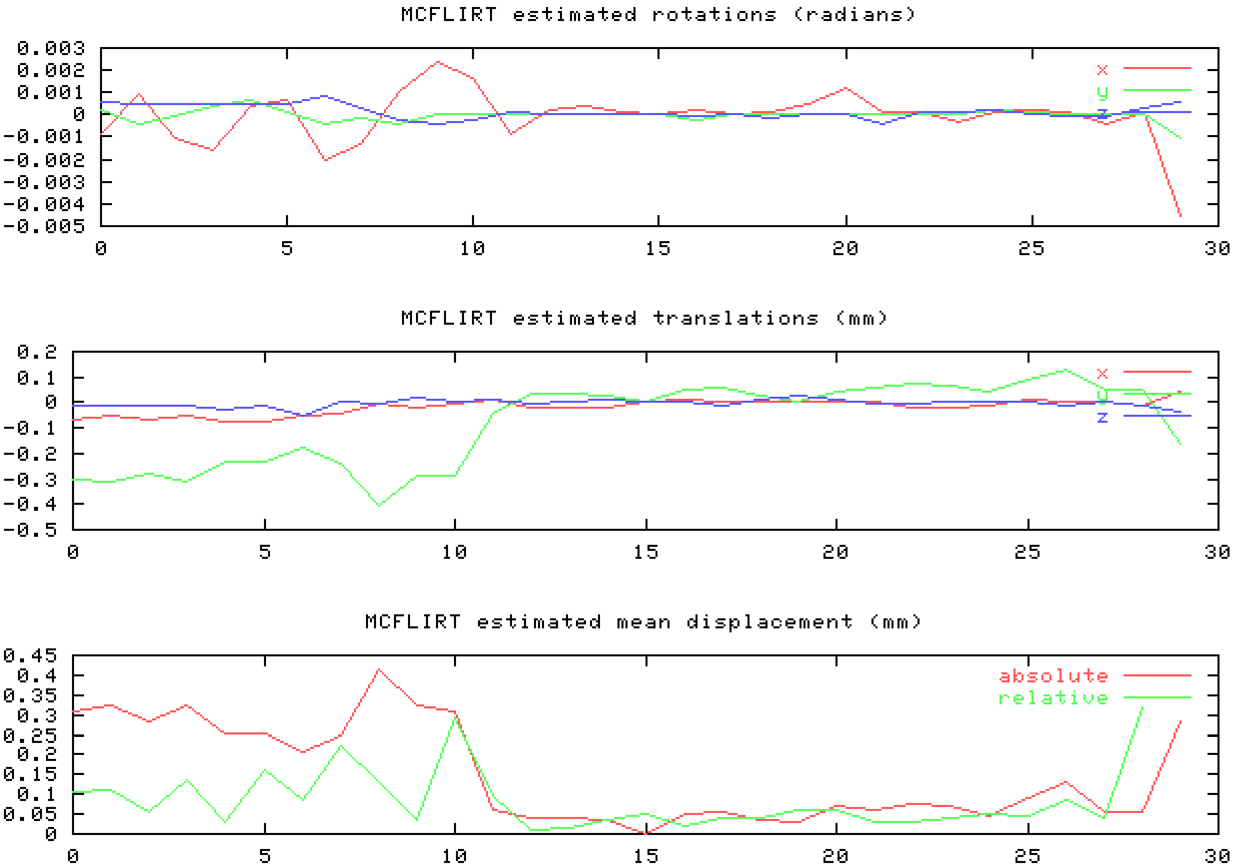
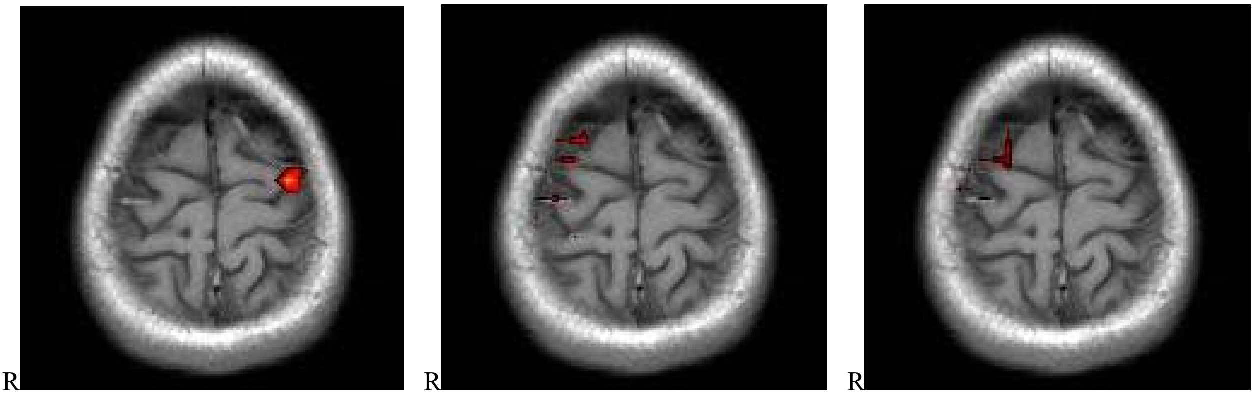


Fig. 5. Mean (across voxels) voxel displacements of subject 1: absolute (each time point with respect to the reference image) = 0.15mm; relative (each time point with respect to the previous timepoint) = 0.08mm



(a) (b) (c)

Fig. 6. Thresholded activation images of Motor Cortex of subject 1 in reply to 3 questions which determines reply as Yes, No & No

Table 2. Co-ordinated information for mode A of subject 1 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
6	399	5.96	13.3	-97.2	-10.1	Gyrus lingualis (GL)
5	70	5.46	-26.9	12.7	62.1	Gyrus frontalis superior (GFs)
4	46	5.16	69.7	-13.4	-42.8	Gyrus temporalis inferior (GTi)
3	26	4.23	22.8	-49.9	48.3	Lobulus parietalis superior (LPs)
2	14	4.97	40.6	-87.9	-50.2	-
1	13	4.02	2.18	27.8	49.1	Gyrus frontalis medialis (GFd)
Sum	568	-	-	-	-	-

Table 3. Co-ordinated information for mode B of subject 1 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
8	1883	7.26	13.3	-97.2	-10.1	Gyrus frontalis medialis (GFd)
7	43	4.79	-61.7	-37.6	-3.69	Gyrus temporalis medius (GTm)
6	38	4.01	27.3	26.5	57	Gyrus frontalis medius (GFm)
5	36	3.29	36.1	-7.46	-60.1	Gyrus temporalis superior (GTs)
4	31	4.76	48.6	-16.7	33.2	Gyrus postcentralis (GPoC)
3	20	3.9	-29.9	-11.4	-55.4	Gyrus temporalis superior (GTs)
2	14	3.9	10.5	40	37.7	Gyrus frontalis medialis (GFd)
1	14	4.2	16.1	53.9	-29.4	Gyrus frontalis superior (GFs)
Sum	2079	-	-	-	-	-

Table 4. Co-ordinated information for mode C of subject 1 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
2	324	6.51	5.26	-92.1	-10.3	Gyrus lingualis (GL)
1	33	3.83	37.4	-2.01	41.4	Gyrus precentralis (GPrC)
Sum	357	-	-	-	-	-

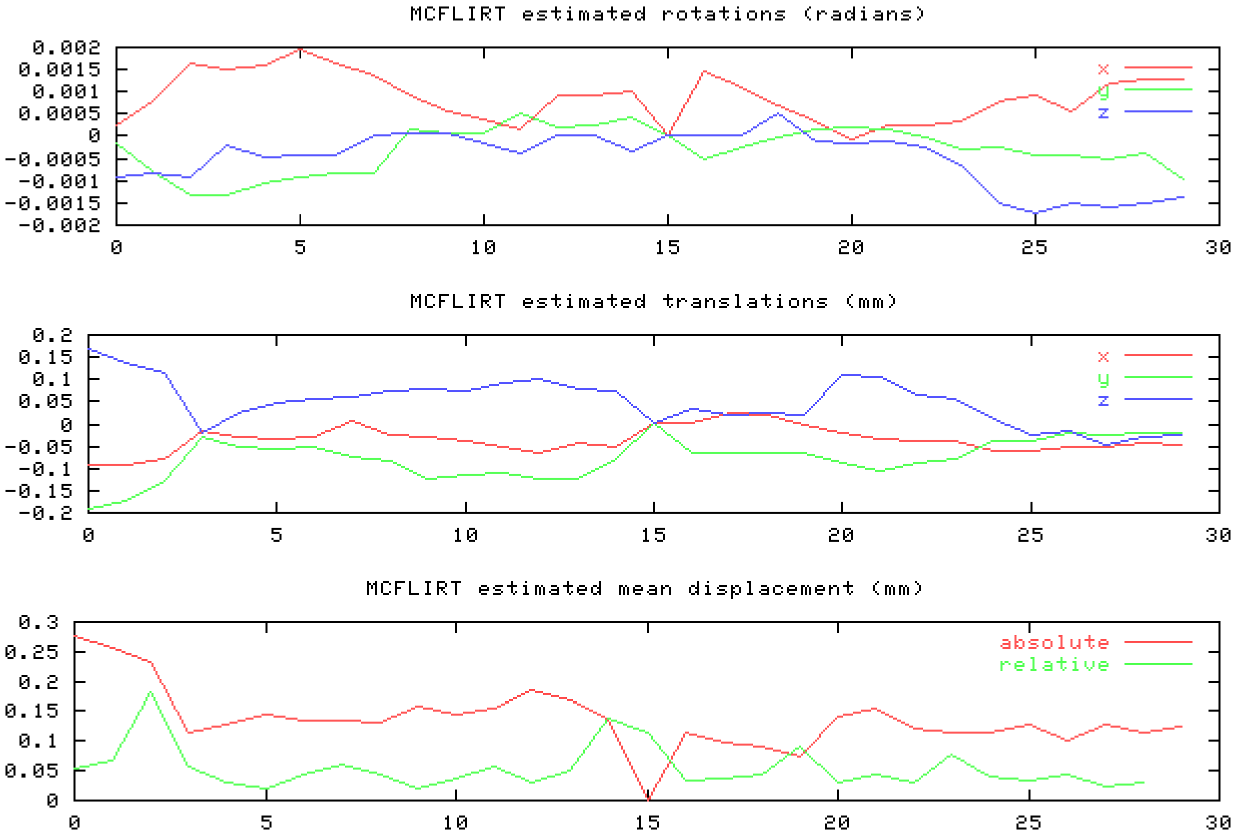
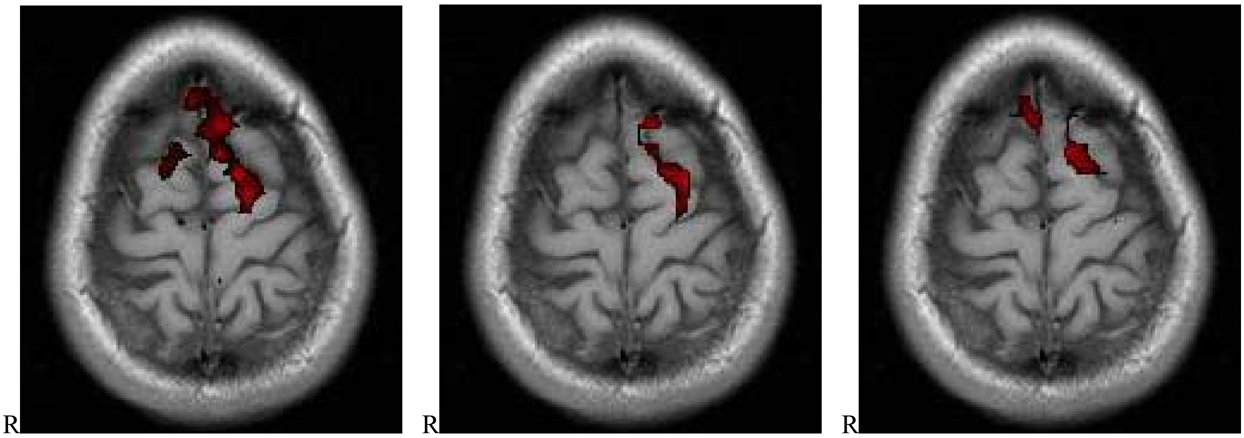


Fig. 7. Mean (across voxels) voxel displacements of subject 2: absolute (each time point with respect to the reference image) = 0.13mm; relative (each time point with respect to the previous timepoint) = 0.05mm



(a) (b) (c)

Fig. 8. Thresholded activation images of Motor Cortex of subject 2 in reply to 3 questions which determines reply as Yes, Yes & Yes

Table 5. Co-ordinated information for mode A of subject 2 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
4	953	6.37	-21.1	-87.1	2.64	Gyrus occipitalis medius (GOm)
3	47	4.82	46.7	23.9	34.6	Gyrus frontalis medius (GFm)
2	38	4.14	-24.9	62.5	25.5	Gyrus frontalis superior (GFs)
1	17	3.37	10.5	-54	-22.3	Ventriculus quartus (V4)
Sum	1055	-	-	-	-	-

Table 6. Co-ordinated information for mode B of subject 2 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
5	721	7.08	-3.87	-105	-35.5	Gyrus lingualis (GL)
4	380	7.32	27	-52	30.2	Tapetum (T)
3	106	5.63	46.7	23.9	34.6	Gyrus frontalis medius (GFm)
2	20	3.78	14.7	-0.74	-0.45	Globus pallidus medialis (GP1)
1	19	3.68	27.6	-7.23	31.2	Fasciculus occipito-frontalis (FOF)
Sum	1246	-	-	-	-	-

Table 7. Co-ordinated information for mode C of subject 2 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
7	368	4.76	-24.6	9.61	54.4	Gyrus frontalis medius (GFm)
6	227	6.45	27	-52	30.2	Tapetum (T)
5	219	5.58	5.42	-112	-34.3	-
4	90	4.4	-38.6	7.86	12.4	Fasciculus longitudinalis superior (FLS)
3	36	4	48.5	40.6	5.18	Gyrus frontalis inferior (GFi)
2	32	4.64	46.7	23.9	34.6	Gyrus frontalis medius (GFm)
1	23	4.07	-43.1	43.8	2.54	Gyrus frontalis medius (GFm)
Sum	995	-	-	-	-	-

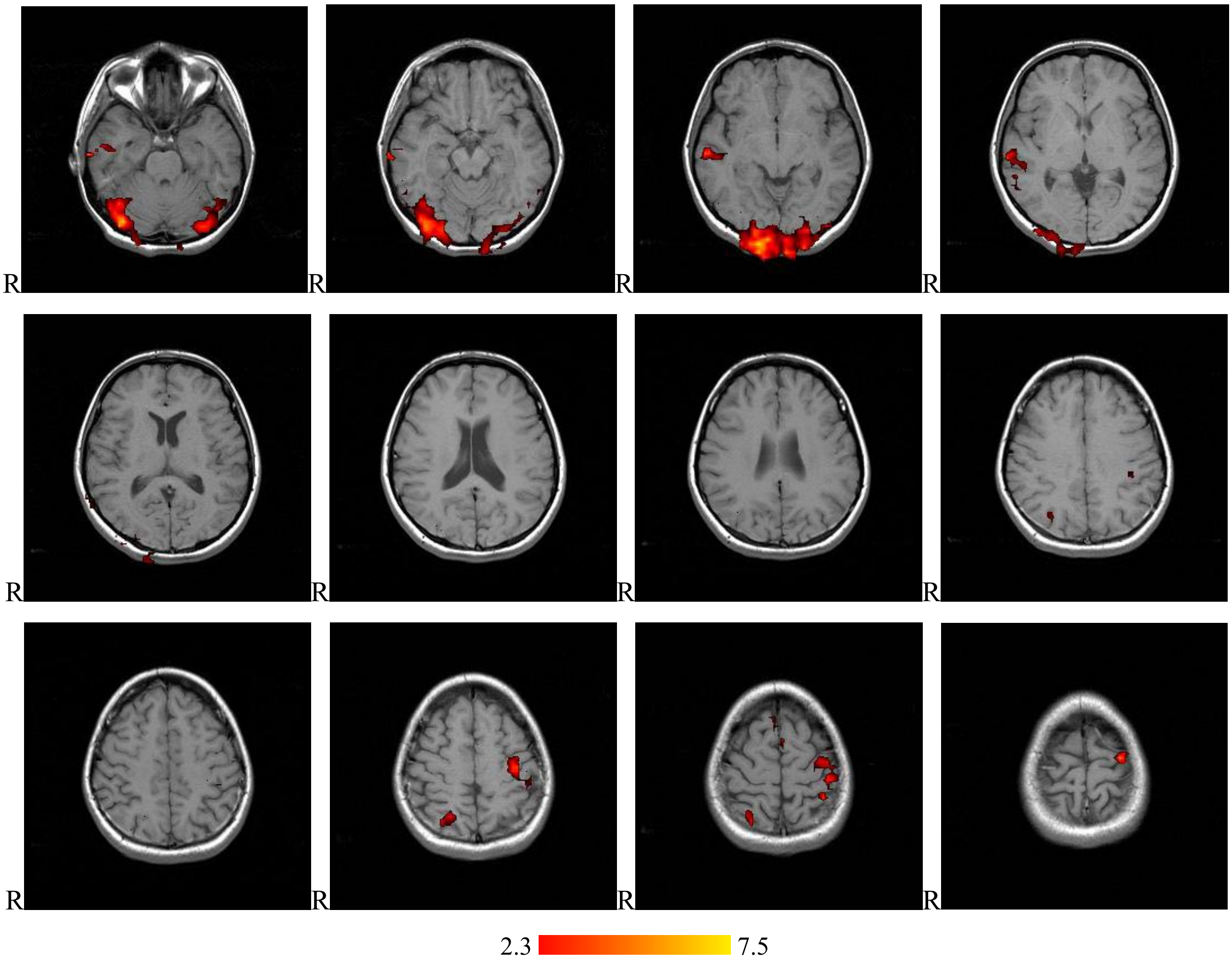
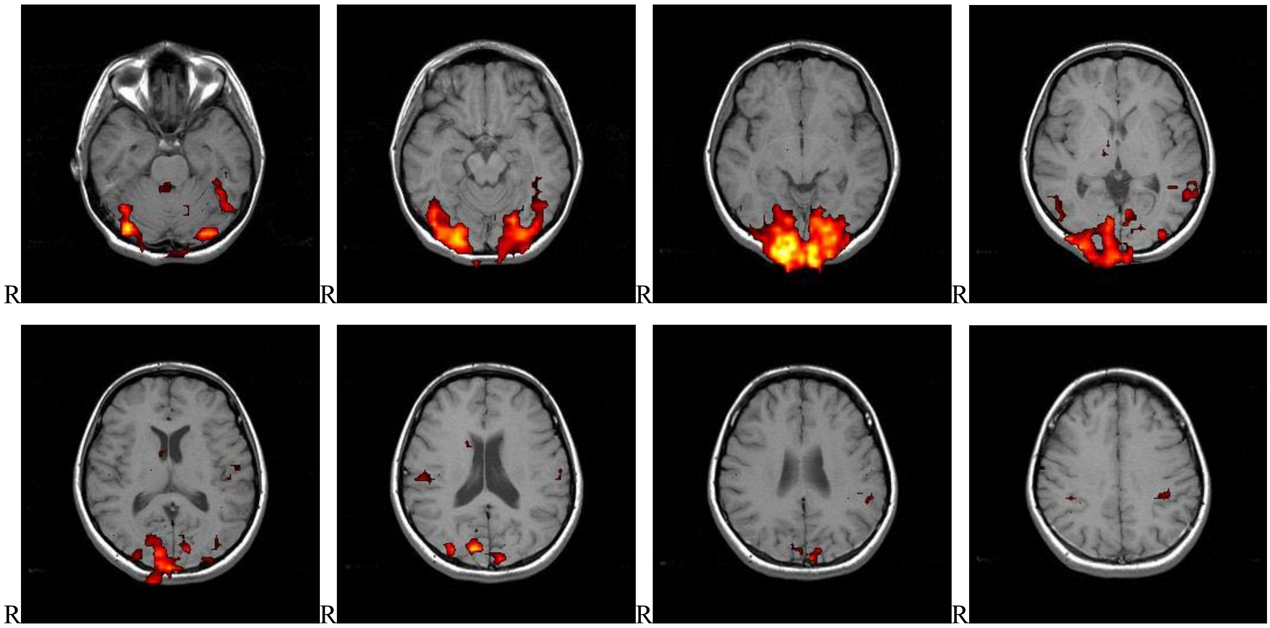


Fig. 9. Thresholded activation images of subject 1 in reply Yes to 2 of 3 questions



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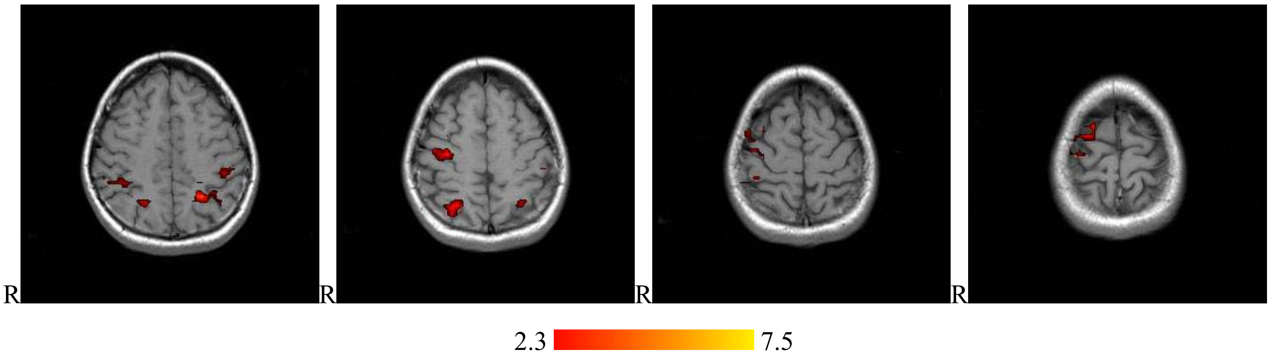

Fig. 10. Thresholded activation images of subject 1 in reply No to 1 of 3 questions

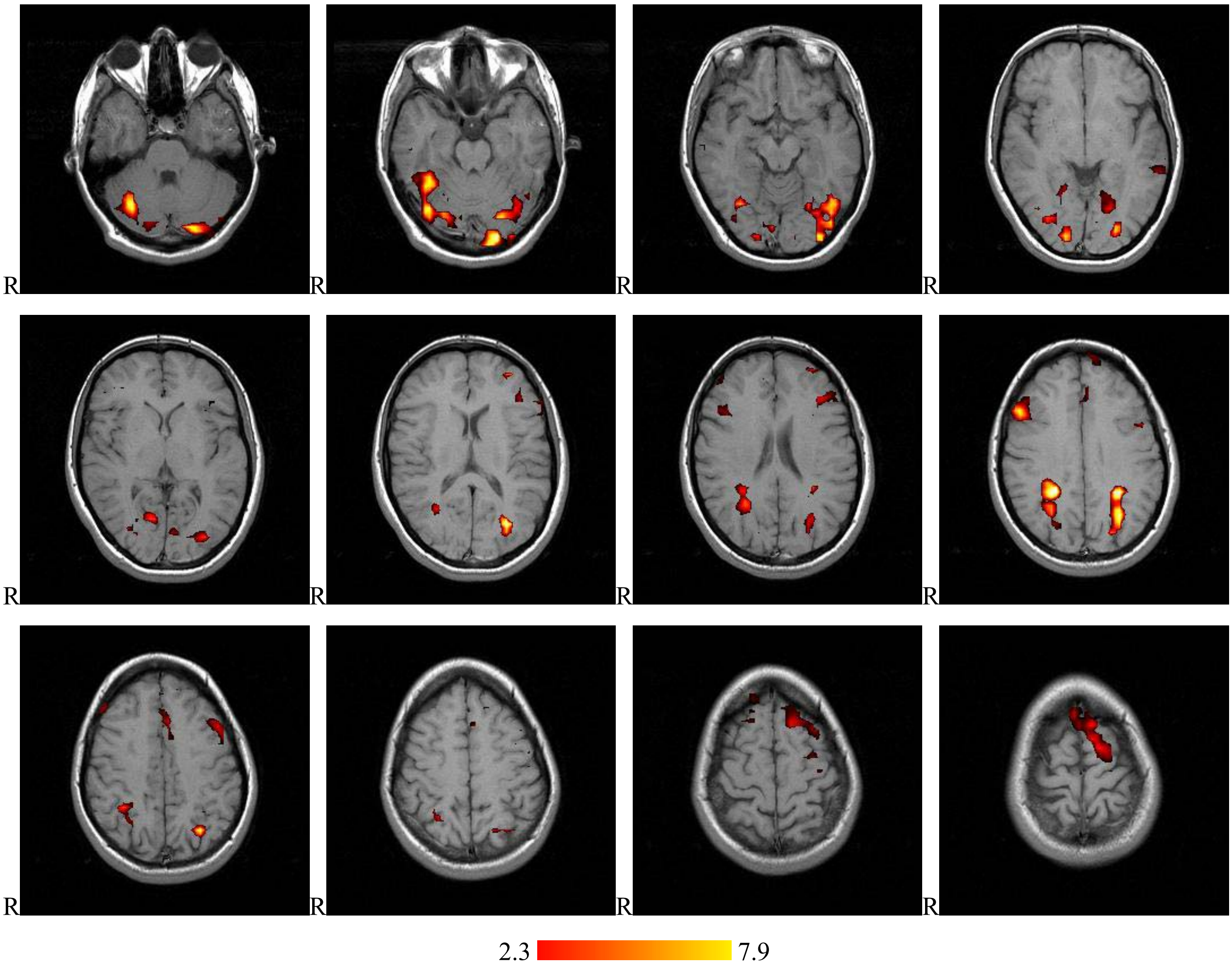

Fig. 11. Thresholded activation images of subject 2 in reply Yes to all 3 questions

Table 8. Co-ordinated information for replying Yes of subject 1 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
6	399	5.96	13.3	-97.2	-10.1	Gyrus lingualis (GL)
5	70	5.46	-26.9	12.7	62.1	Gyrus frontalis superior (GFs)
4	46	5.16	69.7	-13.4	-42.8	Gyrus temporalis inferior (GTi)
3	26	4.23	22.8	-49.9	48.3	Lobulus parietalis superior (LPs)
2	14	4.97	40.6	-87.9	-50.2	-
1	13	4.02	2.18	27.8	49.1	Gyrus frontalis medialis (GFd)
Sum	568	-	-	-	-	-

Table 9. Co-ordinated information for replying No of subject 1 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
11	942	7.55	13.3	-97.2	-10.1	Gyrus lingualis (GL)
10	29	3.68	-46	-14.1	38.8	Gyrus precentralis (GPrC)
9	25	4.51	37.4	-2.01	41.4	Gyrus precentralis (GPrC)
8	23	4.39	27.3	26.5	57	Gyrus frontalis medius (GFm)
7	23	3.61	45.1	-24.3	53	Gyrus postcentralis (GPoC)
6	22	4.37	26.9	-50.2	48.1	Lobulus parietalis superior (LPs)
5	21	5.1	-26.5	-37.8	40.6	Sulcus callosomarginalis (Scm)
4	19	3.88	-61.5	-33.2	-4.26	Gyrus temporalis medius (GTm)
3	14	3.24	-62.8	7.93	9.2	Sulcus lateralis cerebri (Sl)
2	13	3.47	59.8	-10.2	3.82	Gyrus temporalis superior (GTs)
1	13	3.62	20.5	28.4	1.41	Fasciculus occipito-frontalis (FOF)
Sum	1144	-	-	-	-	-

Table 10. Co-ordinated information for replying Yes of subject 1 in standard space and region name from http://www.neurovia.umn.edu/cgi-bin/tal_atlas

Cluster index	Voxels	Z-MAX	X (mm)	Y (mm)	Z (mm)	Region name
5	818	7.95	27.9	-57.8	18.9	Radiatio optica (Ro)
4	497	5.78	-43.1	47.7	11.3	Gyrus frontalis medius (GFm)
3	109	6.61	49.8	19.9	32	Gyrus frontalis medius (GFm)
2	30	4.32	-57.2	-49.8	-24.3	Gyrus temporalis inferior (GTi)
1	24	3.88	54.2	-12.3	-32.4	Gyrus temporalis inferior (GTi)
Sum	1478	-	-	-	-	-

Table 11 indicates that there is significant difference between numbers of activated voxels of 3 modes. Activated voxels in mode B are larger than A and C modes. Table 12 indicates that there is significant difference between numbers of activated voxels of Yes and No results in subject 1.

Table 11. Number of activated voxels

Mode	Subject 1	Subject 2
A	568	1055
B	2079	1246
C	357	995
Total	3004	3296

Table 12. Number of activated voxels

Reply	Subject 1	Subject 2
Yes	568	1478
No	1144	-
Total	1712	1478

Discussion and conclusion

While NAcc activation preceded both risky choices and risk-seeking mistakes, anterior insula activation preceded both riskless choices and risk-aversion mistakes. These findings are consistent with the hypothesis that NAcc represents gain prediction (Knutson et al., 2001), while anterior insula represents loss prediction (Paulus et al., 2003). One of the contributions of this paper is the BIAS task, as it provides a way to operationalize optimal choices, which by extension allows the identification of suboptimal choices. According to financial models, one can define risk-neutral choices based on Bayesian updating as rational and deviations from these choices as irrational. The results therefore indicate that, above and beyond contributing to rational choice, anticipatory neural activation may also promote irrational choice. Thus, financial decision-making may require a delicate balance recruitment of distinct circuits may be necessary for taking or avoiding risks, but excessive activation of one mechanism or the other may lead to mistakes. While the observation that NAcc activation is correlated with subsequent risk taking and risk-seeking mistakes agrees with a gain prediction account of NAcc function (Knutson et al., 2001), the current findings are not as consistent with alternative accounts. Motor preparation accounts predict equal activation prior to motor acts of equal force (Mogenson et al., 1980) and so cannot explain the NAcc's prediction of risk-seeking but not risk-averse choices, since both required active choices indicated by button presses. Similarly, a saliency account predicts equal activation during anticipation of both large gains and losses (Zink et al., 2003) and so cannot account for the NAcc's prediction of risk-seeking but not risk-averse choices. Finally, a behavioral switching account predicts that NAcc activation will increase prior to any switch from a repeated behavior to a novel behavior (Robbins et al., 1986). While the influence of the NAcc in biasing choice was most pronounced when subjects switched from risk-averse to risk-seeking choices, NAcc activation did not predict switches in the opposite direction (from risk-seeking to risk-averse choices). The same arguments apply in reverse to the anterior insula predicting risk averse choices. In either case, theories that fail to include the anticipated subjective value of an outcome cannot easily account for the observed pattern of results. Although both actual and relative gain outcomes increased activation in the MPFC, MPFC activation did not predict subsequent risk-taking behavior, consistent with its proposed role in representing gain prediction error rather than gain prediction (Knutson et al., 2003). Gain outcomes also activated other regions implicated in decision making (e.g., orbitofrontal cortex, medial caudate, anterior cingulate cortex), but activation in these regions also did not predict subsequent risk-taking behavior. While activation in these regions does not correlate with subsequent risk taking, these regions may still play other important roles in decision making (O'Doherty et al., 2003). For instance, anterior cingulated foci showed increased activation under conditions of increased response conflict, consistent with the postulated role of this region in conflict monitoring (Ridderinkhof et al., 2004).

The BIAS task offers a number of advantages in eliciting financial choice behavior. First, because the BIAS task utilizes monetary incentives in a dynamic setting, our findings may generalize to real-world trading scenarios. Second, the BIAS task enables identification of both optimal choices and suboptimal choices. Third, the BIAS task elicits a range of behaviors from each individual, including both risk-seeking and risk-averse choices. Fourth, the event-related design of the study allowed us to correlate anticipatory rather than concurrent neural activation with choice by temporally isolating anticipatory activation and controlling for key antecedent behavioral variables (i.e., earnings, uncertainty). While the event-related analyses ensured that both anticipatory activation and decision making occurred prior to actual choice, the dynamic nature of the BIAS task leaves open the question of whether anticipatory activation preceded decision making or the reverse. Some of the present findings support the idea that activation preceded decision making. Specifically, the link between activation and subsequent choice critically depended upon prior choice. For example, if NAcc activation simply reflected the decision to pick a stock, then the relationship between NAcc activation and the likelihood of choosing a stock should not depend upon prior choice. However, anticipatory NAcc activation significantly predicted the likelihood of subsequent stock choice only if the bond was picked on the previous trial (see Table 3). The same argument also applies to insula activation. Future research that specifically manipulates anticipatory activation could further establish whether such activation influences decisions. The dynamic nature of the BIAS task may have obscured stable individual differences in NAcc activation, which might influence subsequent choice, but are more evident in stationary tasks (Knutson et al., 2005). However, even during this dynamic task, significant individual differences were evident in insula activation during anticipation, and these predicted switching from risky to riskless choices as well as the likelihood of making risk-aversion mistakes while doing so. The link between individual differences in anterior insula activation and subsequent risk-averse choices replicates and extends prior findings (Paulus et al., 2003).

While experts and nonexperts who differed in terms of prior coursework in finance and statistics did not significantly differ in behavior in this experiment, future research should also examine the influence of individual differences in trading experience on financial risk taking, since psychophysiological evidence suggests that experienced traders may show less emotional responsiveness to market events than inexperienced traders (Lo and Repin, 2002). While many psychophysiological measures (e.g., skin conductance, heart rate, pupillary dilation) index anticipatory arousal, the current results suggest that measures that probe anticipatory valence will also be necessary to predict the likelihood of subsequent risky choice. Overall, these findings suggest that risk-seeking choices (such as gambling at a casino) and risk-averse choices (such as buying insurance) may be driven by two distinct neural circuits involving the NAcc and the anterior insula. The findings are consistent with the notion that activation in the NAcc and anterior insula, respectively, index positive and negative anticipatory affective states and that activating one of these two regions can lead to a shift in risk preferences. This may explain why casinos surround their guests with reward cues (e.g., inexpensive food, free liquor, surprise gifts, potential jackpot prizes) – anticipation of rewards activates the NAcc, which may lead to an increase in the likelihood of individuals switching from risk-averse to risk-seeking behavior. A similar story in reverse may apply to the marketing strategies employed by insurance companies. Consideration of risk necessarily involves weighing potential gains against potential losses. The notion that distinct neural mechanisms anticipate gain versus loss suggests a novel componential view of risk taking. Combined with such a view, these findings provide neural targets for investigating complex risk phenomena such as loss aversion, in which people weigh losses more than gains of equivalent size (Kahneman and Tversky, 1979). These findings further imply that neuroeconomic research may foster a more comprehensive theory of individual decision making than the rational actor model and thus may ultimately yield new insights relevant to economic policy and institutional design.

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