Neuroscience Letters 438 (2008) 138–141

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

An event-related fMRI study on risk taking by healthy individuals of high or low impulsiveness

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ARTICLE INFO

Article history:
Received 25 January 2008
Received in revised form 16 April 2008
Accepted 16 April 2008

Keywords:
Orbitofrontal cortex
Insula
Anterior cingulate cortex
Dorsolateral prefrontal cortex
Risk taking
Parietal cortex

ABSTRACT

This event-related functional Magnetic Resonance Imaging study examined the differential neural activities associated with a Risky-Gains task in 18 healthy individuals of high ($n = 9$) or low ($n = 9$) impulsiveness, according to their scores on the Barratt Impulsiveness Scale (BIS). The neural activities of people belonging to the high and low impulsiveness groups were monitored by a 3T MRI scanner while they were performing the Risky-Gains task. We demonstrated that a stronger activation in the insula-orbitofrontal-parietal regions was found in the high impulsiveness group compared to the low impulsiveness group. However, the levels of activation in the lateral prefrontal and anterior cingulate regions did not differ between the two groups. The findings suggest that the neural substrates of comprehension of cognitive and affective information associated with risk-taking decision making may vary according to the impulsiveness among healthy individuals.

Risk-taking behaviors are associated with a series of cognitive and affective processes that aim to balance the potential losses and benefits of an action [1]. The failure to appropriately regulate risk-taking behaviors could lead to socially inappropriate acts or even pathological behaviors presented in people with various neuropsychiatric disorders [12,13,18,30,33]. Clinical studies have revealed several brain regions that are involved in risk-taking decision making. Bechara et al. [2] showed that patients with prefrontal lesions failed to learn from explicit information about risky choices in a gambling task. More specifically, Rogers et al. [31] demonstrated that patients with orbitofrontal cortex (OFC) damage were impaired when making risk-taking choices. Functional neuroimaging studies on healthy adults have reported activation related to risk-taking decision making in the OFC [14,20], the inferior prefrontal cortex (PFC) [26,27], the ventrolateral and ventromedial frontal cortices [8,9], the insula [6], and the parietal regions [27].

Efficient and effective regulation of impulsiveness [23] is an essential prerequisite for advantageous risk-taking decision making. Previous studies have consistently reported significant activation in the lateral PFC and the ACC when participants were exercising inhibitory control [16,17]. The lateral PFC and ACC regions work collaboratively to regulate impulsiveness and to ensure the smooth operation of the risk-taking decision-making process.

This fMRI study examined the neural activities associated with risk taking. The sample consisted of people who were categorized as having High or Low levels of impulsiveness according to their scores on the Barratt Impulsiveness Scale (BIS; 24). Participants' risk-taking behaviors in the two groups were matched according to their performance on the Risky-Gains task (27, with permission) so that differences in neural activations could be explained by the different neurocognitive processes associated with risk taking rather than their behavioral differences [19]. The Risky-Gains task was used to examine the neural activities associated with making a risk-taking decision and receiving the feedback as the consequence of that decision (see Fig. 1). The task requires the participant to acquire as many points as possible by choosing between safe (20 points)

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doi:10.1016/j.neulet.2008.04.061

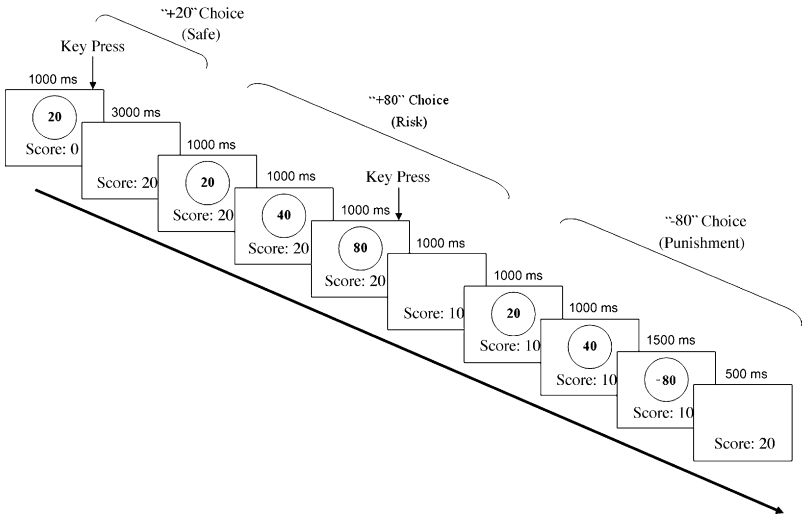

Fig. 1. Schematic representation of the experimental paradigm – the Risky-Gains task.

and risky (40, 80 points) options. In each trial, point options (20, 40, 80) are presented in a fixed sequential order. The participant claims the points by pressing a button when the points appear. The participants always get +20 points because it is "safe" but the other points can be a reward (+40/+80) or punished (−40/−80) options. Immediate feedback is given to the participant. An event-related design was used and each participant completed 96 random trials inside a MRI scanner. Each trial lasted 3.5 s, irrespective of the participant's response.

We performed contrasts comparing "risky versus safe responses" (risk taking), and "punished versus safe responses" (punishment). Specifically, the risk taking contrast could reflect brain activities associated with those cognitive processes underlying the selection between risky and safe options. The punishment contrast reveals brain activities associated with the reaction towards being punished versus rewarded. We performed region of interest (ROI) analyses in the bilateral insula, the OFC, and the parietal regions in order to assess their involvement in the risk-taking decision-making process [27]. The same analyses were performed in the ACC and lateral PFC because these regions are involved in the regulation of impulsiveness [16]. Since the participants differed in their level of impulsiveness but were matched in terms of their risk-taking behaviors, we hypothesized that different patterns of neural activation would be observed in the ACC-lateral PFC regions, but not in the brain regions subserving risk-taking decision making (i.e. the insula–OFC–parietal regions).

Eighteen healthy volunteers (8 females and 10 males), recruited from the community, participated in this study. All the participants were strongly right-handed [37]. They had no previous history of head injuries, neurological illnesses, or psychiatric disorders. According to their scores on the BIS, they were classified into the low and high impulsiveness group. Previous literature indicates that BIS scores are useful for predicting impulsiveness in samples from the normal population [4,22]. There were five men and four women in each of the two groups. The mean BIS score of the high impulsiveness group was 69.44 ± 3.32 and that of the low impulsiveness group was 56.44 ± 4.13 ($Z = 3.58$, $p < 0.001$).

The neural activities of the participants were monitored by a 3.0T Siemens (Siemens, Erlangen, Germany) scanner at the Research Imaging Center, San Antonio, Texas. A gradient-echo echo-planar imaging (EPI) pulse sequence was used. Twenty-four contiguous slices (covering the whole brain) were interleaved and acquired parallel to the AC–PC plane. The EPIs were acquired with a 2-s TR, TE = 30 ms, FOV = 256 mm × 256 mm, matrix size = 128 × 128, flip angle = 90°, slice thickness = 6 mm. For anatomical reference, a spin-echo T1-weighted axial series was obtained (TR = 20 ms, TE = 5.15 ms, FOV = 256 mm × 256 mm, slice thickness = 6 mm). For each slice, 222 images were acquired, with a total scan time of 7 min 24 s.

Raw EPI data were preprocessed and analyzed using *SPM2* (Wellcome Department of Cognitive Neurology, Institute of Neurology, Queen Square, London, UK). Subject-level analyses were conducted by setting up contrasts between the risky (+40, +80) and safe responses (risk taking), and the punished (−40, −80) and safe responses (punishment) at a threshold of $p < 0.001$ (uncorrected). For ROI analyses, signal changes in the selected brain regions were calculated using the WFU PickAltas [21], at a threshold of $p < 0.01$ uncorrected. The signal changes in each of the three ROIs were calculated using MarsbaR region of interest toolbox for SPM (http://marsbar.sourceforge.net; [3]). Specifically, the analyses were conducted in the insula and the OFC for risk taking [14,25,27], and in the lateral PFC and ACC for regulation of impulsiveness [16] selected based on the anatomical definition using the Automated Anatomical Labeling (AAL) software [38].

Behaviorally, independent sample *t*-test revealed nonsignificant differences reaction times between the high and low impulsiveness groups ($t_{16} = 0.13–1.50$, $p = 0.195–0.898$). Paired *t*-test revealed a significantly shorter reaction time in responding to the risky selections (40, 80 points) when compared to responding to the safe selection in both the high and low impulsiveness groups (high: $t_8 = 5.36$, $p = 0.001$; low: $t_8 = 4.87$, $p = 0.001$) (see Table 1).

In the risk-taking contrast, the high impulsiveness group showed stronger activation, relative to the low impulsiveness group, in the insula (BA 13), and the OFC (BA 11, 47). In the punishment contrast, the high impulsiveness group showed a stronger neural activation than the low impulsiveness group in the insula (BA 13), the OFC (BA 47) (see Table 2). An independent sample *t*-test revealed that the high impulsiveness group showed a signifi-

Table 1
Mean (S.D.) of reaction times of the Risky-Gains task

	Reaction time (ms)	
	Safe (20-point trials)	Risk (40-/80-point trials)
High impulsivity ($n = 9$)	471.47 (84.10)	383.04 (54.38)
Low impulsivity ($n = 9$)	490.06 (84.51)	380.00 (43.93)

Table 2
ROI analysis of the high versus low impulsivity contrast in the risk versus safe and punish versus safe contrasts

		BA	Side	Coordinate			Cluster	*T*
				x	*y*	*z*		
Risk taking (risk vs. safe)	Insula	13	R	34	6	14	29	3.64
		13	L	−36	−2	−8	15	2.98
	Inferior OFC	47	R	36	34	−2	104	3.60
		47	L	−46	30	−16	95	3.33
	Precuneus	5	R	4	−54	68	82	3.43
		7	L	−10	−52	48	16	3.31
	Angular gyrus	40	L	−40	−58	40	108	3.43
	Inferior parietal lobule	40	L	−42	−36	40	62	3.32
Punishment (punished vs. safe)	Insula	13	R	34	6	14	40	3.59
		13	L	−36	−6	−12	28	3.68
	Inferior OFC	47	R	36	34	−2	37	3.64
		47	L	−46	30	−16	75	3.40
	Precuneus	5	R	2	−46	72	37	3.30
		7	L	−10	−52	48	47	3.91
	Angular gyrus	39	L	−40	−58	40	37	3.56
		39	L	−46	−64	42	17	2.92

OFC = orbitofrontal cortex; BA = Brodmann's area; L = left hemisphere; R = right hemisphere; *x*, *y*, *z* in MNI coordinates.

cantly greater percentage signal change than the low impulsiveness group in the right insula ($t_{16} = 2.11$, $p = 0.050$), the left OFC ($t_{16} = 2.21$, $p = 0.042$), the right and left parietal regions ($t_{16} = 2.79$, $p = 0.013$ and $t_{16} = 2.67$, $p = 0.017$, respectively) in the risk-taking contrast. There were no significant percentage signal changes in the punishment contrast. Details of the activation and the plot of the percentage signal change are shown in Figs. 2 and 3. For regulation of impulsiveness, no significant differences in neural activations in the lateral PFC and the ACC were observed between the two groups.

Contrary to our *a priori* speculation, we observed differential patterns of activation in the brain areas associated with risk taking (insula–OFC–parietal regions) but not in those involved in the regulation of impulsiveness (lateral PFC–ACC regions). These findings suggest that in a healthy population, the impact of the level of impulsiveness appears to be on the cognitive-affective reactions to risk taking, as reflected by the significantly stronger activation in the insula–OFC–parietal regions.

Many studies have found that risk taking involves activation of the insula [14,26], which plays an important role in risk estimation [27] as well as guiding behavior based upon the anticipation of emotional consequences [34]. The insula is involved in comprehension of the affective information associated with choices during decision making [10,36]. For example, awareness of threat and the internal state of the body [7]. Therefore, the heightened insula activity in the high impulsiveness group may signify affective reactions to risky choices.

Recent studies have clearly demonstrated that the OFC cortex is involved in reward-related decision making [11,32,39]. The OFC, which is strongly connected with the striatal system, is responsible for behavioral and motivational control [15]. More specifically, it plays a significant role in forming associations between environmental stimuli and rewards [31,35,40]. Cohen et al. [5] have further reported stronger OFC activation in high-risk than low-risk decisions. Our finding of stronger OFC activation presented by the high than low impulsiveness group suggest a higher degree of contemplation and mental consideration by people of high impulsiveness during risk taking.

Increased posterior parietal activation together with insula activity observed in this work is consistent with the expectation of anatomical connections between these two regions [27]. The higher

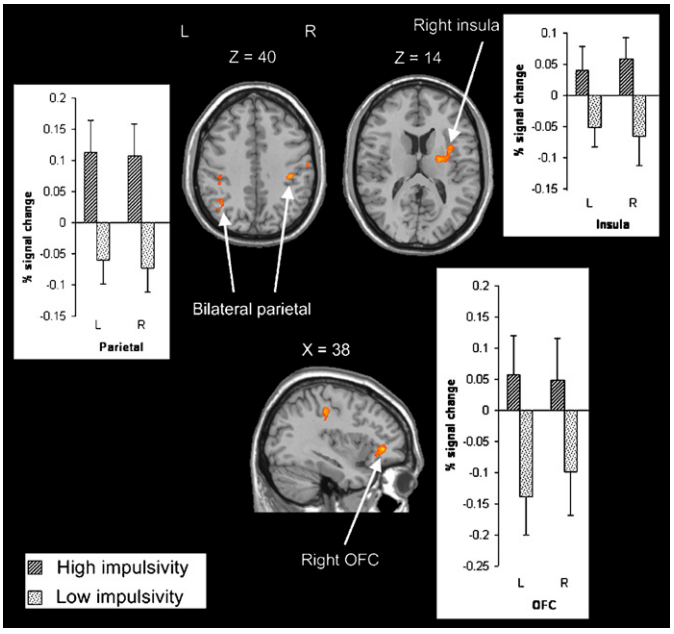

Fig. 2. Plot of percent signal change comparing the high and low impulsiveness groups in risk taking measured by the contrast between risky vs. safe responses. OFC = orbitofrontal cortex; right (R) is right; L = left hemisphere; R = right hemisphere; *x*, *y*, *z* in MNI coordinates.

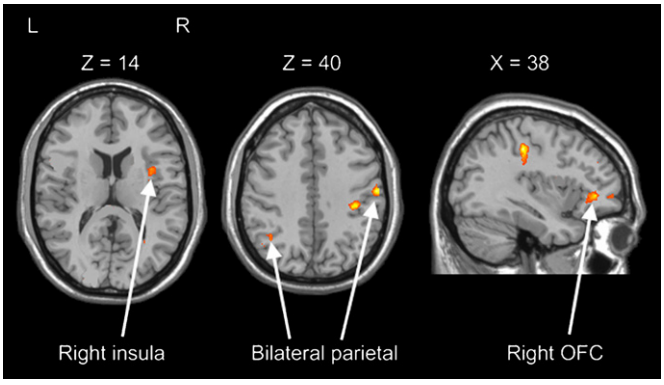

Fig. 3. Activation maps showing the results of the comparison between the high and low impulsiveness groups during punishment measured by the contrast between punished vs. safe responses. OFC = orbitofrontal cortex; right (R) is right; L = left hemisphere; R = right hemisphere; *x*, *y*, *z* in MNI coordinates.

level of activation of the posterior parietal region could alternatively suggest that those in the high impulsiveness group need to recruit additional neural resources from the parietal regions for regulation of impulsive outputs [16].

The comparable neural activations in the lateral PFC–ACC regions between the high and low impulsiveness groups were unexpected. This observation is quite different from the data obtained from clinical populations [16] using various experimental paradigms [4,28,29]. Given the multi-component nature of the construct of inhibition [24,25], it is possible that the variance captured by the BIS are different from that reflected by the PFC–ACC activations. On the other hand, the nonsignificant group differences in the lateral PFC–ACC activations may be due to the fact that our participants were healthy individuals who showed only a very narrow range of variation in their level of impulsiveness. This together with the small sample sizes are limitations that restricted the statistical power of our observations. More participants with a broader range of impulsiveness should be recruited in future studies to increase the between-group variance and to confirm our current findings.

Acknowledgements

The project was supported by (1) the Research Output Prize of The University of Hong Kong awarded to TMC Lee, and (2) Niche Area Research Grant on Applied Cognitive Neuroscience and Neuroplasticity of The Hong Kong Polytechnic University awarded to CCH Chan.

References

[1] E. Arce, D.A. Miller, J.S. Feinstein, M.B. Stein, M.P. Paulus, Lorazepam dose-dependently decreases risk-taking related activation in limbic areas, Psychopharmacology 189 (2006) 105–116.
[2] A. Bechara, H. Damasio, D. Tranel, A.R. Damasio, Deciding advantageously before knowing the advantageous strategy, Science 275 (1997) 1293–1295.
[3] M. Brett, J.L. Anton, R. Valabregue, J.B. Poline, Region of interest analysis using an SPM toolbox [abstract]. Presented at the 8th International Conference on Functional Mapping of the Human Brain, June 2–6, Sendai, Japan. Available on CD-ROM in NeuroImage 16 (2002), No. 2.
[4] S.M. Brown, S.B. Manuck, J.D. Flory, A.R. Hariri, Neural basis of individual differences in impulsivity: Contributions of corticolimbic circuits for behavioral arousal and control, Emotion 6 (2006) 239–245.
[5] M.X. Cohen, A.S. Heller, C. Ranganath, Functional connectively with anterior cingulate and orbitofrontal cortices during decision-making, Cogn. Brain Res. 23 (2005) 61–70.
[6] H.D. Critchley, C.J. Mathias, R.J. Dolan, Neural activity in the human brain relating to uncertainty and arousal during anticipation, Neuron 29 (2001) 537–545.
[7] H.D. Critchley, S. Wiens, P. Rotshtein, A. Ohman, R.J. Dolan, Neural systems supporting interoceptive awareness, Nat. Neurosci. 7 (2004) 189–195.
[8] R. Elliott, R.J. Dolan, C.D. Frith, Dissociable functions in the medial and lateral orbitofrontal cortex: Evidence from human neuroimaging studies, Cereb. Cortex 10 (2000) 308–317.
[9] R. Elliot, G. Rees, R.J. Dolan, Ventromedial prefrontal cortex mediates guessing, Neuropsychologia 37 (1999) 403–411.
[10] M. Ernst, M.P. Paulus, Neurobiology of decision making: a selective review from a neurocognitive and clinical perspective, Biol. Psychiat. 58 (2005) 597–604.
[11] N. Eshel, E.E. Nelson, J.R. Blair, D.S. Pine, M. Ernst, Neural substrates of choice selection in adults and adolescents: Development of the ventrolateral prefrontal and anterior cingulate cortices, Neuropsychologia 45 (2007) 1270–1279.
[12] S. George, R.D. Roger, T. Duka, The acute effect of alcohol on decision making in social drinkers, Psychopharmacology 182 (2005) 160–169.
[13] F. Jollant, F. Bellivier, M. Leboyer, B. Astruc, S. Torres, R. Verdier, D. Castelnau, A. Malafosse, P. Courtet, Impaired decision making in suicide attempts, Am. J. Psychiat. 162 (2005) 304–310.
[14] A.L. Krain, A.M. Wilson, R. Arbuckle, F.X. Castellanos, M.P. Milham, Distinct neural mechanisms of risk and ambiguity: a meta-analysis of decision making, NeuroImage 32 (2006) 477–484.
[15] D.C. Krawczyk, Contributions of the prefrontal cortex to the neural basis of human decision making, Neurosci. Biobehav. R 26 (2002) 631–664.
[16] T.M.C. Lee, J.X. Zhang, C.C.H. Chan, K.S.L. Yuen, L.W. Chu, R.T.F. Cheung, Y.S. Chan, P.T. Fox, J.H. Gao, Age-related differences in response regulation as revealed by functional MRI, Brain. Res. 1076 (2006) 171–176.
[17] T.M.C. Lee, W.H. Zhou, X.J. Luo, K.S.L. Yuen, X.Z. Ruan, X.C. Weng, Neural activity associated with cognitive regulation in heroin users: a fMRI study, Neurosci. Lett. 382 (2005) 211–216.
[18] D.S. Leland, M.P. Paulus, Increased risk-taking decision-making but not altered response to punishment in stimulant-using young adults, Drug. Alcoh. Depen. 78 (2005) 83–90.
[19] C.S. Li, C. Huang, R.T. Constable, R. Sinha, Gender differences in the neural correlates of response inhibition during a stop signal task, NeuroImage 32 (2006) 1918–1929.
[20] X. Liu, D.K. Powell, H. Wang, B.T. Gold, C.R. Corbly, J.E. Joseph, Functional dissociation in frontal and striatal areas for processing of positive and negative reward information, J. Neurosci. 27 (2007) 4587–4597.
[21] J.A. Maldjian, P.J. Laurienti, R.A. Kraft, J.H. Burdette, An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets, NeuroImage 19 (2003) 1233–1239.
[22] S.B. Manuck, J.D. Flory, J.M. McCaffery, K.A. Matthews, J.J. Mann, M.F. Muldoon, Aggression, impulsivity, and central nervous system serotonergic responsivity in a non-patient sample, Neuropsychopharmacology 19 (1998) 287–299.
[23] J. Miller, K. Flory, D. Lynam, C. Leukefeld, A test of the four-factor model of impulsivity-related traits, Pers. Indiv. Differ. 34 (2003) 1403–1418.
[24] J.T. Nigg, On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy, Psychol. Bull. 126 (2000) 220–246.
[25] J.H. Patton, M.S. Stanford, E.S. Barratt, Factor structure of the Barratt Impulsiveness Scale, J. Clin. Psychol. 51 (1995) 768–774.
[26] M.P. Paulus, N. Hozack, B. Zauscher, J.E. McDowell, L. Frank, G.G. Brown, D.L. Braff, Prefrontal, parietal, and temporal cortex networks underlie decision-making in the presence of uncertainty, NeuroImage 13 (2001) 91–100.
[27] M.P. Paulus, C. Rogalsky, A. Summons, J.S. Feinstein, M.B. Stein, Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism, NeuroImage 19 (2003) 1439–1448.
[28] B.S. Peterson, M.J. Kane, G.M. Alexander, C. Lacadie, P. Skudlarski, H.C. Leung, J. May, J.C. Gore, An event-related functional MRI study comparing interference effects in the Simon and Stroop tasks, Cogn. Brain Res. 13 (2002) 427–440.
[29] M.N. Potenza, H.C. Leung, H.P. Blumberg, B.S. Peterson, R.K. Fulbright, C.M. Lacadie, P. Skdlarski, J.C. Gore, An fMRI stroop task study of ventromedial prefrontal cortical function in pathological gamblers, Am. J. Psychiat. 160 (2003) 1990–1994.
[30] B.B. Quednow, K. Kuhn, C. Hoppe, J. Westheide, W. Maier, I. Daum, M. Wagner, Elevated impulsivity and impaired decision-making cognition in heavy users of MDMA ("Ecstasy"), Psychopharmacology 189 (2007) 517–530.
[31] R.D. Rogers, A.M. Owen, H.C. Middleton, E.J. Williams, J.D. Pickard, B.J. Sahakian, T.W. Robbins, Choosing between small, likely rewards and large, unlikely rewards activates inferior and orbital prefrontal cortex, J. Neurosci. 20 (1999) 9029–9038.
[32] E.T. Rolls, The functions of the orbitofrontal cortex, Brain Cogn. 5 (2004) 11–29.
[33] J.S. Rubinsztein, P.C. Fletcher, R.D. Rogers, L.W. Ho, F.I. Aigbrihio, E.S. Paykel, T.W. Robbins, B.J. Sahakain, Decision-making in mania: a PET study, Brain 124 (2001) 2550–2563.
[34] A.G. Sanfey, J.K. Rilling, J.A. Aronson, L.E. Nystrom, J.D. Cohen, The neural basis of economic decision-making in the ultimatum game, Science 300 (2003) 1755–1758.
[35] W. Schultz, P. Dayan, P.R. Montague, A neural substrate of prediction and reward, Science 275 (1997) 1593–1599.
[36] A. Simmons, I. Strigo, S.C. Matthews, M.P. Paulus, M.B. Stein, Anticipation of aversive visual stimuli is associated with increased insula activation in anxiety-prone participants, Biol. Psychiat. 60 (2006) 402–409.
[37] P.J. Snyder, L.J. Harris, Handedness, sex and familiar sinistrality effects on spatial tasks, Cortex 29 (1993) 115–134.
[38] N. Tzourio-Mazoyer, B. Landeau, D. Papathanassiou, F. Crivello, O. Etard, N. Delcroix, B. Mazoyer, M. Joliot, Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain, NeuroImage 15 (2002) 273–289.
[39] S. Ursu, C.S. Carter, Outcome representations, counterfactual comparisons and the human orbitofrontal cortex: Implications for neuroimaging studies of decision-making, Cogn. Brain Res. 23 (2005) 51–60.
[40] C.A. Winstanley, D.E.H. Theobald, R.N. Cardinal, T.W. Robbin, Contrasting roles of basolateral amygdala and orbitofrontal cortex in impulsive choice, J. Neurosci. 24 (2004) 4718–4722.