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Current Opinion in Neurobiology

Neuroeconomics: what have we found, and what should we search for

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Neuroeconomics is an interdisciplinary field, crossing boundaries between Economics, Psychology, and Neuroscience. Its original program was to provide a test for a large number of competitive theories of decision making. It has in part realized this program, and we review the main findings here. But its results are also posing the need for a new theoretical unifying framework. We outline a possible line of future research.

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Current Opinion in Neurobiology 2009, **19**:672–677

This review comes from a themed issue on
Neurobiology of behaviour
Edited by Catherine Dulac and Giacomo Rizzolatti

Available online 4th November 2009

0959-4388/$ – see front matter

DOI 10.1016/j.conb.2009.09.012

Introduction

Neuroeconomics [1,2] is the application of conceptual structure and experimental techniques widely used in Neuroscience to the study of economic behavior. This is a young discipline, but has been very active in the last decade. It is time to take some stock, see what has been learned, and where we move on now. We focus in this survey on the study of economic decision that a single agent takes in isolation. Economic analysis views this as the process in which an individual chooses between different possible streams of consumption that occur in the future, when these streams are not certain but random.

For example, an important economic choice is the selection of a university degree: each has associated future stream of income and consumptions, all occurring at some date, and not necessarily certain, because they depend on our skill, the labor market, the evolution of laws regulating the profession and so on. A choice of a degree is really a choice among different future streams of uncertain rewards.

Decision Theory is the theory of individuals making such decisions. Implicit in the classical view of Decision Theory [3,4] were several principles that we recall briefly.

a. Common currency: we make choices between objects that are sometimes of very different nature. A central idea of economic analysis is that when we make decisions, we first translate the rewards offered by each option into a common currency, then compare the two different quantities (utilities) and pick the option with the highest utility.
b. Precise beliefs: the probability over events may be given to us (e.g. when we toss a dice), or we may have to formulate it ourselves (e.g. when we bet on the stock market): so we may be unsure about the probability of different events. But we should always be able to assign one, and our choices should reflect this well-defined probability, assigning less weight to the rewards obtained in unlikely events.
c. Integration of outcomes: we evaluate uncertain outcomes taking into account our final wealth, obtained by adding the current reward and the existing wealth. Let us call a lottery any random device that assigns monetary prizes with some probability. If we are facing the draw of two consecutive lotteries, one which is almost certain to give a loss of nine dollars, and the other almost certain to give a gain of ten, we might console ourselves that this is almost surely a net gain of one dollar, and we should choose this sequence of two lotteries over nothing for sure. If we do this, we integrate the outcomes keeping an eye on the final wealth position, and ignore the wins and losses along the way.
d. Planning decomposition: When we plan for the future, we evaluate the utility of a stream of consumption as the resultant of the aggregation of an immediate utility next period and the prospective utility from the consumption form the second period on; this prospective utility function is the same as the current utility function from the consumption form the first period on; this prospective utility is the same as the current utility. In an extremely simple version, this model is reduced to simple sum of the utility in every period, with a single discount factor [4].
e. Bygones are bygones: if we choose between lottery A and B, select A, observe the outcome of both, and find that B had a larger outcome, we should typically choose again A if asked to a second time, unless we learned something we did not know, for example if we have no reason to change the probability we attach to events. The second time over the choice is exactly the

same, and the reasons for making that choice the first time are still there: there is no regret, nor self-congratulation.

Two-dimensional man

The classical view of the decision process reduces preferences that satisfy these principles to two parameters: our attitude to risk and our attitude to the tradeoff between rewards in different points in time. 'Parameter' has to be taken in a more general meaning than 'real number': a utility function is a parameter. We can now state the last assumption of the classical model:

f. Independence: the two parameters are independent. There is no correlation between attitude to risk and impatience. There is no correlation between the two parameters and other fundamental features of an individual, first and foremost intelligence.

Several substantial extensions of this classical model have been suggested; extensions motivated at least as much by the acumen of the decision theorists than by the relentless beating of the experimental evidence, as one can see from the fact that the classical paradoxes — Allais' [5], Ellsberg's [6], Strotz's spendthriftiness and commitment [7], and Bell–Loomes–Sugden's regret [8,9] — are all based on *thought* experiments, anecdotal evidence, or introspection. Paradoxes are statements defying intuition provided by a theory, and Allais' paradox would not exist without the independence axiom.

The thought experiment presented in Ellsberg [6] asks a subject to choose among lotteries when the probability of the events is not precisely defined. Subjects asked to choose display a specific aversion to undefined probabilities, and their choices have a disturbing feature: there is no belief on the possible states of the world that can explain the behavior of the subjects according to expected utility theory; instead they behave as if a malevolent nature chose a probability over events to minimize their utility. The modeling of ambiguity aversion removed the assumption of a precise belief and replaced the single belief with a set [10], or the cost of nature to harm the decision maker [11].

Abandoning the integration assumption is one of the main innovations in Prospect Theory (PT [12•]), a theory of decision making based on three distinct assumptions. First, individuals evaluate each prospect (which may be taken here to be the same as lottery) from a reference point: they value changes in wealth and welfare, not final states. Second (loss aversion): in this evaluation, gains loom larger than losses; the loss of utility from monetary loss of one dollar matters more than the gain of one dollar. Third (risk sensitivity): utility is evaluated according to the principle that changes in subjective responses decline with the size of the stimulus. If the reference point is zero then the value function is concave above zero (risk aversion in gains) and convex below (risk loving in losses).

The recognition that future planning may produce inconsistencies came early [7]: an individual planning today and free to reconsider his plan at later date may later prefer to deviate from his plan, even if his original expectations of future means and desires are verified. When utility is time separable, he will follow the plan if and only if he discounts the future with exponential discount. This time inconsistency in planning does not require dual systems, or lack of self-control, to occur: planning at successive points in time aligns if and only if the discounting is exponential. When inconsistency occurs, a theory is needed to predict how the individual will decide: a solution to the problem has been provided [13,14]. A systematic study of regret was introduced in economic analysis in the papers of Bell [8] and Loomes and Sugden [9].

The research program in Neuroeconomics began, and in large measure still is, a systematic test of theories that have been presented in the past, the determination of the neural structures underlying the choice process, and a reconstruction of the process itself. Our survey will first explore the main results that have been achieved in the past, on the basis of the brief summary we have just given; it will then explore some recent developments and what they may lead to.

What have we learned

Existence of a common currency for economic evaluations has found strong support, from both evidence gathered in fMRI experiments [15•] and single neuron recording in monkeys.

The activity of individual neurons from the Orbito-frontal Cortex (OFC) was recorded [16,17] while monkeys were choosing among offers of juices of different types and quantities. In the analysis of data, first the subjective value (utility) for each monkey in each experimental session was estimated fitting a sigmoid to the observed choices. If for instance the monkey chose with equal probability four units of juice A (say, water) and one unit of juice B (unsweetened Kool-Aid), then the value of B was estimated to be around four times the value of A. The utility of the two options presented in each trial was computed, and correlated with neurons' activity. Firing rate of neurons in the OFC was correlated with the utility of the options: neurons of the OFC code subjective value of the goods. The firing rate was instead invariant with respect to the side in which the option was presented, and hence of the action chosen by the animal to select the same good in different trials: value encoding is good-based, instead of action based. The same experiment shows that the firing rate is also menu invariant [18]: namely, independent of what other goods are presented as the other option.

The method adopted in these experiments [16,18] is an example of the psychometric–neurometric method [19•], which has wide generality. In sensory perception, neural activity codes a subjective response to a stimulus, not its objective properties. For example, in the perception of weight, doubling a weight only increases by a smaller amount of the sensory response by the subject. Researchers should then study the relationship between neural (e.g. firing rate [16]) and psychological measurements (subjective value, for economic decisions), the latter derived from the observation of behavior, choice in our case.

Menu independence does not exclude the possibility that coding of economic value depends on the general context of a choice. Tobler *et al.* [20] measured the activity of dopamine neurons at the time of delivery of reward. At the beginning of the trial a cue signaled to the monkey the size of a reward to be delivered with 50% probability after a time interval. The size of the reward varied, with a ratio of 10 between largest and smallest. However, the magnitude of the activation at reward was similar in all trials, independently of the size of the reward: the neuron had adapted during to the time interval to the information provided by the cue. Such adaptive coding fulfills a basic need: while the range of rewards is unlimited, the discriminatory ability of the brain is finite, so its effectiveness is increased if it is allocated over the most likely range of rewards, as in visual perception [21].

The other topics have been more controversial, and a consensus is still far. The study of the neural system underlying choice of rewards over time provides a clear example. The hypothesis that separate neural systems, limbic and prefrontal, value immediate and delayed rewards respectively is proposed and tested by McClure *et al.* [22•]. Subjects choose between an earlier reward R at date d and a later reward R' at date d'. Rewards are monetary, but similar results hold for primary rewards [23]; also $d' > d$, and $R' > R$ (higher payments later); d may be zero (immediate payment) or strictly positive. The initial hypothesis leads to the prediction that choice pairs where $d = 0$ will be associated with higher activation in the limbic system, as compared to those where $d > 0$; second, prefrontal activation should occur in both types of choices; and, third, such activity should be stronger when the delayed option is selected. These predictions are largely supported.

Analysis of the neural system underlying evaluation of rewards in time according to the psychometric–neurometric method leads Kable and Glimcher [19•] to different conclusions. First, the discounting of each subject is determined from choices: there are substantial individual differences, but a hyperbolic discounting provides a good fit. If this subjective value, estimated for each individual, is used as a regressor, then brain regions are determined that have an activity proportional to the value, independently of the discounting of the individual. These regions are those identified as coding immediate rewards [22•]: ventral striatum, medial prefrontal cortex, and posterior cingulated cortex. The activity in these regions is decreasing in the length of the delay of the offered payment, independently of the discount rate. These results suggest a unitary, instead of dual, system of evaluation of intertemporal rewards. This conclusion does not exclude the possibility of time inconsistency. In fact, since [19•] the estimated discounting is hyperbolic, decision will produce deviation from past plans, according to the Strotz's criterion. How these inconsistencies are managed is not discussed.

Similar diversities arise in the conclusion of the analysis of the neural basis of the processes arise in ambiguity [24] as well as gains and losses [25,26,27•,28–30]. A neural basis of regret has been determined [31•,32]: the key idea is that regret involves counterfactual thinking, and OFC codes specifically personal responsibility for the counterfactual event.

Five-dimensional man

The classical [3,4] theory of human economic decision making is a two-dimensional personality theory: attitudes to risk and to intertemporal tradeoffs summarize the essential features of an individual, and suffice to provide predictions on his future behavior and response to policy changes. The limitations of this model had been proved by theoretical analysis and experimental testing, and Neuroeconomics has contributed to this clarification. There is however less agreement on what will replace that model and what a complete theory of human decision making should be. This theory will probably not be a correction or an extension of the classical theory. Consider for example loss aversion. If defined rigorously by revealed preferences [33] loss aversion is characterized by a property of the value function for monetary payments arbitrarily close to zero (because it is defined by the ratio between its left and right hand derivative at zero). This seems to make the experimental test very difficult. The intuitive idea behind loss aversion is probably different, and is usually understood as the expression of different systems handling the response to rewards and punishments. Similarly, the role of factors like intelligence in decision making as well as in social and strategic behavior is beginning to be clear in experimental and empirical research (see below) but does not find room in the structure of classical theory.

A more general view is implicit in the analysis of individual behavior as shaped by personality traits, and there is now a wide consensus around their structure. Although personality theory is a theory of individual differences, understanding what generates these differences means understanding the process underlying decision. Even if one is not interested in individual differences in attitude to gains and losses, one will provide an understanding of how attitudes to gains and losses work. The neural basis of personality traits is now being studied systematically, and surveys of what we know are already available [34].

What do we know of personality traits and economic decision making? This time, experiments and empirical work have been ahead of theory. First, personality traits are very powerful in predicting economic outcomes. Comparing [35•] the effect of personality traits on three important life outcomes (mortality, divorce and marital stability, educational and occupational attainment) with other predictors (Socio-Economic Status (SES) and IQ), demonstrates that the average effects of personality is comparable or larger to the effects of SES and IQ. This idea is now inspiring active research in economics: a recent survey [36] reviews the implications for economic research. Some of the implications may be unexpected: biological markers associated with personality traits may affect profitability and survival of traders in financial markets [37].

Among personality traits, cognitive skills, and intelligence have a special status. Meta-analysis of past research [38•] shows that impatience in intertemporal choice tasks, or Delayed Discounting (DD) correlates negatively with cognitive ability. Recent studies suggest that the correlation extends beyond intertemporal choice to fundamental characteristics of economic preferences: independence between risk attitude and time preferences is probably false. Cognitive skills measured by intelligence (e.g. by Raven's matrices) and numeracy correlate negatively with impatience in a DD task, and positively with willingness to take risk in a lottery choice task [39]. They also correlate positively with cooperative behavior in a trust game.

What produces such correlations? For intertemporal preferences, in Shamosh *et al.* [40] data on impatience (DD), performance in the *n*-back recall working memory (WM) task, intelligence (*g*), and fMRI analysis of correlation of brain activation and WM were gathered. WM and *g* explain equally well DD, suggesting that the processes relating WM to DD are the same as for *g*. Brain activity in regions associated with performance in WM task (most notably, anterior prefrontal cortex) covary negatively with impatience; WM-related activity also partially mediated the effect of *g*) on DD. If one accepts the theory that decisions in intertemporal problems recruit two distinct neural systems [22•], then the role of these cognitive skill is to allow a better integration of the signals from these two systems. Alternatively, rewards in the future are harder to evaluate, hence subjects with reduced cognitive skills are less likely to select them. But recent evidence [39], showing that the correlation of cognitive ability and discounting is similar for short-term and long-term discounting, seems to offer support for the alternative theory. In addition the simultaneous correlation of cognitive skill and preferences in different domains show that the effect of cognitive skills on preferences has still to be understood. For example, higher cognitive skills reduce loss aversion, as well as the difference in risk sensitivity in gain and loss domain.

The transition from a two-dimensional to a five-dimensional view of human decision making requires a theory, and its experimental testing. This might be a future direction for Neuroeconomics.

Acknowledgements

This research is supported by the NSF (SES-0924896) and ESRC/MRC.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest

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3. Savage LJ: *The Foundation of Statistics*. 1972 edition. Dover Publications, Inc.; 1954.
4. Koopmans TC: **Stationary ordinal utility and impatience**. *Econometrica* 1960, **2**:287-309.
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6. Ellsberg D: **Risk, ambiguity, and the savage axioms**. *Q J Econ* 1961, **75**:643-669.
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8. Bell DE: **Regret in decision-making under uncertainty**. *Oper Res* 1982, **30**:961-981.
9. Loomes G, Sugden R: **Regret theory: an alternative theory of rational choice under uncertainty**. *Econ J* 1982, **92**:805-824.
10. Gilboa I, Schmeidler D: **Maxmin expected utility with non-unique prior**. *J Math Econ* 1989, **18**:141-153.

The paper provides an axiomatic foundation of ambiguity aversion, first introduced informally by Ellsberg [6], extending the expected utility analysis to include behavior exhibited in the Ellsberg's paradox. In the representation of preferences, the single belief in expected utility is replaced by a set of beliefs: when the decision maker contemplates the value of an action, he assumes the pessimistic attitude that events will occur under the worse possible scenario in this set.

11. Maccheroni F, Marinacci M, Rustichini A: **Ambiguity aversion, robustness, and the variational representation of preferences**. *Econometrica* 2006, **74**:1447-1498.
12. • Kahneman D, Tversky A: **Prospect theory — analysis of decision under risk**. *Econometrica* 1979, **47**:263-291.

This classic paper introduces several extension to the classical model [3] of decision under uncertainty. First, the choice process has two phases: the first (editing) performs a preliminary analysis of a prospect, and offers a simpler representation. In this phase heuristics and biases occur. In the second (evaluation) the value of a prospect is estimated. Differently from expected utility, the probability enters nonlinearly into the evaluation of the prospect, and the value function has zero as the reference point, exhibits loss aversion, and decreasing response to size of the stimulus. We focus on the latter set of innovations in this paper.

13. Pollack, Phelps E: **On second-best national savings and game-equilibrium growth**. *Rev Econ Stud* 1968, **35(2)**:185-199.

Given that an individual with discounting that is not exponential may revise his earlier plans when the later date occurs, a theory of how decisions are made is necessary. The authors reject the idea that the decision maker will never come to term with his inconsistencies, and instead introduce the idea that the decision at time t is made by anticipating future deviations.

14. Laibson D: **Golden eggs and hyperbolic discounting**. *Q J Econ* 1997, **2**:443-477.

15. • O'Doherty JP: **Lights, camembert, action! The role of human orbitofrontal cortex in encoding stimuli, rewards and choices**. *Ann N Y Acad Sci* 2007, **1121**:254-272.

A survey of the recent results on the role of human OFC in human decision making. Five main and distinct functions are outlined. First, OFC encodes the values of the stimuli that are presented to the subjects. Second, OFC maintains the representation of the expected rewards. Third, OFC also participates in learning, receiving and processing prediction error signals from dopamine neurons. Fourth, OFC uses some knowledge of the structure of the problem to guide predictions of future rewards. Fifth, OFC may compute the chosen action, and represent the value of the action in light of the experience.

16. Padoa-Schioppa C, Assad JA: **Neurons in the orbitofrontal cortex encode economic value**. *Nature* 2006, **441**:223-226.

17. Tremblay L, Schultz W: **Relative reward preference in primate orbitofrontal cortex**. *Nature* 1999, **398**:704-708.

18. Padoa-Schioppa C, Assad JA: **The representation of economic value in the orbitofrontal cortex is invariant for changes of menu**. *Nat Neurosci* 2007, **11(1)**:95-102.

19. • Kable JW, Glimcher PW: **The neural correlates of subjective value during intertemporal choice**. *Nat Neurosci* 2007, **10**:1625-1633.

Subjects in the experiment choose in every trial between an immediate payment of \$20, or a later payment of amounts ranging from \$20.25 to \$110, with delays from 6 hours to 180 days. In the notation of McClure *et al.*, [22•], $d = 0$ in every trial, so direct comparison between the two experiments is difficult. The best fit in the analysis of choices is provided by the hyperbolic model, where the subjective value of the amount x at date D is $VS = x/(1 + kD)$ so the utility function of the monetary values is assumed to be linear ($u(x) = x$). From Strotz's result, a decision maker with this utility will face time inconsistency, even if the evaluation at each point in time is done by a unitary evaluation system.

20. Tobler PN, Fiorillo CD, Schultz W: **Adaptive coding of reward value by dopamine neurons**. *Science* 2005, **307**:1642-1645.

21. Laughlin SB: **A simple coding procedure enhances a neuron's information capacity**. *Zeitschrift fuer Naturforschung* 1981, **36c**:910-912.

Interneurons in fly's eye code visual stimuli according to histogram equalization: the response function transforms the typical distribution in the fly's environment into the uniform distribution. This enables the neurons to encode contrast fluctuations most efficiently.

22. • McClure S, Laibson D, Lowenstein G, Cohen J: **Separate neural systems value immediate and delayed rewards**. *Science* 2004, **306**:503-507.

The main hypothesis and experimental design are described in the text. Data are analyzed as follows. A β-regressor is equal to 1 on the decision epochs in trails where $d = 0$, and equal to $1/2$ when $d > 0$; a δ-regressor is equal to 1 in all decision epochs. Both regressors are 0 in baseline conditions. The authors then introduce the concept of 'difficult' decisions (those made in trials in which the percentage difference between the early and late payment was less than 0.35 or larger than 0.03), 'under the assumption that areas involved in decision making would be engaged to a greater degree (and therefore exhibit greater activity) by more difficult decisions'. This idea identifies regions that are active in all decisions, only more so in the harder ones. So two possible explanations seem possible: the δ system is required to integrate signals from two separate systems, or rather a system solving better a more difficult problem, and not so much as involved in self-control.

23. McClure SM, Ericson K, Laibson DI, Loewenstein G, Cohen JD: **Time discounting for primary rewards**. *J Neurosci* 2004, **27(21)**:5796-5904.

24. Hsu M, Bhatt M, Adolphs R, Tranel D, Camerer CF: **Neural systems responding to degrees of uncertainty in human decision-making**. *Science* 2005, **310**:1680-1683.

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26. Dickhaut J, McCabe K, Nagode J, Rustichini A, Smith K: **The impact of the certainty context on the process of choice**. *Proc Natl Acad Sci* 2003, **100(6)**:3536-3541.

27. • Tom SM, Fox CR, Trepel C, Poldrack RA: **The neural basis of loss aversion in decision-making under risk**. *Science* 2007, **315**:515-518..

Subjects in the experiment saw in each trial a lottery of two outcomes, a gain (range from \$10 to \$40) and a loss (range from $-$\$5 to $-$\$20), with equal probability. They had to choose between the lottery and zero payment for sure. Analysis of behavior was based on logistic estimate, using a piecewise linear function with slopes β_{loss} and β_{gain}. Analysis of neural data focused on the decision event, using values of outcomes as main regressors. Since gains and losses varied independently across the pairs of outcomes, a test of the separate effect of gains and losses is possible. Main results: first, there is no response to increasing losses of the brain regions associated with fear, vigilance, and discomfort. Second, a group of regions including striatum, ventro medial prefrontal cortex, ventral anterior cingulate, and medial OFC showed increasing activity for gains and decreasing activity for losses. The piecewise linear function is a standard concave utility function: the kink at the origin plays no role in the analysis of the data, and could be replaced with a smooth pasting of the two branches, so it is not clear why this is a test of loss aversion rather than risk aversion.

28. De Martino B, Kumaran D, Seymour B, Dolan RJ: **Frames, biases and rational decision-making in the human brain**. *Science* 2006, **313**:684-687.

A study of framing of choices in gains and losses environments. Subjects first see an initial amount £A, and have then to choose between a lottery with outcomes A (described as 'keep all') and 0 ('lose all'), and a sure amount a smaller than A. Framing is introduced by presenting the amount a as 'Keep a' (gain frame) or 'Lose $A - a$' (loss frame). Behavioral analysis shows that the lottery is chosen more frequently in the loss frame than in the gain one. Analysis of brain data focuses on the interaction between frames and decision, with four main regressors $(G,S), (G,R), (L,S), (L,R)$ (where (G,S) is choice of Safe in Gain frame, and (L,R) is choice of the lottery (risky) in Loss domain, and so on. The difference between contrast between $(G,S) - (G,R)$ and $(L,S) - (L,R)$ is a measure of the sensitivity to framing, and amygdala is the most prominent region identified by the contrast. Orbital and medial prefrontal cortex activity predicted a smaller sensitivity to the framing effect.

29. Liu X, Powell DK, Wang H, Gold BT, Corbly CR, Joseph JE: **Functional dissociation in frontal and striatal areas for processing of positive and negative reward information**. *J Neurosci* 2007, **27**:4587-4597.

30. Kuhnen CM, Knutson B: **The neural basis of financial risk taking**. *Neuron* 2005, **47**:763-770.

31. • Camille N, Giorgio Coricelli G, Jerome Sallet GJ, Pradat-Diehl P, Duhamel R, Sirigu A: **The involvement of the orbitofrontal cortex in the experience of regret**. *Science* 2004, **304**:1167-1170.

The study compares choices and self-reported measures of emotional responses, for both normal subjects and OFC patients, who observe outcomes of binary lotteries they have previously chosen. The key comparison is between the partial and complete feedback treatment. In partial feedback subjects observe only the outcome of the lottery they chose, so they can check whether the obtained outcome is smaller than the other, unobtained, outcome of the same lottery (inducing disappointment). Whether one or the other of these two outcomes obtains does not involve their previous decision. In complete feedback they can observe the outcome of both lotteries, so they can check what they could have received had they made a different choice (regret). Normal subjects respond to both disappointment and regret, and choose to minimize future regret. Instead, patients only respond to disappointment, and do not anticipate negative consequences of their choices. OFC codes valuation of outcomes depending on personal responsibility of the individual.

32. Coricelli G, Critchley HD, Joffily M, O'Doherty JP, Sirigu A, Dolan RJ: **Regret and its avoidance: a neuroimaging study of choice behavior**. *Nat Neurosci* 2005, **8**:1255-1262.

A fMRI study based on the experimental design of Camille *et al.* [31•]. OFC is found to code regret as well as relief, that is positive emotion associated with an obtained outcome larger than the counterfactual one.

33. Köbberling V, Wakker P: **An index of loss aversion**. *J Econ Theory* 2005, **122**:119-131.

An index of loss aversion should measure how losses are more prominent in the individual's utility than gains, invariant to monotonic transformations of the utility function. The utility function is defined on positive and negative monetary prizes. One may define such utility as $U(x) = u(x)$ for positive x's and $U(x) = \lambda u(x)$ for negative ones, and interpret λ as a measure of loss aversion. But a simple redefinition of $u^*(x) = \lambda u(x)$ for negative x's would then give an equivalent representation with loss aversion parameter equal to 1. In other words, even if the utility function U is uniquely determined for negative values, the λ and the u factors cannot be determined separately. To address this problem, the authors define an index of loss aversion as the ratio of the right and left derivative of the utility at 0, namely: $\lambda \equiv (\lim_{x \uparrow 0} u'(x))/(\lim_{x \downarrow 0} u'(x))$. This index is invariant with respect to monotonic transformations.

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• **power of personality: the comparative validity of personality traits, socioeconomic status, and cognitive ability for predicting important life outcomes**. *Perspect Psychol Sci* 2007, **2(4)**:313-345.

A reevaluation of how well personality traits affect outcomes, after the criticism of Walter Mischel's 1968 book, in particular as compared to effects of situations. The effects in the studies were either standardized regression coefficients (in studies with continuous outcomes) or some form of odd ratios (in studies with categorical outcomes). Personality traits are aggregated into broad Big Five categories (Conscientiousness (C), Positive Emotions/Extraversion (E), Neuroticism/Negative Emotion (N), Hostility/Disagreebleness (D)). Most of the effects are natural: for example C and E have a positive effect on life span, and N and D a negative one. The average effects in the correlation metric of personality traits are low for mortality, higher for divorce and educational and occupational attainment.

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37. Coates J, Gurnell M, Rustichini A: **Second to fourth digit ratio predicts success among high-frequency financial traders**. *Proc Natl Acad Sci* 2009, **106(2)**:623-628.

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• **meta-analysis**. *Intelligence* 2008, **36**:289-305.

A meta-analysis of the relation between intelligence and delayed discounting, including 24 studies. The most important inclusion criteria were: intelligence had to be measured with a standard test or one readily convertible into one (e.g. an SAT test); the study had to report a size effect, the DD had to be measured by an explicit choice involving a tradeoff between size and delay of the reward. A study was excluded if IQ and DD data were not for the same sample. Time preference measures were either the number of delayed choices made, or parameter estimates of discount factor. Mean age of subjects ranged from 4 years to 45. Findings: the weighted mean effect size, with fixed effects, was $r = -0.246, P < 0.001$ (with random effects $r = -0.246, P < 0.001$); the correlation is negative, and small to medium size in Cohen's classification. No moderator effect of hypothetical *versus* real rewards, or DD measure, or type of intelligence was found. The effect size was substantially smaller ($r = -0.12$) in studies that used chance payoff.

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