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Gains and Losses: A Common Neural Network for Economic Behaviour

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GAINS AND LOSSES: A COMMON NEURAL NETWORK FOR ECONOMIC BEHAVIOUR[1]

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Abstract

Event-related functional magnetic resonance imaging was used to investigate the neural mechanisms underlying intertemporal preference for symmetric gains and losses in certain conditions, by asking subjects to choose between two gains or two losses available at different points in time. Our data suggest that a common system is activated when an immediate reward/punishment is available, irrespectively of the impulsive /reflective behaviour performed by the individual.

Keywords: *intertemporal preferences; gains; losses; certainty; sign effect; functional magnetic resonance imaging; decision-making*

J.E.L. classification: D87**,** D90, D91

According to recent evidence (Frederick et al., 2002), the traditional Discounted Utility model (Samuelson, 1937) has a limited ability to describe realistic models of behaviour and indeed there are several documented empirical regularities that seem to contradict this statement both in certainty and uncertainty conditions. As a result, researchers not only propose alternative models of discounting — particularly, of the hyperbolic type, but also turn to intertemporal preference with the use of neuroscientific tools, such as functional magnetic resonance imaging, to deepen understanding of the neural mechanisms underlying time preference and other decision-making domains.

This study provides support for the existence of one of the best documented anomalies: the *sign effect* or *gain-loss asymmetry*, a behavioural pattern which has been observed not only for monetary choices, but also for non-monetary rewards and punishments (Frederick et al., 2002;Loewenstein and Prelec, 1992;Read, 2004). Specifically, the study investigates the intertemporal preference for symmetric monetary gains and losses in certain conditions and the no wealth effects hypothesis (Dimitri, 2007) with functional magnetic resonance imaging.

Recent evidence on gains and losses has been provided in the economic literature by Thaler (1981) and Benzion et al. (1989), obtaining similar results: implicit discount rates tended to vary inversely with respect to increasing level of size of the outcome and time delay and, most important, were smaller for losses than for gains. Furthermore, studies on non-monetary gains and losses showed that subjects were typically more inclined to pay more for non-immediate rewards and non-delayed punishments (Loewenstein, 1987).

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In recent years, neural mechanisms of intertemporal preference have been also investigated but mainly with respect to rewards or punishments (Berns et al., 2006; Glimcher et al., 2007; Hariri et al., 2006; Kable and Glimcher, 2007; McClure et al., 2007; McClure et al., 2004; Wittmann et al., 2007), in patients (Boettiger et al., 2007), or in non-humans primates (Kim et al., 2008).

Among the above-mentioned studies, McClure et al. (2004) considered intertemporal choice for monetary rewards only showing that this was the result of an integration of two separate neural systems: limbic and paralimbic structures — including the ventral striatum, the medial orbitofrontal cortex, the medial prefrontal cortex, the posterior cingulated cortex, and the left posterior hippocampus, preferentially engaged when an immediate option was available. Lateral prefrontal and the posterior parietal cortex were instead recruited irrespectively from time delay; even if, the activation of these latter regions increased as the delay between the late and the early choice increased. In line with previous studies on intrapersonal dynamic conflict (Laibson, 1997), these findings supported the hypothesis of multiple agents in the evaluation of immediate and delayed choices at a neurobiological level. It appears therefore that the possible competion between the two different neural systems could be responsible for inconsistencies during intertemporal choice behaviours (Frederick et al., 2002).

More recently, McClure et al.'s findings have been confirmed by Xu et al. (2009) who investigated the neural mechanism underlying both monetary rewards and punishments. Xu et al. also showed that the dorsolateral prefrontal cortex, the ventromedial prefrontal cortex, the insula, the thalamus, the posterior parietal cortex, and the striatum were more active in the processing of losses than of gains. Among these regions, only the dorsolateral prefrontal cortex and the posterior parietal cortex were activated during the processing of gains as well as losses.

In spite of these preliminary findings, the neurobiological foundation of intertemporal choice for gains and losses remains largely unknown. To this end, we conducted an fMRI study in which monetary gains and losses were investigated in certain conditions. We also evaluated the effect of the following variables: euro amount, time delay, and percent difference between the two alternatives of choice.

Methods

Twenty-eight right-handed healthy volunteers (14 M, 14 F) took part in the study. Volunteers were not aware on the purpose of the study and did not have a specific economic background. They were instructed that there were no correct answers, but that they were required to state their preferences in a series of positive and negative choice tasks.

Subjects were instructed that at the end of the experiment they would be paid €16 in cash as a participation fee. Subjects were also instructed that they could receive an additional reward which would be paid in the form of a top-up mobile telephone. Specifically, the final reward given to each subject would be determined by the choices they made during the experiment for a maximum of €10. The top-up would be effected on the day calculated as the mean between the time delays of the selected preferences. Subjects were explicitly told that because of this payment scheme they should make choices as though they were the ones they would actually receive. This method of reward was determined in order to tie the monetary incentive to the performance task and also equalize transaction costs. Nevertheless, each participant received a top-up mobile telephone of €10 with a delay of two weeks.

An event-related paradigm was used. In each trial the subjects saw an image showing two different monetary choices (two gains or two losses) presented on either side of the screen for 6 s, with the smaller and more immediate gain/loss always presented on the left. Responses were provided by pressing one of two buttons corresponding to the location of the options on the screen. Three different payoff (5, 15, 30 Euros) were used. The percent difference in Euros between the two choices were 10% and 50% (e.g.: 5€ today or 5,50€ two weeks). The delay between the late and the early choice were the following: today – two weeks, today – 1 month, two weeks- 1 month, 1 month-1 month and 2 weeks.

Data were acquired with a Philips Intera system at 3 Tesla and a gradient-echo echo-planar sequence (repetition time (TR), 2000 ms; echo time (TE), 35 ms; field of view (FOV), 230x230 mm; matrix of acquisition, 80x80 matrix; thickness of the slice, 3 mm). A spin-echo T2-weighted anatomical image was first acquired to enable localization of functional images (TR, 3000 ms; TE, 10 ms; FOV, 230x230 mm; matrix of acquisition, 230x230 matrix; axial slice, 30; thickness of the slice, 3 mm). At the end of each session, 3D anatomical high-resolution images were acquired. The 3D images were of the spin-echo T1-weighted sequence type (TR, 9900 ms; TE, 46 ms; FOV, 256x256 mm; matrix of acquisition, 256x256 matrix; 170 sagittal slices; thickness of the slice, 1 mm). Data were analyzed with SPM5 and group analyses was performed using a random-effect model.

Results

Since no differences were found between the neural networks activated during the processing of gains and losses, a conjunction analysis was conducted. The conjunction analysis showed activation in a large neural network comprising occipital, parietal and prefrontal cortex. Activations were mostly bilateral.

The anterior and posterior cingulate, and the medial orbitofrontal cortex were instead activated for choices in which the gain/loss was available immediately (Figure 1a). These brain regions were obtained as the difference between the areas related to the processing of the option “today” and the areas related to all the other options. Note that we considered as preference for immediate choices, the choices that had an option available immediately and this option was actually selected by the participant.

On the contrary, the occipital and the parietal cortex were recruited for delayed options (Figure 1b). These regions were obtained as the difference between the areas related to the processing of all the other options and the areas related to the option “today”. Moreover, when the more immediate option was selected, increased activity was found in the right lateral and dorsolateral prefrontal cortex. The activation of these regions increased as the delay between the late and the early choice increased (Figure 1c). Areas related to the motor response and the control condition were subtracted in each analysis.

Discussion

A common widespread neural network was activated by processing of gains and losses, suggesting that the same brain structures support every economically relevant behaviour. Regions of the emotional system, namely the posterior cingulate and the medial prefrontal cortex were recruited when an immediate option was available. These brain areas, rich in dopaminergic innervations, have been typically associated with emotional and motivational systems and implicated in addiction, impulsivity, and also processing of different types of reward, including money (Biederman and Faraone, 2002; Biederman and Spencer, 2002; Knutson et al., 2001; Koob and Bloom, 1988; Winstanley et al., 2004). These regions have been also found to increase their activity with reward size and during the processing of the preferred reward (McClure et al., 2004; Rogers et al., 2004; Tom et al., 2007).

In contrast, the occipital and the parietal cortex, in association with the lateral and dorsolateral prefrontal cortex were engaged in delayed choices. These brain regions have been typically associated with high-level processes suggesting that these areas play a role in different cognitive processes, including working memory, representation of numerical quantities, abstract problem solving, attention, future planning, self-control and decision-making (Baker et al., 1996; Cohen et al., 1997; Dehaene et al., 1998; Figner et al., ; Huettel et al., 2005; Kim et al., 2009; Miller and Cohen, 2001; Paulus et al., 2002; Platt and Glimcher, 1999; Smith and Jonides, 1999; Tanji and Hoshi, 2001; Watanabe et al., 2005)

All in all, the present data are in line with previous functional results, providing further evidence regarding the existence of a dual-system model for the evaluation of immediate and delayed outcomes (McClure et al., 2007; McClure et al., 2004; Tanaka et al., 2004; Xu et al., 2009). It should be noted that other studies (Glimcher et al., 2007; Kable and Glimcher, 2007), in line with single-system models, showed that the limbic system was not specifically recruited for choices in which the reward was available immediately. On the other hand, evidence for multiple-system models is supported in different literary sources (for a review see Kalenscher and Pennartz, 2008) and also by neuroimaging experiments not only in the field of time preference for monetary outcomes but also in decision-making under uncertainty and social decision-making (for a review see Loewenstein et al., 2008), and for primary rewards tasks (McClure et al., 2007).

Despite these disagreements, the neurobiological investigation of time preference — considering jointly gains and losses, is only at its initial stage. To our knowledge, only Xu et al. (2009) investigated the neural mechanisms underlying intertemporal choice for monetary rewards and punishments, in certain conditions, by means of functional imaging techniques. Further research is needed to clarify the conditions and the variables that could differentiate neural networks underlying the processing of positive and negative outcomes. Meanwhile, under the experimental conditions applied here we can concluded that: (1) irrespective of the other variables investigated, different circuits were activated according to the availability of the option (gain/loss) in time and (2) decision-making processes recruited a common neural system during the processing of gains and losses.

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References

Baker, S.C., Rogers, R.D., Owen, A.M., Frith, C.D., Dolan, R.J., Frackowiak, R.S., Robbins, T.W., 1996. Neural systems engaged by planning: a PET study of the Tower of London task. Neuropsychologia 34, 515-526.

Benzion, U., Rapoport, A., Yagil, J., 1989. Discount rates inferred from decisions: an experimental study. Management Science 35, 270-284.

Berns, G.S., Chappelow, J., Cekic, M., Zink, C.F., Pagnoni, G., Martin-Skurski, M.E., 2006. Neurobiological substrates of dread. Science 312, 754-758.

Biederman, J., Faraone, S.V., 2002. Current concepts on the neurobiology of Attention-Deficit/Hyperactivity Disorder. Journal of Attention Disorders 6 Suppl 1, S7-16.

Biederman, J., Spencer, T., 2002. Methylphenidate in treatment of adults with Attention-Deficit/Hyperactivity Disorder. Journal of Attention Disorders 6 Suppl 1, S101-107.

Boettiger, C.A., Mitchell, J.M., Tavares, V.C., Robertson, M., Joslyn, G., D'Esposito, M., Fields, H.L., 2007. Immediate reward bias in humans: fronto-parietal networks and a role for the catechol-O-methyltransferase 158(Val/Val) genotype. The Journal of Neuroscience 27, 14383-14391.

Cohen, J.D., Perlstein, W.M., Braver, T.S., Nystrom, L.E., Noll, D.C., Jonides, J., Smith, E.E., 1997. Temporal dynamics of brain activation during a working memory task. Nature 386, 604-608.

Dehaene, S., Dehaene-Lambertz, G., Cohen, L., 1998. Abstract representations of numbers in the animal and human brain. Trends Neuroscience 21, 355-361.

Dimitri, N., 2007. A note on the reward-loss duality in time consistent decisions. University of Siena, Department of Economic Policy, Finance and Development, Working paper 8.
Figner, B., Knoch, D., Johnson, E.J., Krosch, A.R., Lisanby, S.H., Fehr, E., Weber, E.U., Lateral prefrontal cortex and self-control in intertemporal choice. Nature Neuroscience 13, 538-539.

Frederick, S., Loewenstein, G., O'Donoghue, T., 2002. Time discounting and time preference: a critical review. Journal of Economic Literature 40, 351-401.

Glimcher, P.W., Kable, J., Louie, K., 2007. Neuroeconomic studies of impulsivity: now or just as soon as possible? The American Economic Review 97, 142-147.

Hariri, A.R., Brown S. M., Willamson D. E., Flory J. D., de Wit H., B., M.S., 2006. Preference for immediate over delayed rewards is associated with magnitude of ventral striatal activity. The Journal of Neuroscience 26, 13213-13217.

Huettel, S.A., Song, A.W., McCarthy, G., 2005. Decisions under uncertainty: probabilistic context influences activation of prefrontal and parietal cortices. The Journal of Neuroscience 25, 3304-3311.

Kable, J.W., Glimcher, P.W., 2007. The neural correlates of subjective value during intertemporal choice. Nature Neuroscience 10, 1625-1633.

Kalenscher, T., Pennartz, C.M., 2008. Is a bird in the hand worth two in the future? The neuroeconomics of intertemporal decision-making. Progress in Neurobiology 84, 284-315.

Kim, S., Hwang, J., Lee, D., 2008. Prefrontal coding of temporally discounted values during intertemporal choice. Neuron 59, 161-172.

Kim, S., Hwang, J., Seo, H., Lee, D., 2009. Valuation of uncertain and delayed rewards in primate prefrontal cortex. Neural Networks 22, 294-304.

Knutson, B., Fong, G.W., Adams, C.M., Varner, J.L., Hommer, D., 2001. Dissociation of reward anticipation and outcome with event-related fMRI. Neuroreport 12, 3683-3687.

Koob, G.F., Bloom, F.E., 1988. Cellular and molecular mechanisms of drug dependence. Science 242, 715-723.

Laibson, D., 1997. Golden Eggs and Hyperbolic Discounting. Quarterly Journal of Economics and Philosophy 112, 443-477.

Loewenstein, G., 1987. Anticipation and the valuation of delayed consumption. The Economic Journal 97, 666-684.

Loewenstein, G., Prelec, D., 1992. Anomalies in intertemporal choice: evidence and interpretation. The Quarterly Journal of Economics 107, 573-597.

Loewenstein, G., Rick, S., Cohen, J.D., 2008. Neuroeconomics. Annual Review of Psychology 59, 647-672.

McClure, S.M., Ericson, K.M., Laibson, D.I., Loewenstein, G., Cohen, J.D., 2007. Time discounting for primary rewards. The Journal of Neuroscience 27, 5796-5804.

McClure, S.M., Laibson, D.I., Loewenstein, G., Cohen, J.D., 2004. Separate neural systems value immediate and delayed monetary rewards. Science 306, 503-507.

Miller, E.K., Cohen, J.D., 2001. An integrative theory of prefrontal cortex function. Annual Review of Neuroscience 24, 167-202.

Paulus, M.P., Hozack, N., Frank, L., Brown, G.G., 2002. Error rate and outcome predictability affect neural activation in prefrontal cortex and anterior cingulate during decision-making. Neuroimage 15, 836-846.

Platt, M.L., Glimcher, P.W., 1999. Neural correlates of decision variables in parietal cortex. Nature 400, 233-238.

Read, D., 2004. Intertemporal choice. In: Koehler, D. Harvey N. (Eds.), Blackwell Handbook of Judgment and Decision Making. Blackwell, Oxford, pp. 424-443.

Rogers, R.D., Ramnani, N., Mackay, C., Wilson, J.L., Jezzard, P., Carter, C.S., Smith, S.M., 2004. Distinct portions of anterior cingulate cortex and medial prefrontal cortex are activated by reward processing in separable phases of decision-making cognition. Biological Psychiatry 55, 594-602.

Samuelson, P. A., 1937. A note on measurement of utility. Review of Economic Studies 4, 155-161.

Smith, E.E., Jonides, J., 1999. Storage and executive processes in the frontal lobes. Science 283, 1657-1661.

Tanaka, S.C., Doya, K., Okada, G., Ueda, K., Okamoto, Y., Yamawaki, S., 2004. Prediction of immediate and future rewards differentially recruits cortico-basal ganglia loops. Nature Neuroscience 7, 887-893.

Tanji, J., Hoshi, E., 2001. Behavioral planning in the prefrontal cortex. Current Opinion in Neurobiology 11, 164-170.

Thaler, R.H., 1981. Some empirical evidence on dynamic inconsistency. Economic Letters 8, 201-207.

Tom, S.M., Fox, C.R., Trepel, C., Poldrack, R.A., 2007. The neural basis of loss aversion in decision-making under risk. Science 315, 515-518.

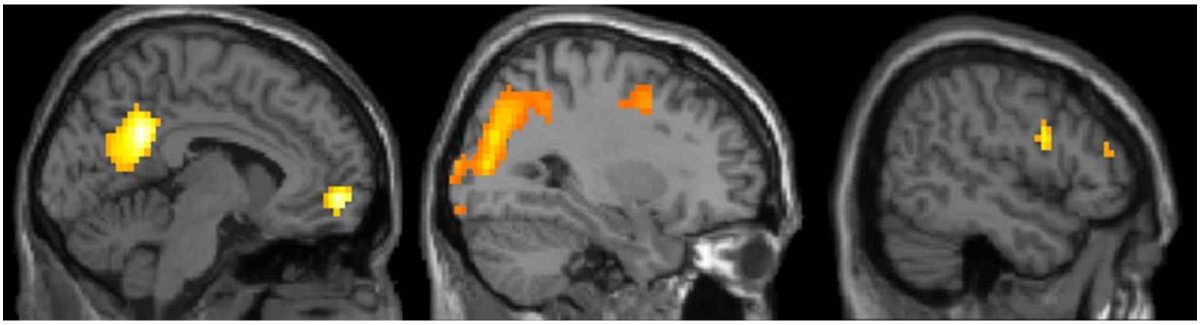
Watanabe, M., Hikosaka, K., Sakagami, M., Shirakawa, S., 2005. Functional significance of delay-period activity of primate prefrontal neurons in relation to spatial working memory and reward/omission-of-reward expectancy. Experimental Brain Research 166, 263-276.

Winstanley, C.A., Theobald, D.E., Cardinal, R.N., Robbins, T.W., 2004. Contrasting roles of basolateral amygdala and orbitofrontal cortex in impulsive choice. The Journal of Neuroscience 24, 4718-4722.

Wittmann, M., Leland, D.S., Paulus, M.P., 2007. Time and decision making: differential contribution of the posterior insular cortex and the striatum during a delay discounting task. Experimental Brain Research 179, 643-653.

Xu, L., Liang, Z.Y., Wang, K., Li, S., Jiang, T., 2009. Neural mechanism of intertemporal choice: from discounting future gains to future losses. Brain Research 1261, 65-74.

Figure 1. Brain regions that are activated for item in which the monetary choice was available immediately (a) or was delayed in time (b,c). Clusters are superimposed on the SPM5's template.



a **b** **c**

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