Neuroeconomics :

Neuroscience of decision making

Lecture N7

Decision making under risk.

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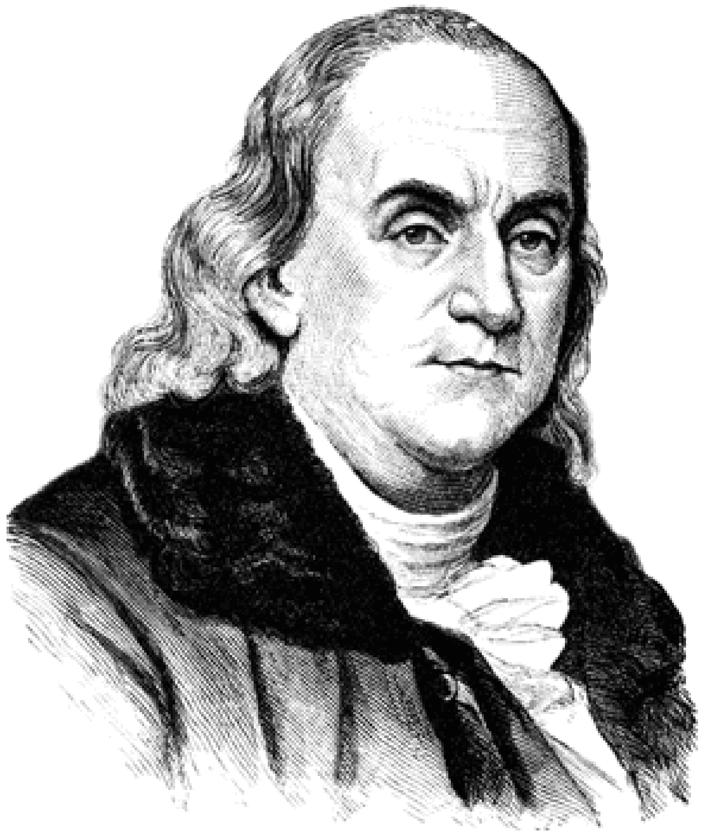
Region	**Main Functions**
Ventral striatum (NA)	anticipated value
Orbitofrontal cortex/ ventral medial prefrontal cortex	derives an integrated value signal, learn values
Insular cortex (IC)	awareness of body states, emotions (e.g. disgust)
Amygdala	anticipated costs, emotion-related learning (e.g. fear conditioning)
anterior/dorsal Cingulate cortex	conflict monitoring, behavioral adjustments
Dorsolateral prefrontal cortex (DLPFC)	cognitive control & planning

Expected utility theory

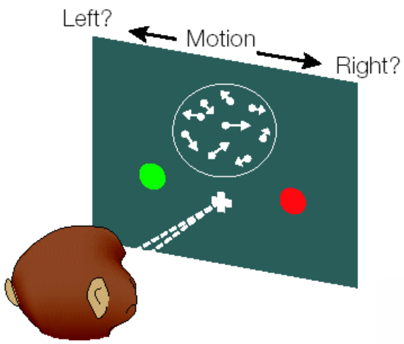
Subjective value * Probability

- EU theory: to each alternative is assigned a weighted average of its utility values the probabilities of outcomes EU = ∑ p U

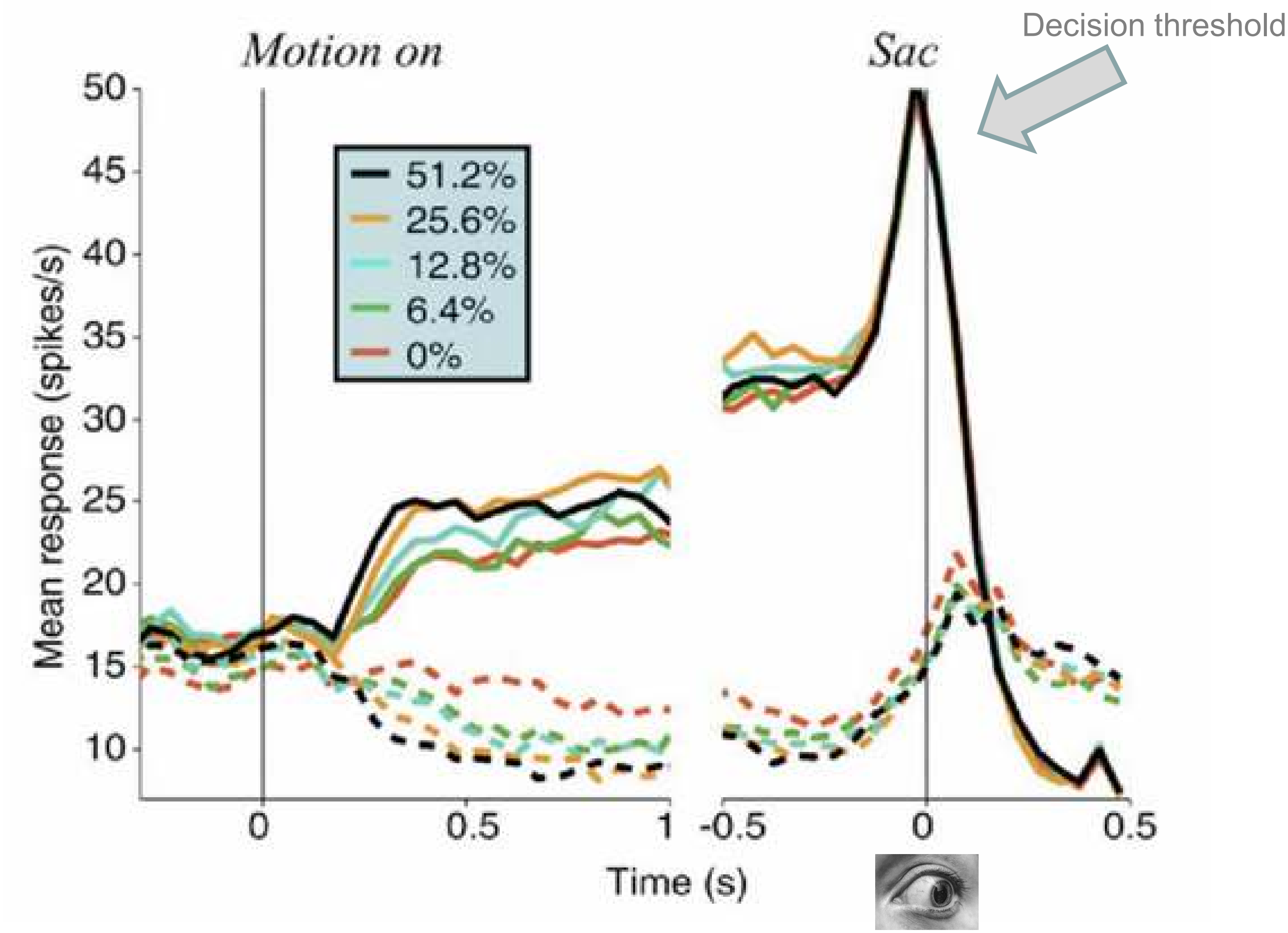


“In this world nothing can be said to be certain, except death and taxes”

Benjamin Franklin, 1789

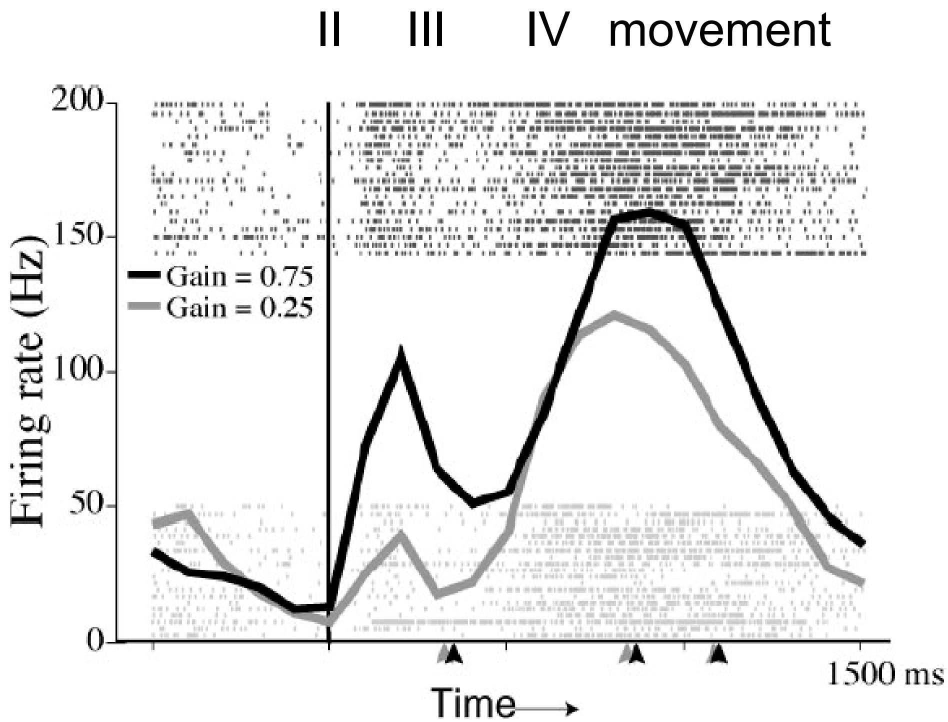

Left?
Motion
Right?

Area LIP

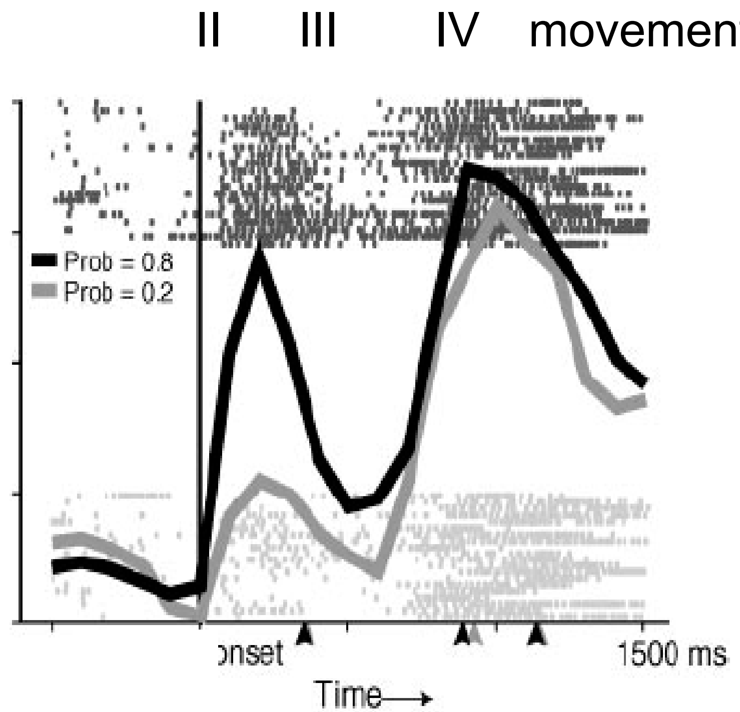

Decision threshold
Motion on
Sac
51.2%
25.6%
12.8%
6.4%
0%
Mean response (spikes/s)
50
45
40
35
30
25
20
15
10
0
0.5
1
-0.5
0
0.5
Time (s)

Gain low/high

Probability low/high



Condition 1



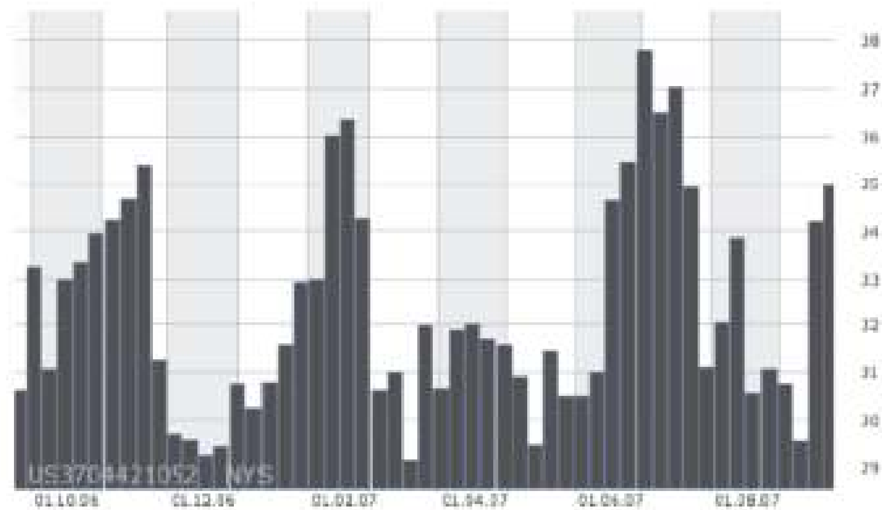
Condition 2

LIP codes probability and value

Platt & Glimcher (1999)

Risk as uncertainty of the outcome.

Roulette

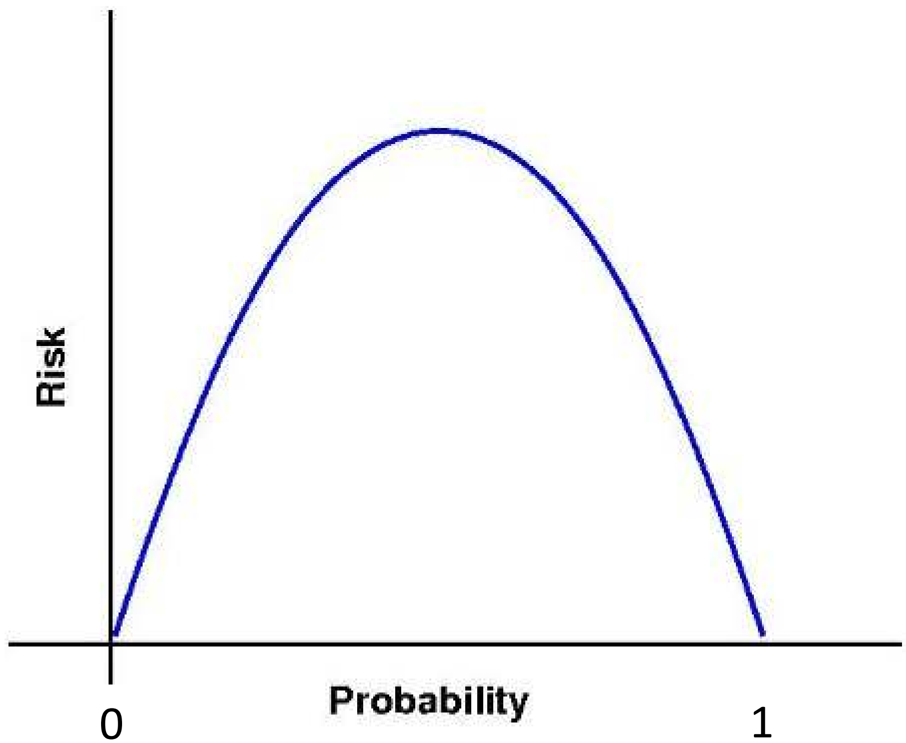


Stocks

Risk

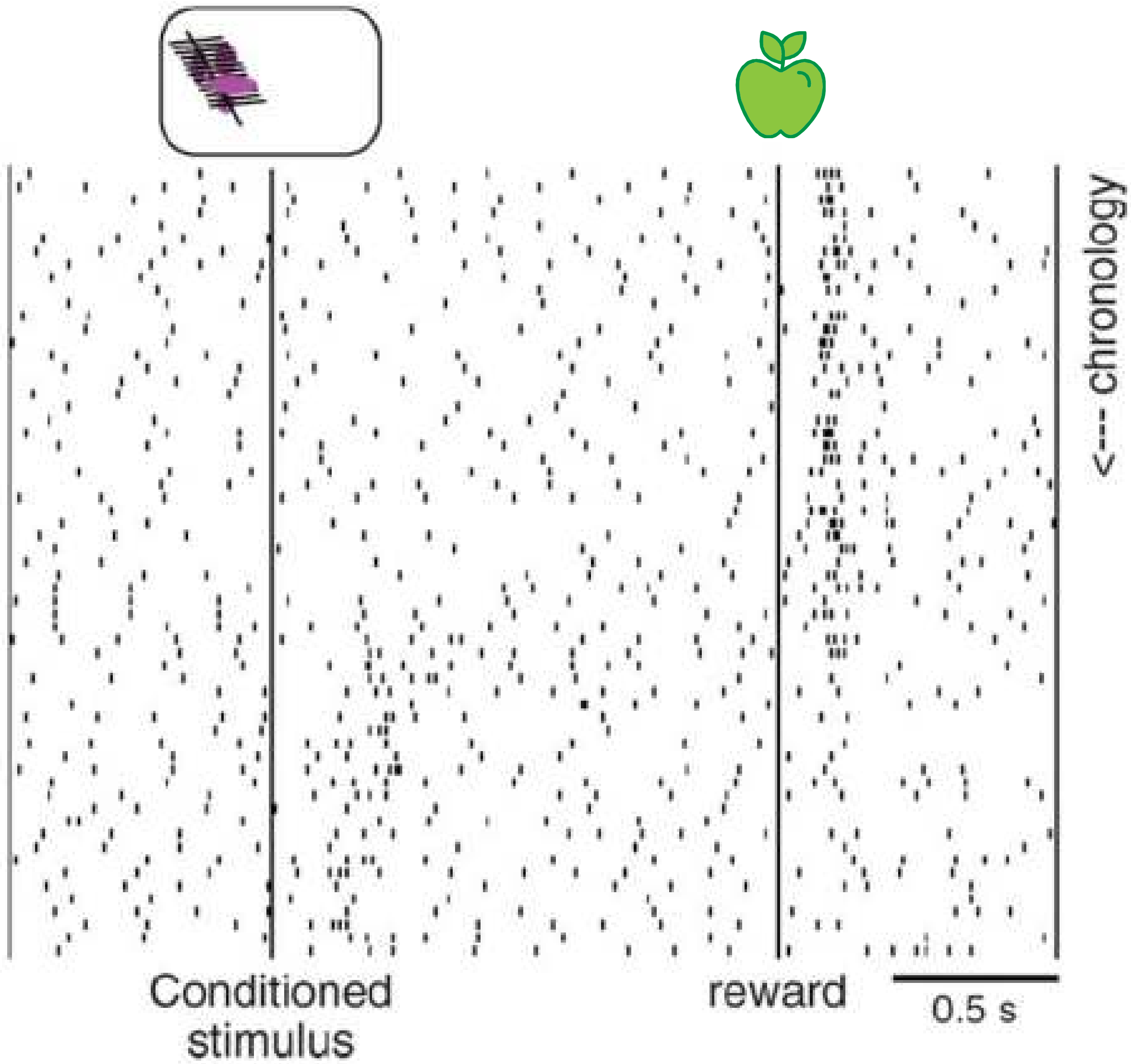
- A possible general definition: risk increases with the perceived chance that a bad outcome will occur.
- For animals living in the wild: risk increases with the perceived chance of death, either through predation or starvation.
- But economists and decision theorists link the concept of risk with the concept of uncertainty.

Burke and Tobler, 2011

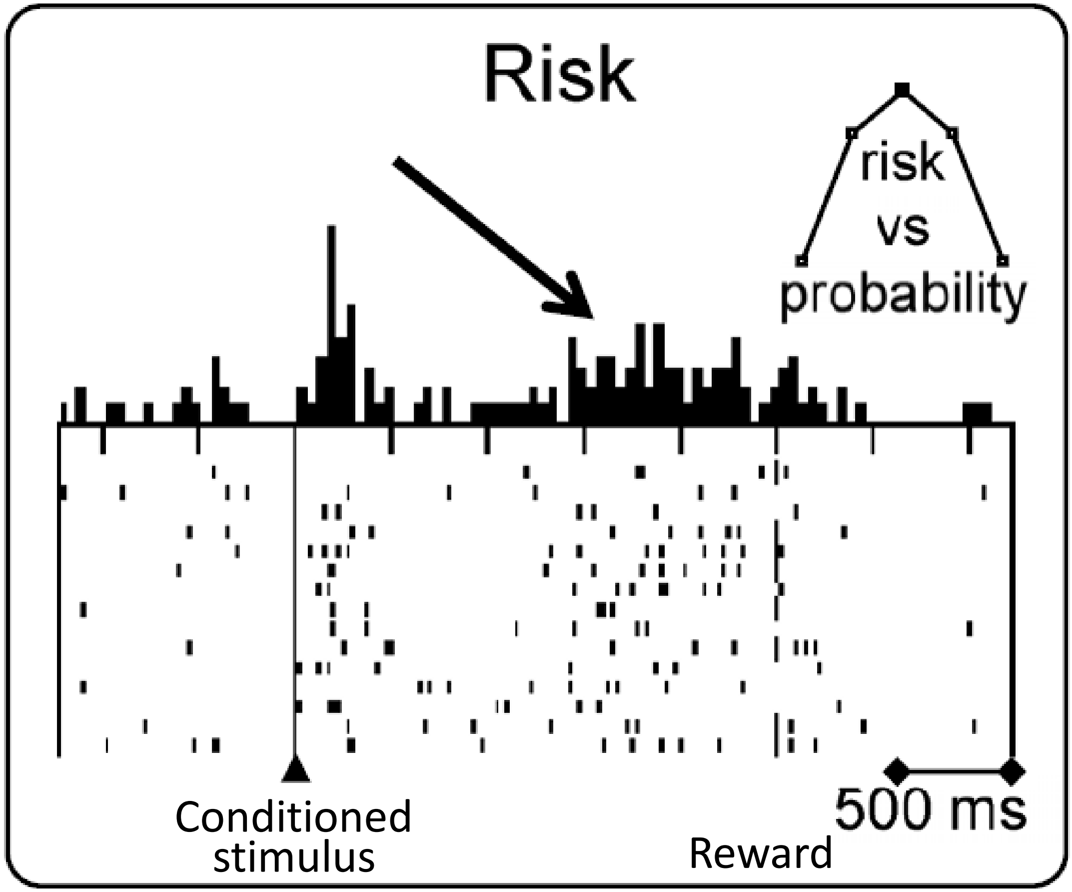


Risk as uncertainty/reward variance, is an inversely quadratic function of probability that is minimal at p = 0 and p = 1 and maximal at p = 0.5 (solid line).

Actual reward and prediction of reward in the NAc (ventral striatum)



Annu. Rev. Psychol. 2006. 57:87–115

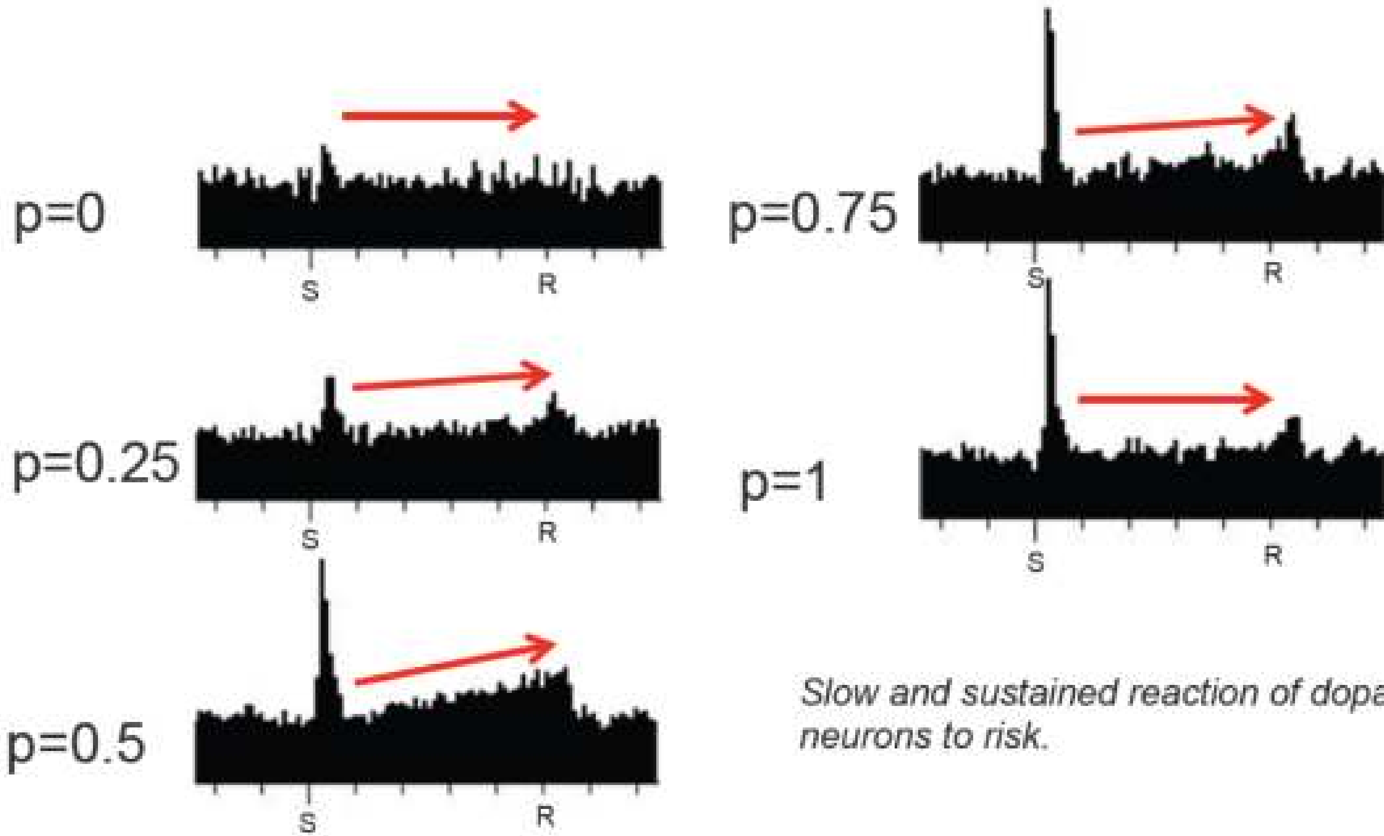


Sustained activations related to risk. The risk response occurs during the stimulus-reward interval (arrow) subsequently to the phasic, value-related activation to the stimulus (triangle).

The inset, top right, shows that risk (ordinate) varies according to an inverted U function of reward probability (abscissa)

Schultz 2010 *Fiorillo et al. (2003)*

Risk & Dopamine Neurons

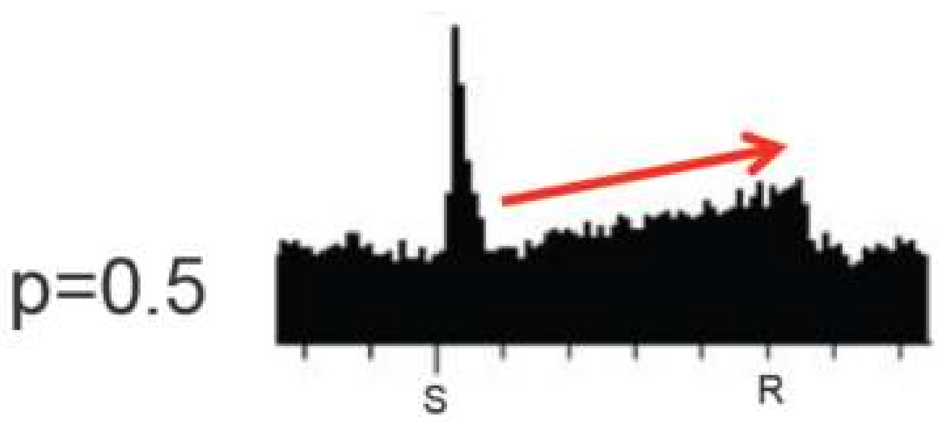


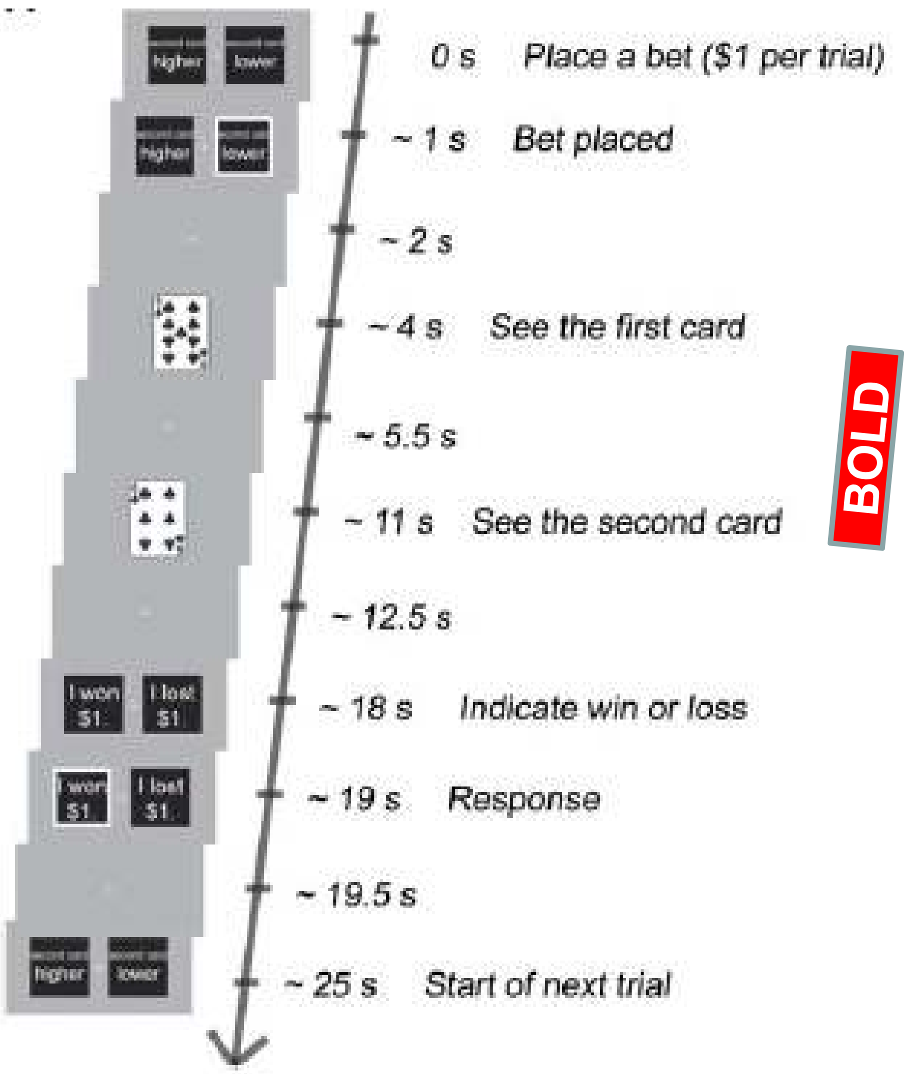
Slow and sustained reaction of dopamine neurons to risk.

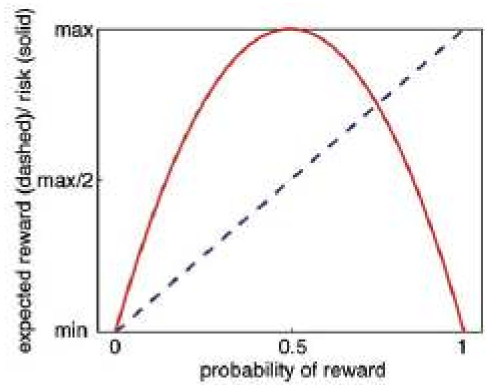
Fiorillo et al. (2003)

Sustained activations related to risk.

- The sustained risk-related response occurs during the stimulus-reward interval subsequently to the phasic, value-related activation to the stimulus .





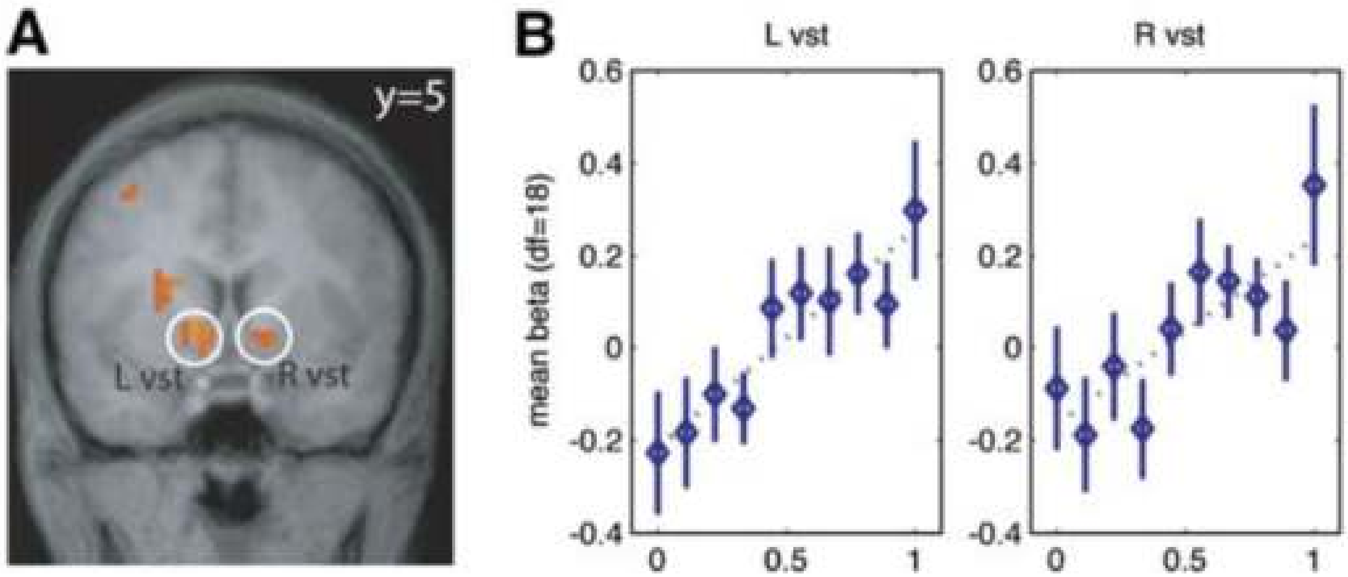


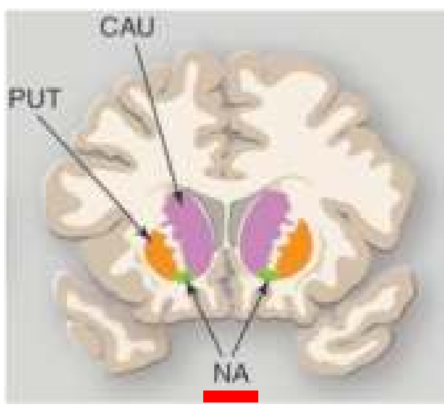
Before seeing two cards, subjects first placed a $1 bet on one of two options, “second card higher” or “second card lower” (than first card shown).
Subjects could earn $1 if they guessed the right card and lost $1 if they were wrong.

Expected reward, measured as mathematical expectation of reward, increases linearly in the probability of reward *p* (dashed line).
Risk, measured as reward variance, is an inversely quadratic function of probability that is minimal at *p* = 0 and *p* = 1 and maximal at *p* = 0.5 (solid line).

Preuschoff et al. (2006)

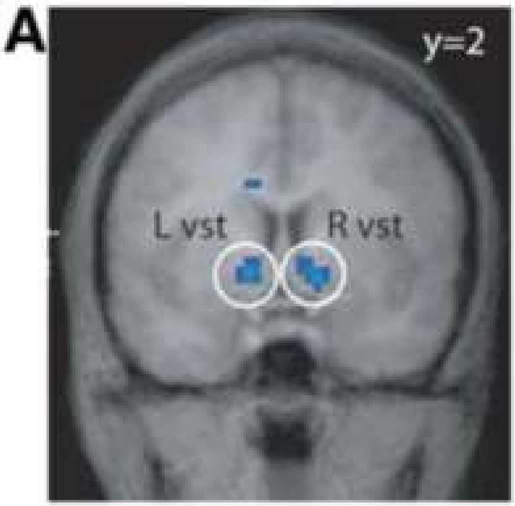
Immediate neural correlates of expected reward at the ventral striatum

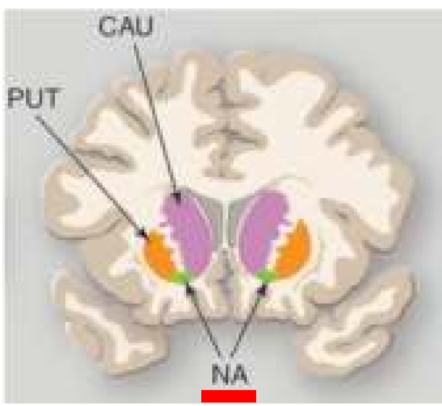


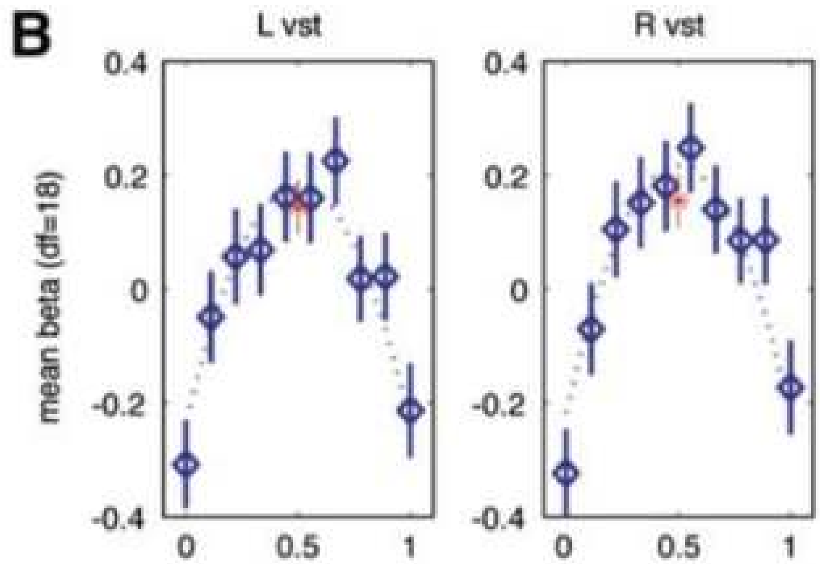


Preuschoff et al. (2006)

Delayed neural correlates of risk at the ventral striatum

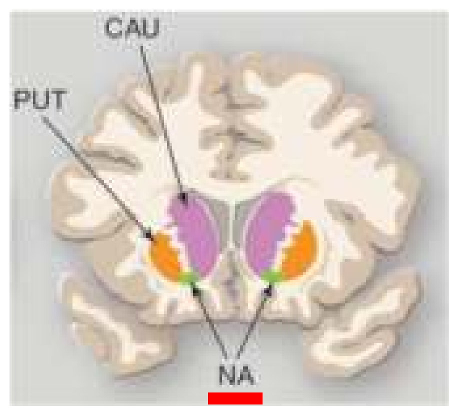






Preuschoff et al. (2006)

- Expected reward is immediately coded in the ventral striatum
- Risk seems to be also coded by reward-sensitive dopamine neurons of the ventral striatum
- But risk-related code is delayed in the ventral striatum
- Overall, dopamine neurons show a slow, sustained reaction to risk



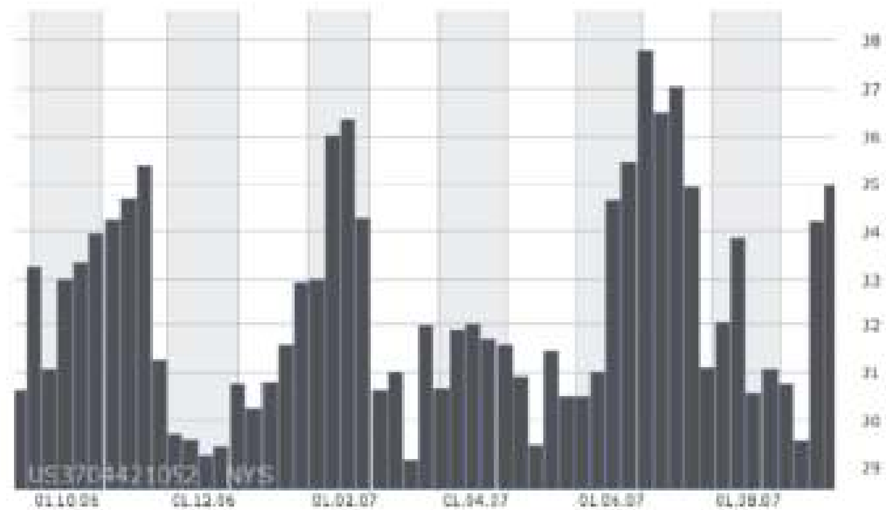
Risk as a form of uncertainty

- Economists and decision theorists interested in human behavior often divide uncertainty into two distinct concepts:
  - risk, where the probabilities of potential outcomes are known
  - ambiguity, where the probabilities are not precisely known (Knight, 1921; Ellsberg, 1961; "uncertainty" and "ambiguity" are sometimes also used synonymously).

Burke and Tobler, 2011

Decisions under (uncertainty)

Roulette

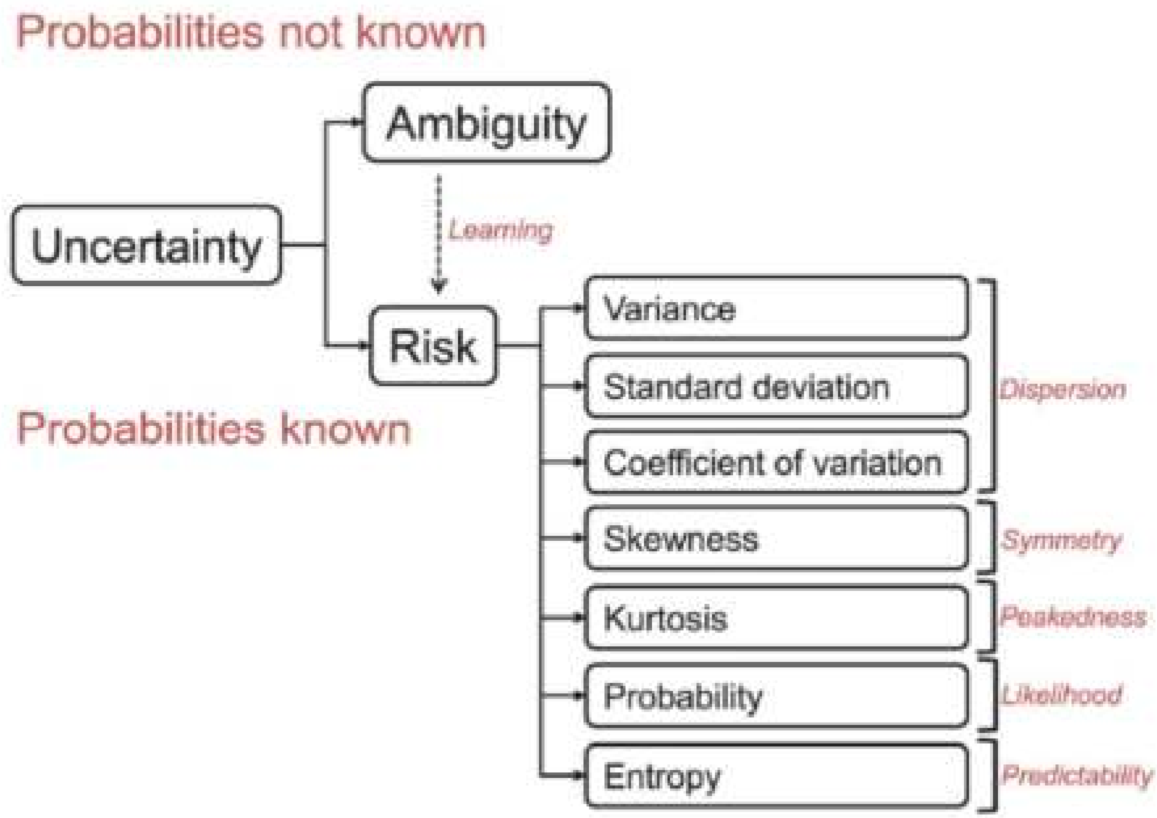


Stocks

risk

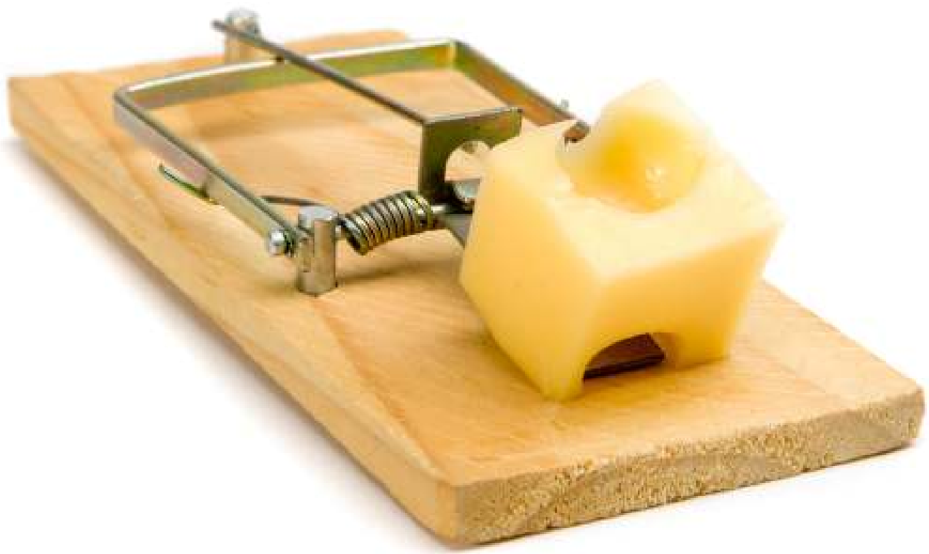
ambiguity

Different forms of reward-related uncertainty.



Burke and Tobler, 2011

- Animals and (often) humans have to learn the probabilities of outcomes through repeated sampling, gradually turning ambiguity into risk.



Burke and Tobler, 2011

Terminology in decision theory

- Decision under **risk**
  - The exact probabilities for all occurrences are known
  - Variance of outcomes measures risk

    E.g. wheel of fortune

- Decision under **ambiguity** (or uncertainty)
  - The probabilities of occurrences are imprecise or unknown

    E.g. investing in the stock market

- Rational economic analysis assumes that ambiguous situations can be reduced to risky situations.
  - In the absence of any information about probabilities, all possible values (in the extreme, between 0 and 1) should be assumed to be equally likely, with the midpoint of the range of possible likelihoods (e.g., .5) as the best estimate.

1. Expected Utility Theory

$$EU(X) = \sum_{x} p(x)u(x),$$

2. Risk–Return Models

$$\mathrm{WTP}(X) = \mathrm{V}(X) - b\mathrm{R}(X).$$

WTP - willingness to pay for risky option *X*
V(*X*) - option's return
R(*X*) - risk with the assumption that people will try to minimize level of risk for a given level of return
b - index of risk aversion.

V(*X*) = *EV* of option *X*
R(*X*) = variance

3. Prospect Theory (Kahneman and Tversky, 1979)

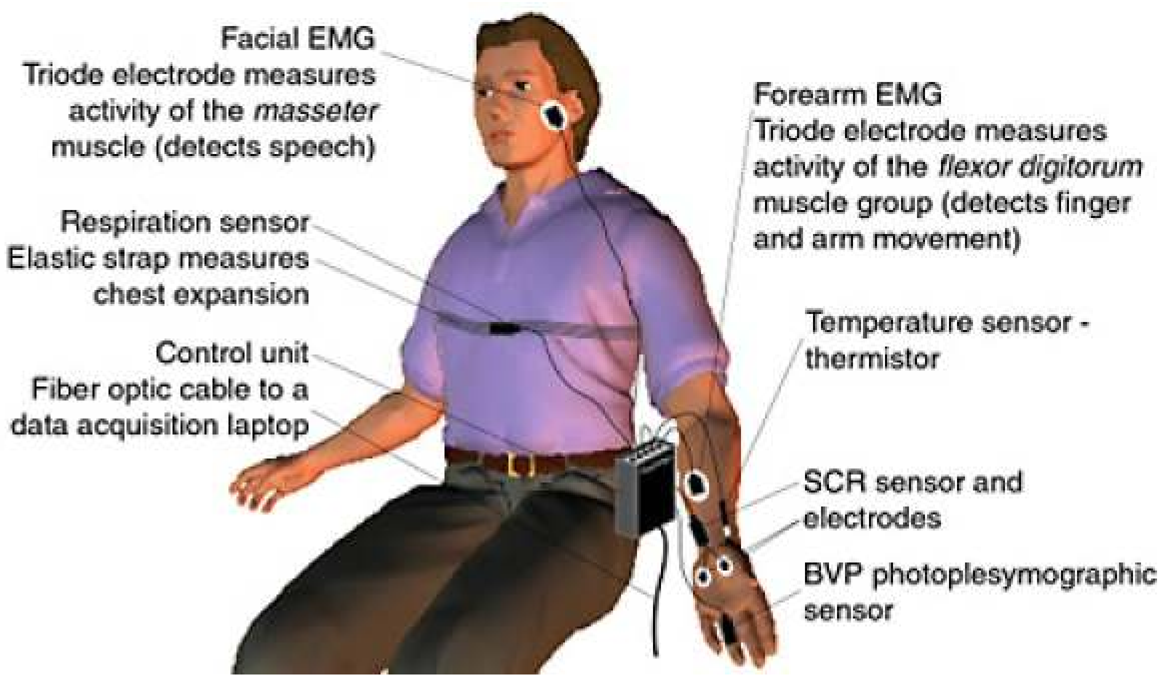
Decision under risk

- While people are attracted to expected value, they are instead repelled by risk.

- One implication of preferences against risk is that people should prefer gambles with relatively steady outcomes over those with more variable outcomes.


RISK
AHEAD

A of 10 professional traders during live trading sessions shows that traders exhibits significant emotional response, as measured by elevated levels of skin conductance and cardiovascular variables, during certain transient market events such as increased price volatility or intra-day breaks in trend.



Lo AW, Repin DV. The psychophysiology of real-time financial risk processing. J Cogn Neurosci. 2002 Apr 1;14(3):323-39.

Expected utility theory

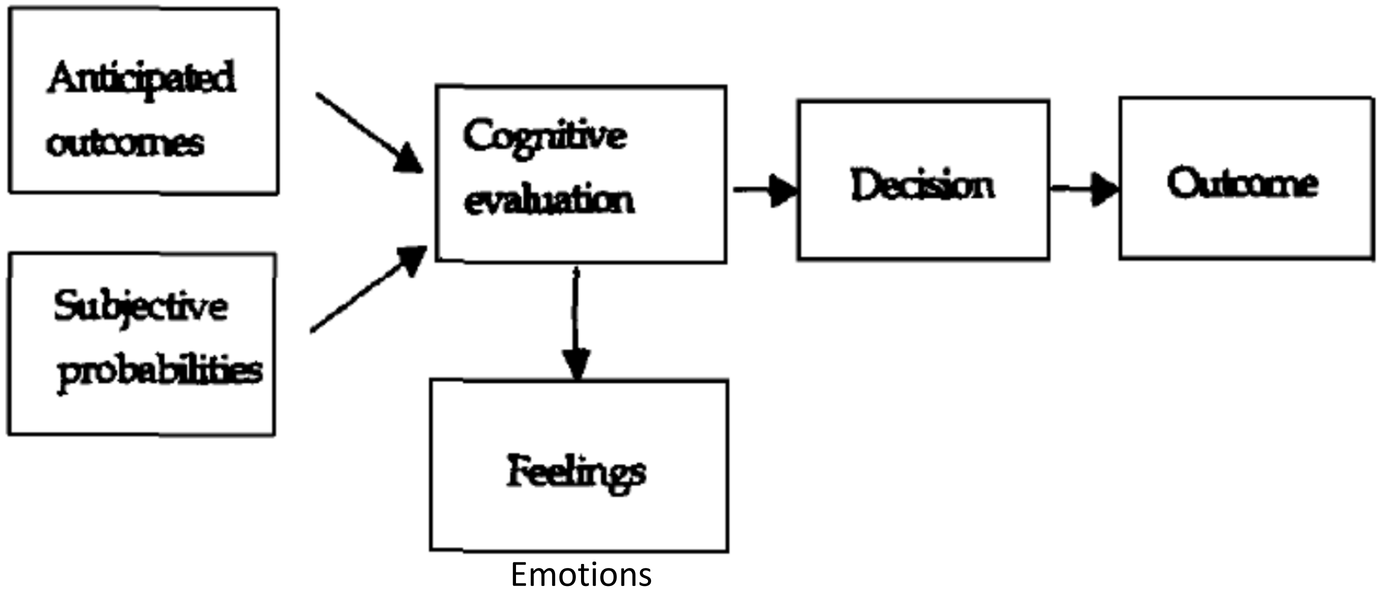
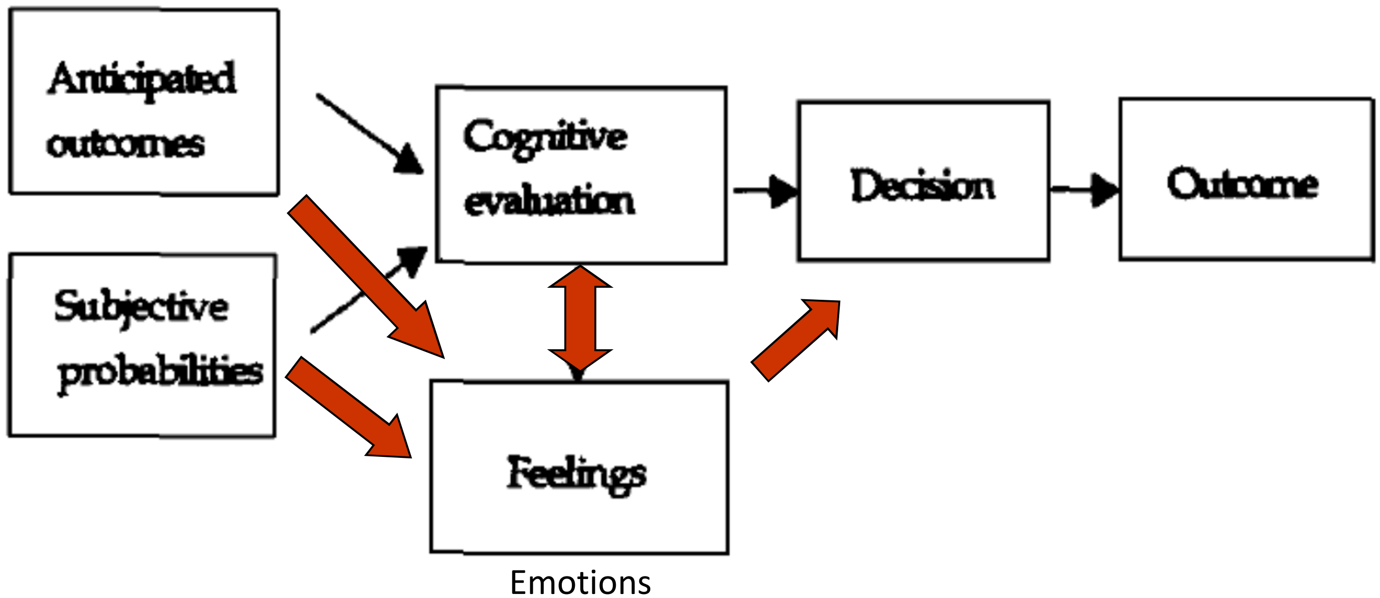


Figure 1. Consequentialist perspective.

G. Loewenstein et al., 2001

Risk as Feelings



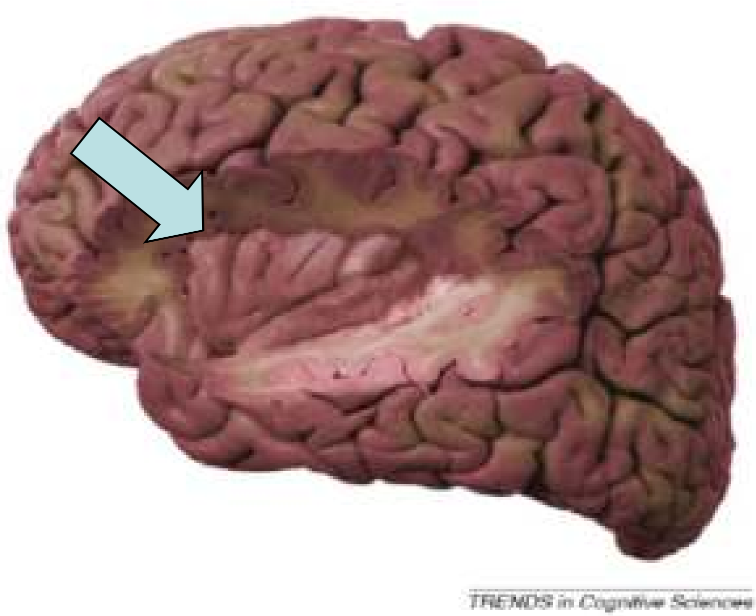
(a) `feelings can arise without cognitive mediation (probabilities, outcomes, and other factors can directly give rise to feelings)

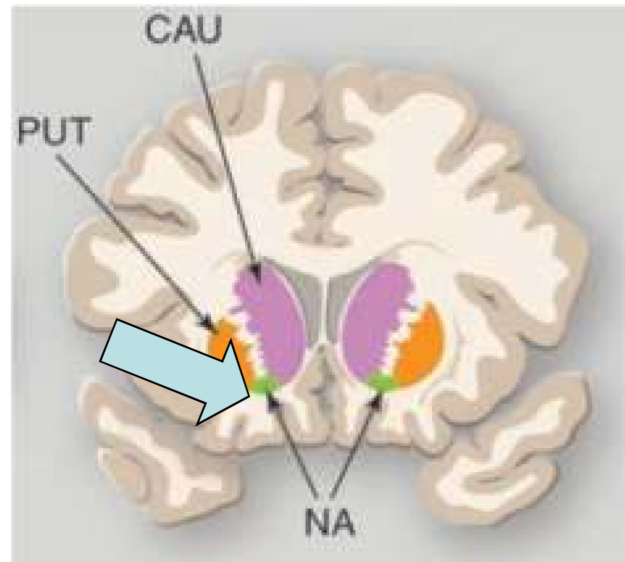
(b) the impact of cognitive evaluations on decisions (behavior) is mediated, at least in part, by affective responses (cognitive evaluation gives rise to feelings that in turn affect behavior).

G. Loewenstein et al., 2001

The “risk as feeling” perspective (Loewenstein et al., 2001) suggests that risk perception is underlined by an emotional evaluation of the stimulus that form the basis for experiences of risk.

“Somatic marker” and “risk as feelings” models suggest that anticipation of uncertain outcomes can generate emotional arousal (Bechara et al., 1996; Loewenstein et al., 2001).





anterior Insula (insular cortex)

Ventral striatum (nucleus accumbens)

Anticipatory affect model (Knutson & Greer, 2008).

1. Uncertainty elicits increased emotional arousal.
2. Since most future events are subjectively uncertain, potential gains should elicit positive arousal (e.g., excitement) & neural activity in the ventral striatum (NAcc).
3. Potential losses should elicit negative arousal (e.g., anxiety) & neural activity in the anterior insula.
4. Positive arousal promotes approach, whereas the negative arousal promotes avoidance.

Wu et al. 2012

Anticipatory affect model (Knutson & Greer, 2008).

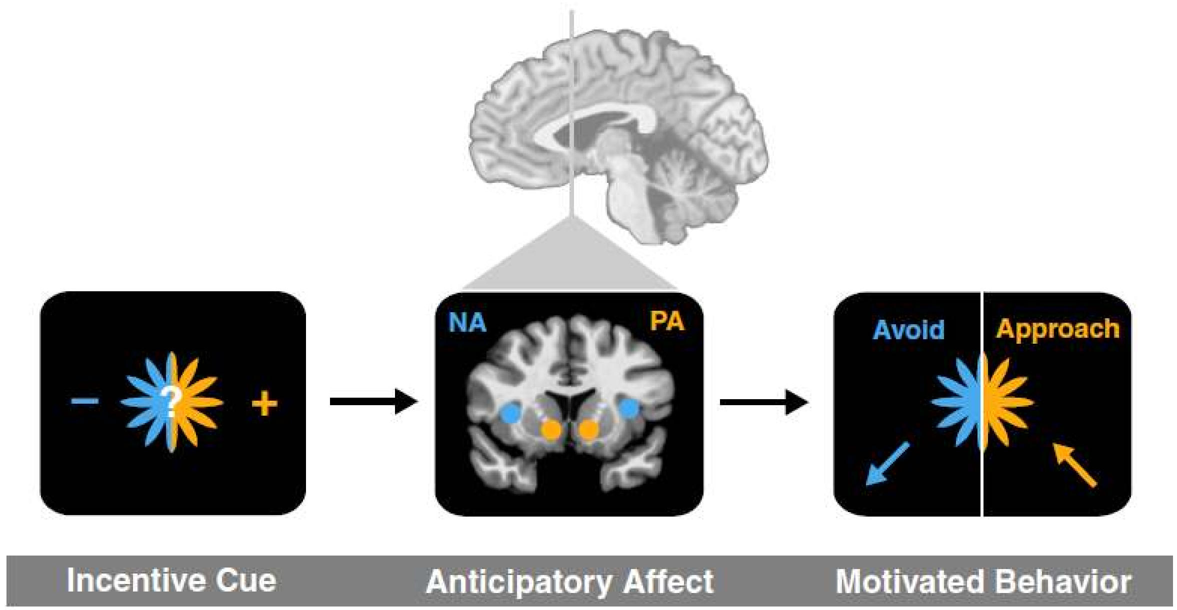


FIGURE 1 | An anticipatory affect model (adapted from Knutson and Greer, 2008). An incentive cue for uncertain future outcome first elicits brain activation in at least two brain regions (NAcc and anterior insula) associated with anticipatory affect (positive arousal and negative arousal, respectively). The balance of activation in related circuits then promotes either approach toward or avoidance of risk.

- anterior insula (negative arousal)
- ventral striatum (positive arousal)

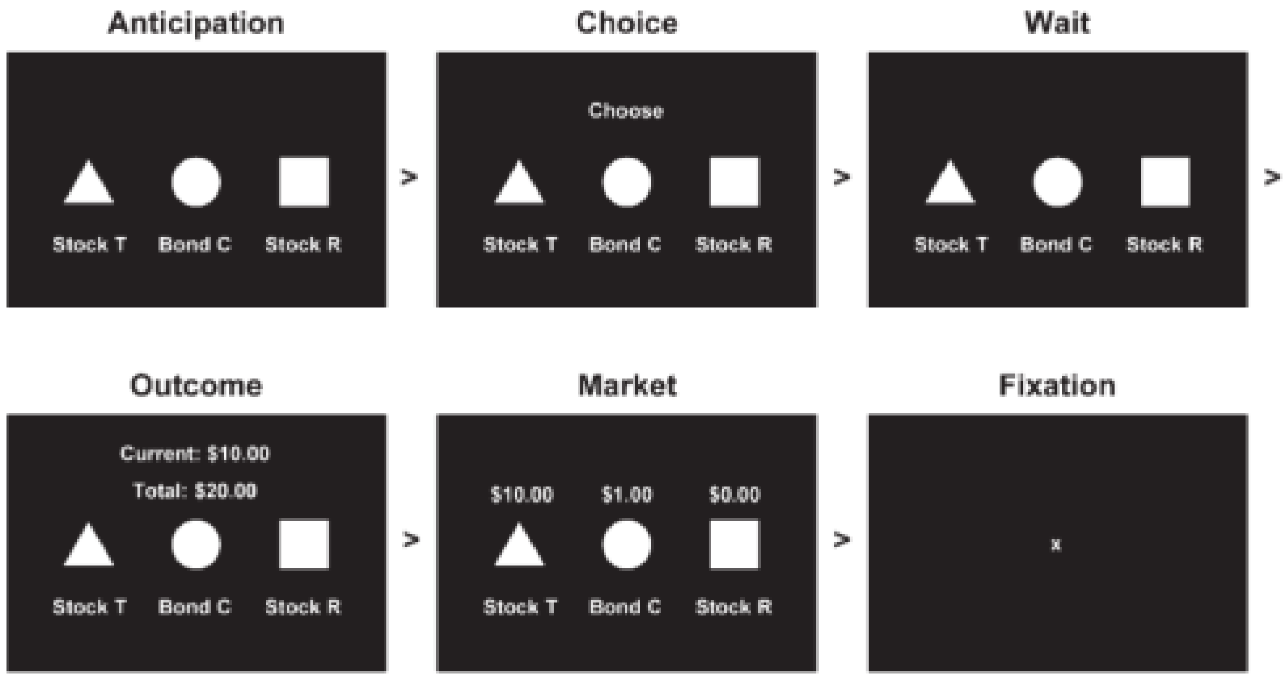
Wu et al. 2012

Hypothesis

- If positive arousal increases, uncertain gains should appear more prominent, which should lead people to approach the risk (all else being equal).

- If negative arousal increases, uncertain losses should appear more prominent, which should lead people to avoid the risk.

The Behavioral Investment Allocation Strategy (BIAS)



Good stock, i.e., +$10 with 50% probability, +$0 with 25% probability, and −$10 with 25% probability

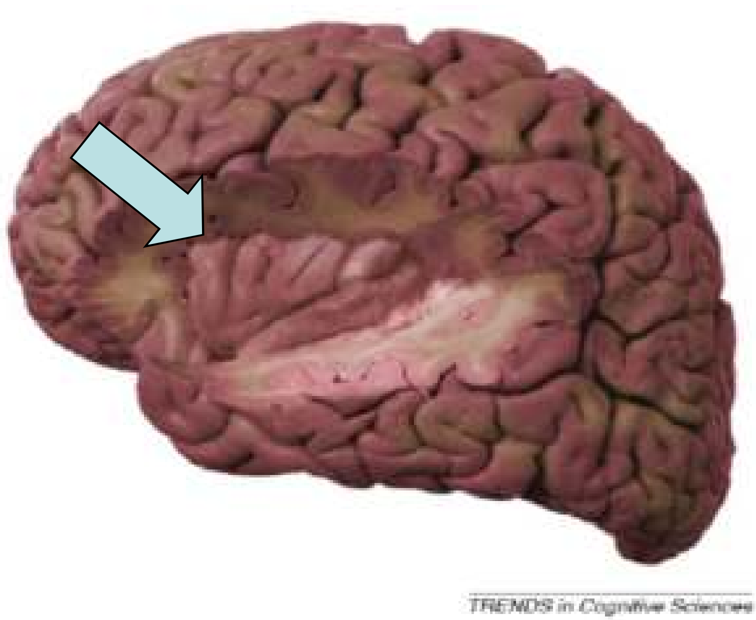
Bad stock, i.e., +$10 with 25% probability, +$0 with 25% probability, and −$10 with 50% probability

Bond paid $1 with 100% probability on each trial.

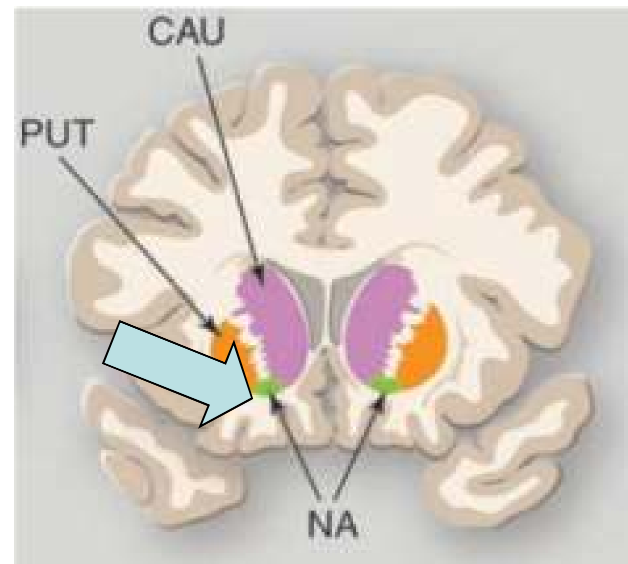
Subjects were informed about the distributions before performing the task.

C. Kuhnen and B. Knutson The Neural Basis of Financial Risk Taking Neuron, Vol. 47, 763–770, 2005

Anticipatory affect model (Knutson & Greer, 2008).



anterior Insula (insular cortex)

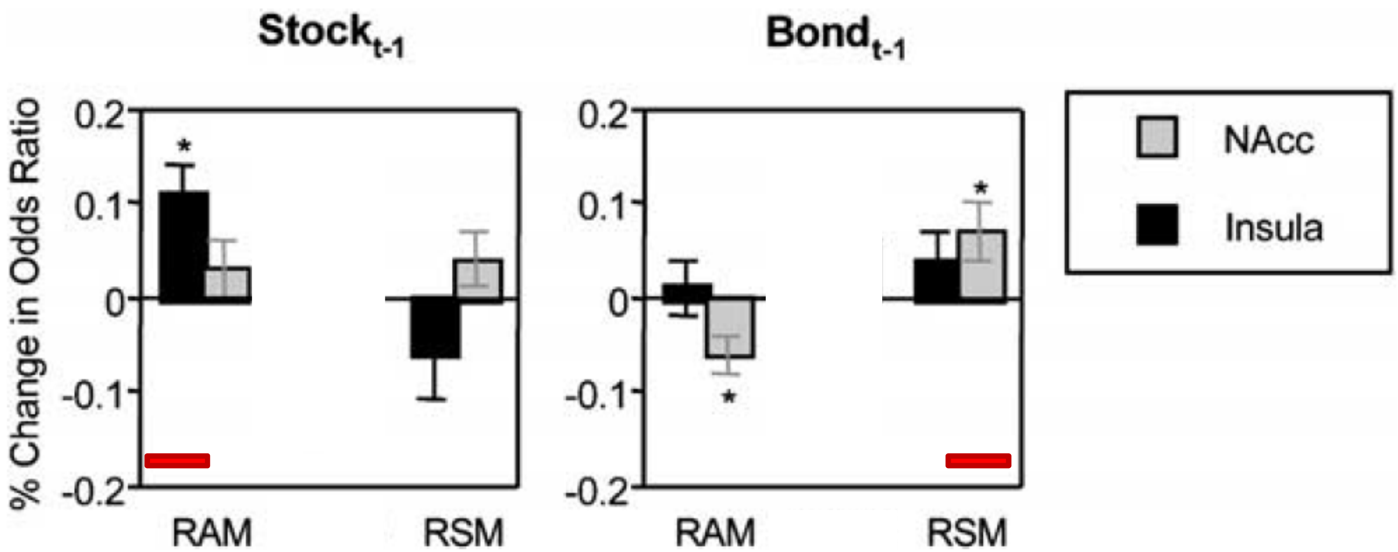


ventral striatum (nucleus accumbens)

Logistic regressions results

- When the prior choice was riskless (i.e., the bond), anticipatory NAcc (ventral striatum) activation increased the likelihood of making a risk-seeking mistake (a 0.1% increase in NAcc (ventral striatum) activation led to a 0.07% increase in the odds of making a risk-seeking mistake; $p < 0.05$).
- When the prior choice was risky (i.e., a stock), anterior insula activation increased the likelihood of making a risk-aversion mistake (a 0.1% increase in insula activation led to a 0.11% increase in odds of making a risk-aversion mistake; $p < 0.05$).

C. Kuhnen, B. Knutson, 2005



Risk-aversion mistakes (RAM)
Risk-seeking mistakes (RSM)
The odds = the ratio of the probability of making that choice divided by the probability of not making that choice.

C. Kuhnen, B. Knutson, 2005

Anticipatory affect model

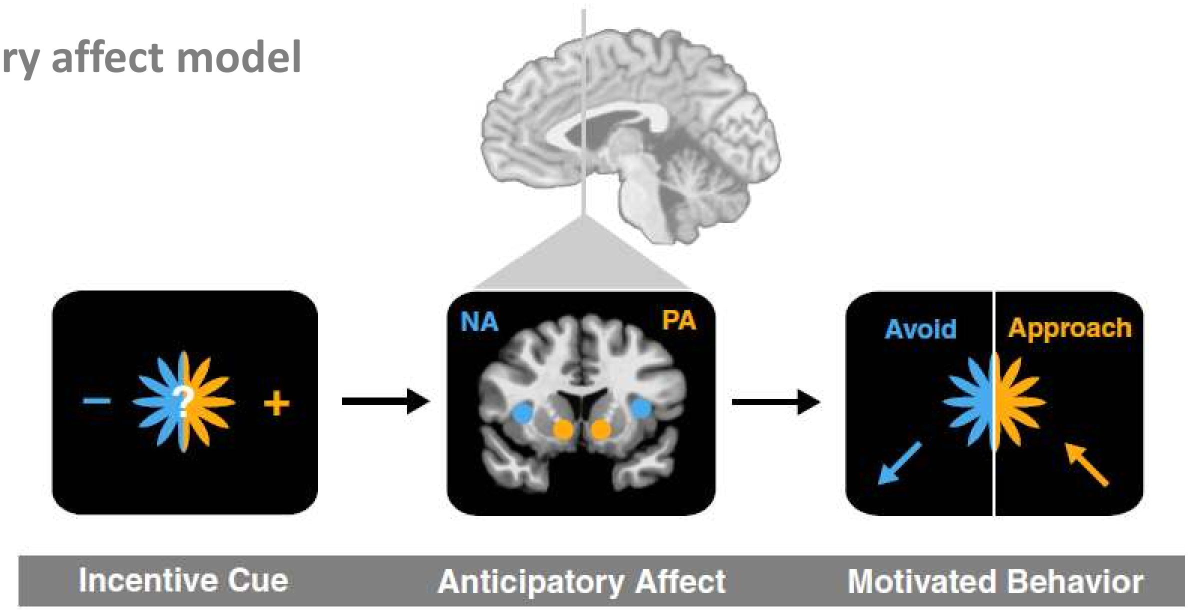


FIGURE 1 | An anticipatory affect model (adapted from Knutson and Greer, 2008). An incentive cue for uncertain future outcome first elicits brain activation in at least two brain regions (NAcc and anterior insula) associated with anticipatory affect (positive arousal and negative arousal, respectively). The balance of activation in related circuits then promotes either approach toward or avoidance of risk.

Ventral striatum (nucleus accumbens) activation precedes risky choices & risk-seeking mistakes, while anterior insula activation precedes riskless choices & risk-aversion mistakes.

Wu et al. 2012

Anticipatory affect model (Knutson & Greer, 2008).

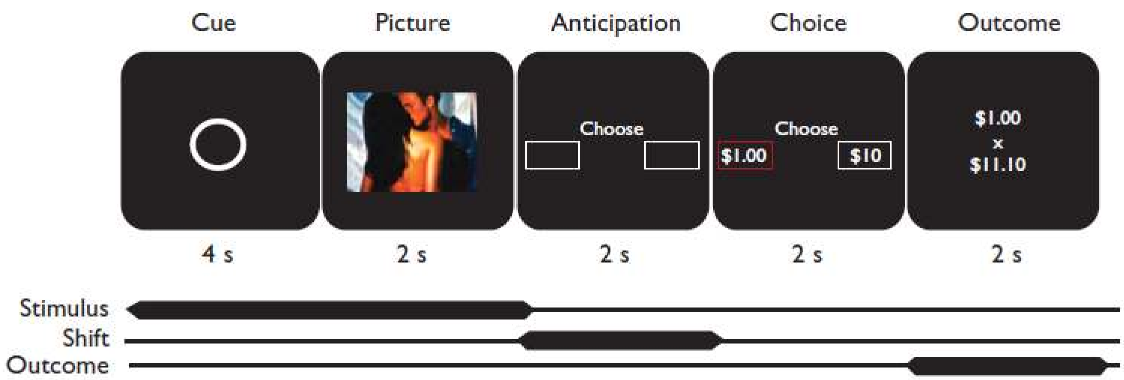


Fig. 1 Cued risk task structure and regressor timing. Participants first viewed affective stimuli consisting of a shape (cue: circle, triangle, square) followed by a picture (picture: erotic couples, household appliances, snakes and spiders). Next, participants gambled by first waiting (anticipation), next choosing the high or low-risk option (choice), and finally viewing the outcome of their choice (outcome). Conjoined regressors modeled brain activation in response to affective stimuli (cue + picture) and during anticipation of choosing the gamble (anticipation).

Erotic stimuli increased subsequent high-risk choices (68 %) relative to neutral stimuli (57 %).

Knutson et al. 2008

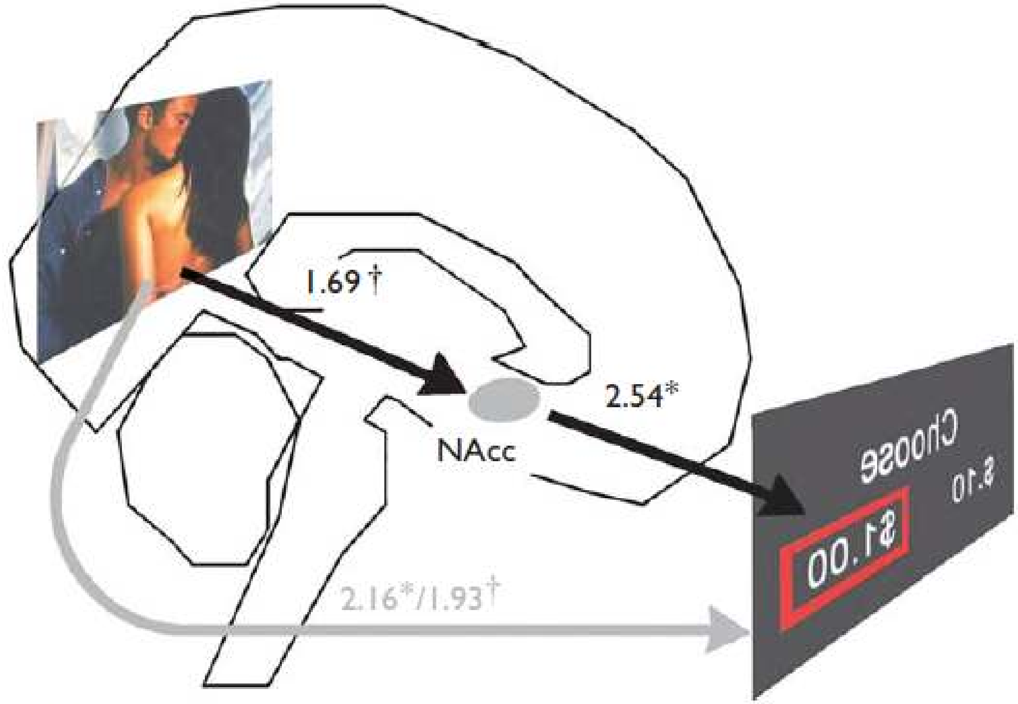


Fig. 3 Anticipatory nucleus accumbens (NAcc) activation partially mediates the influence of positive stimuli on subsequent shifts to the high-risk option (t-scores above paths, $^{*}P<0.025$, $^{\dagger}P<0.05$; one-tailed). Bootstrapped (robust; $n=1000$) mediation analysis indicated a significant path from positive stimuli to NAcc activation [$\beta=0.037$, SEM$=0.022$; $t(315)=1.69$, $P<0.05$, one-tailed] and a significant path from NAcc activation to high-risk shifts [$\beta=0.411$, SEM$=0.162$; $t(315)=2.54$, $P<0.05$, one-tailed]. The path from positive stimuli to high-risk shifts was also significant [$\beta=0.137$, SEM$=0.063$; $t(315)=2.16$, $P<0.05$, one-tailed], but less so [$\beta=0.121$, SEM$=0.063$; $t(315)=1.93$, $P<0.05$, one-tailed] after adding indirect paths involving NAcc activation to the model. Bias corrected and accelerated confidence intervals (CIs) verified the significance of this partial mediation (CI bounds$=0.0002-0.0447$). Of the model covariates (i.e. cumulative earnings, anterior insula activation), only losses on the previous trial [$t(315)=-9.14$, $P<0.001$] significantly predicted shifts to the high-risk option.

Knutson et al. 2008

- Anticipation of viewing rewarding stimuli (erotic pictures for 15 heterosexual men) increased financial risk taking, and that this effect was partially mediated by increases in the ventral striatum (NAcc) activation.

- These results are consistent with the hypothesis (anticipatory affect model) suggesting “if activity of the ventral striatum increases than positive arousal increases and uncertain gains should appear more prominent, which should lead people to approach the risk” (Wu et al. 2012).

Anticipatory affect model (Knutson & Greer, 2008).

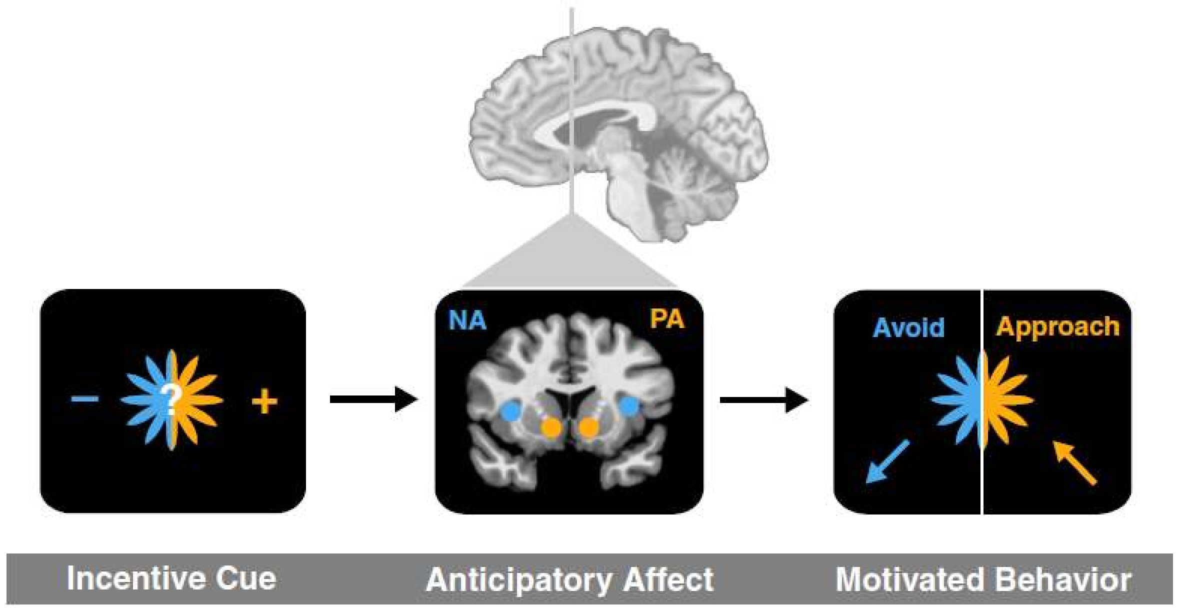


FIGURE 1 | An anticipatory affect model (adapted from Knutson and Greer, 2008). An incentive cue for uncertain future outcome first elicits brain activation in at least two brain regions (NAcc and anterior insula) associated with anticipatory affect (positive arousal and negative arousal, respectively). The balance of activation in related circuits then promotes either approach toward or avoidance of risk.

Wu et al. 2012

http://www.knifethrower.com

Risk aversion / Risk attitude

- 50 % chance of €100 vs. €49
- Majority prefers the latter even though the expected value of the former is higher

- The traditional risk–return model assume a single parameter, referred to as “risk attitude ” or “ risk tolerance.”
- This parameter is identified empirically from a person’s choices.
  - Someone who is indifferent between € 49 for sure and a 50 % chance gamble of € 0 and € 100 is risk averse.
  - The € 1 difference between the EV of the gamble (i.e., € 50) and the certainty equivalent of € 49 - the risk premium. Greater risk aversion results in a larger risk premium.

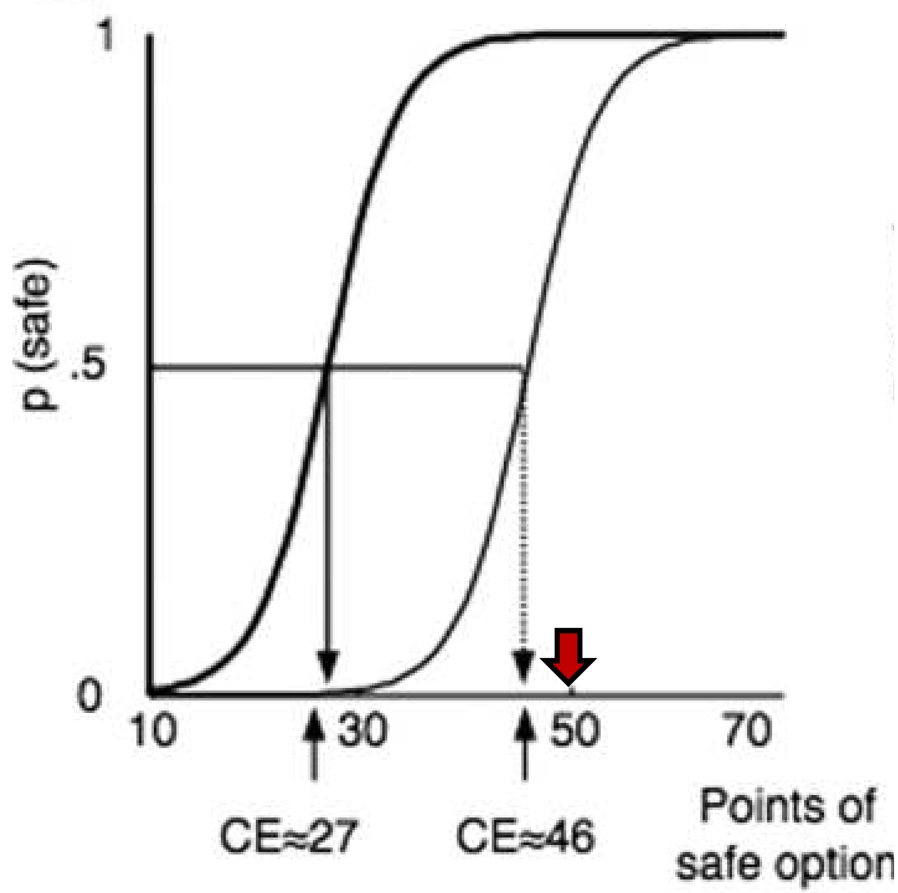
Risk Attitude – limitations

- Unfortunately for the interpretation of risk attitude as a personality trait, it is far from stable across situations for most individuals (Bromiley and Curley, 1992).

- The same person often shows different degrees of risk-taking in financial, career, health and safety, ethical, recreational, and social decisions (MacCrimmon and Wehrung, 1986 ; Weber *et al* ., 2002 ; Hanoch *et al* ., 2006).

$$\mathrm{WTP}(X) = \mathrm{V}(X) - b\mathrm{R}(X).$$

Risk aversion & certainty equivalent (CE)

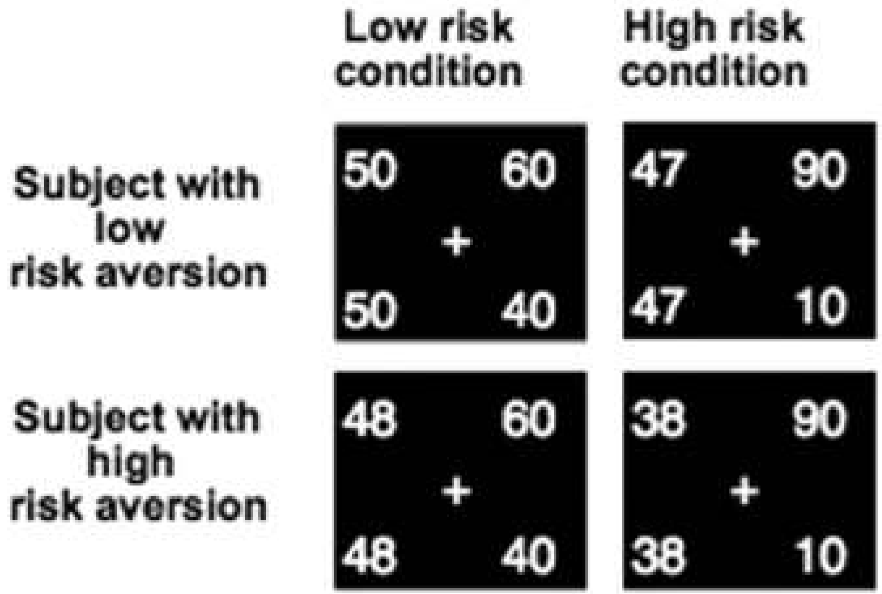


The CE of a gamble is the amount for which an agent is indifferent between receiving it for sure and opting for the gamble. This definition implies that the probability of choosing the CE instead of the gamble is p = 0.5. Examples show probability distributions of safe choices as a function of safe amounts for two participants with different degrees of risk aversion (thick line for stronger risk aversion with lower CE)

Risk aversion

- Thus, the risk aversion of each participant can be identified using the **certainty equivalent** (CE).
- For example, the difference between the CEs of two gambles with the same EV but different levels of risk (CE low risk gamble − CE high risk gamble) reflects risk aversion.

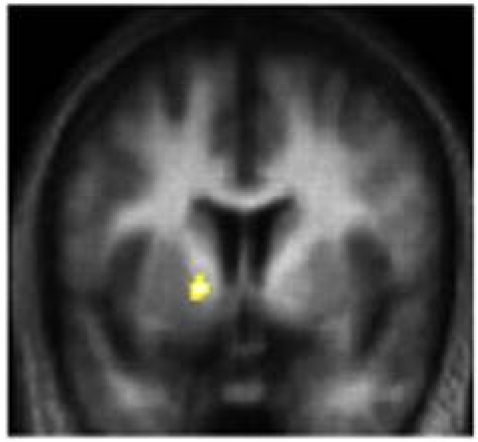
  A larger difference between these two CEs indicates higher effect of risk – higher risk aversion.



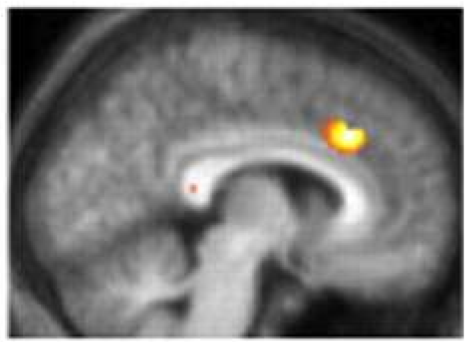
Participants chose between either a safe option or one of two gambles with two equiprobable outcomes

In each trial, participants chose between a safe and a risky option. The staircase method (PEST procedure) iteratively adjusted the safe option in consecutive trials to approximate choice indifference between the two options.

Christopoulos et al. 2009

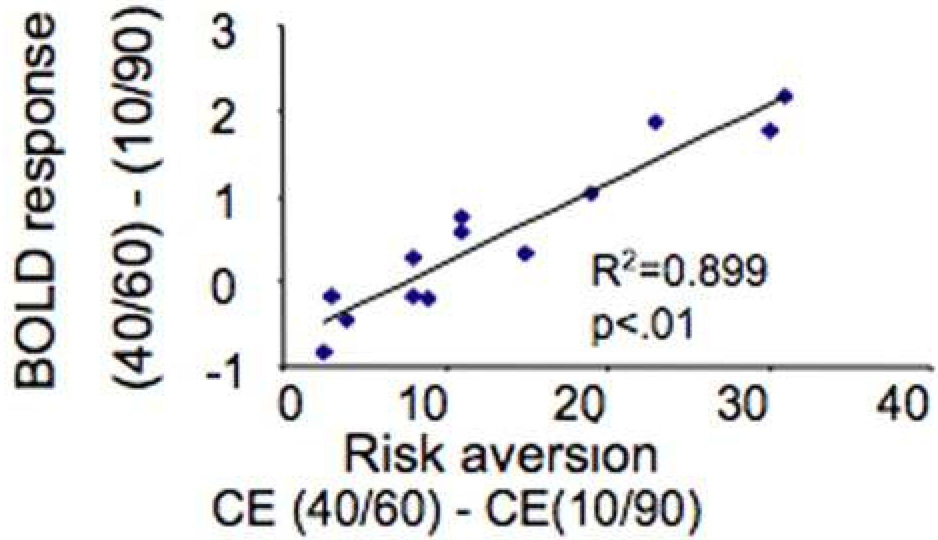


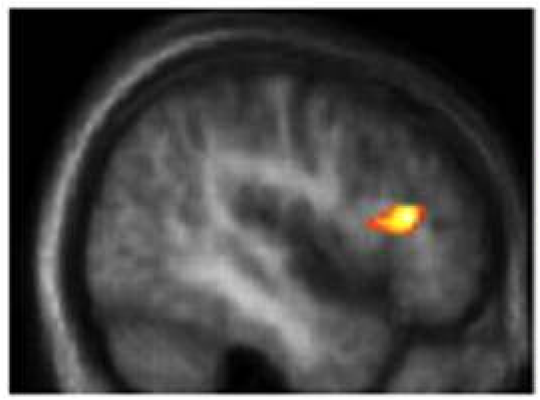
Value of options is coded by the ventral striatum (NAc). Activity is sensitive to magnitude/EV differences



Risky choices are coded by the dorsal cingulate cortex (dACC): stronger activity preceding a choice of the high risk option then activity preceding a choice of the low risk one.

Christopoulos et al. 2009

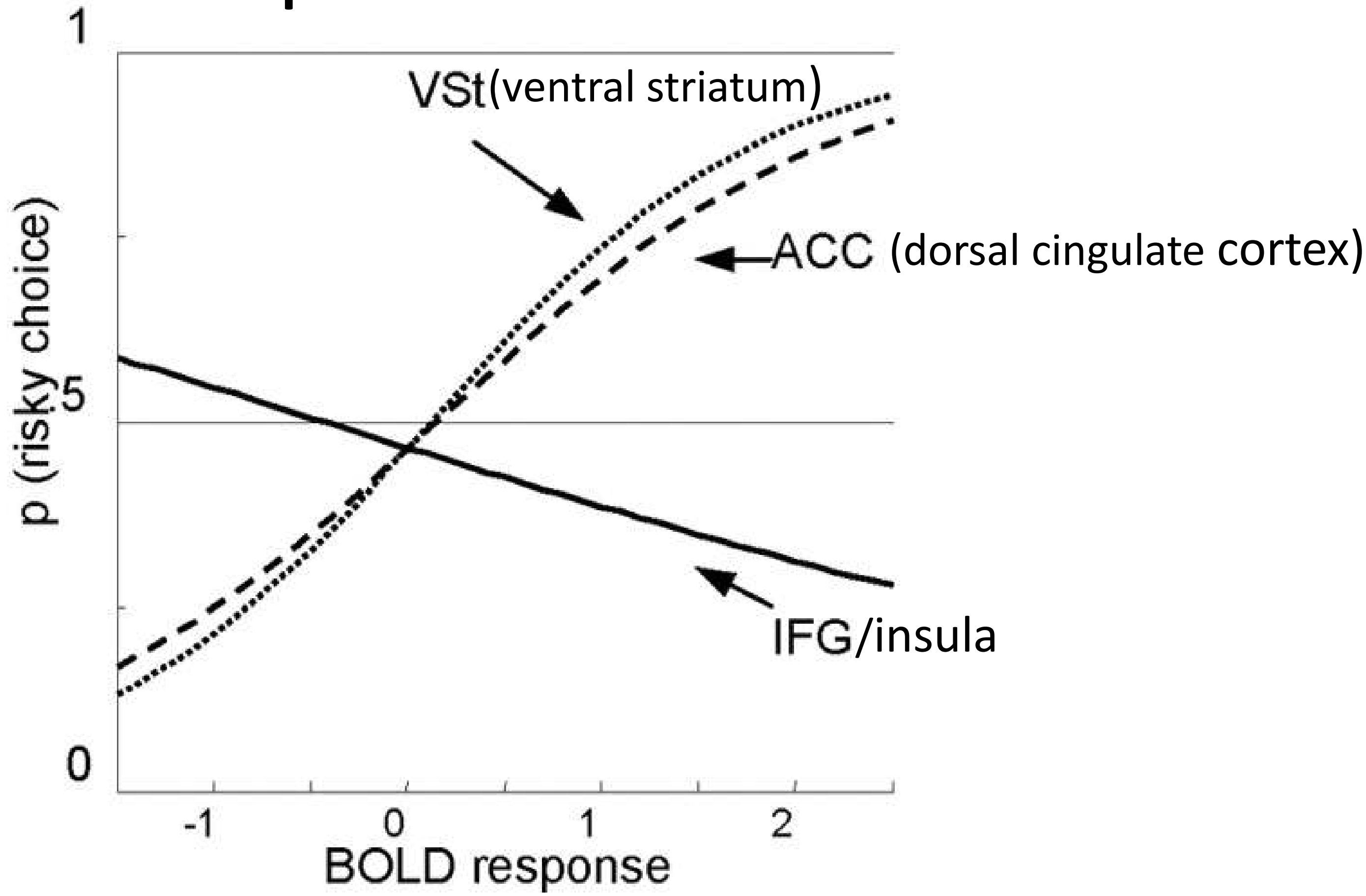




Increased differential anterior insula/inferior frontal gyrus (IFG) activity with risk aversion. The more risk averse the participant, the larger the difference in BOLD response in Insula/IFG .

Christopoulos et al., 2009

Detection of risky choices by combined brain signals of decision parameters.

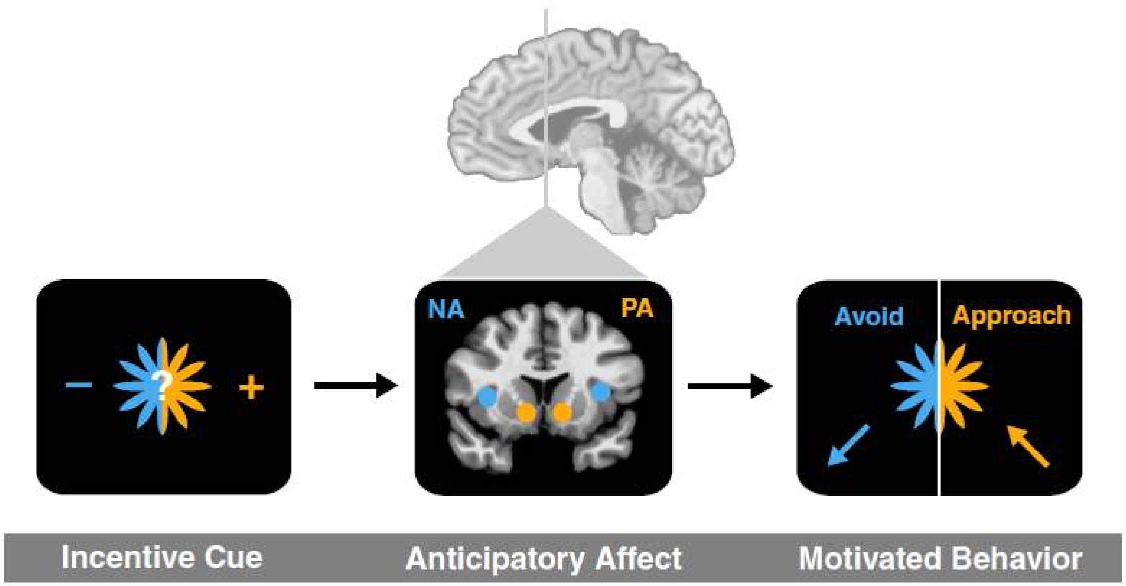


Contribution of brain structures to probability of risky choice. *x*-axis represents level of BOLD responses (of VSt, dACC, or IFG), whereas *y*-axis represents the probability of a risky choice, as computed by the regression equations. Increasing activity of the VSt (ventral striatum) and dACC (dorsal cingulate cortex) increases the probability of a risky choice. On the contrary, increasing activity of the anterior insular/IFG increases the probability of a safe choice.

Christopoulos et al., 2009

- Value-related activity of the ventral striatum and risk-related cingulate responses **increased** the probability of a risky choice.

- Whereas insula/IFG responses **decreased** the probability of a risky choice.



Anticipatory affect model (Knutson & Greer, 2008).

Meta-analysis

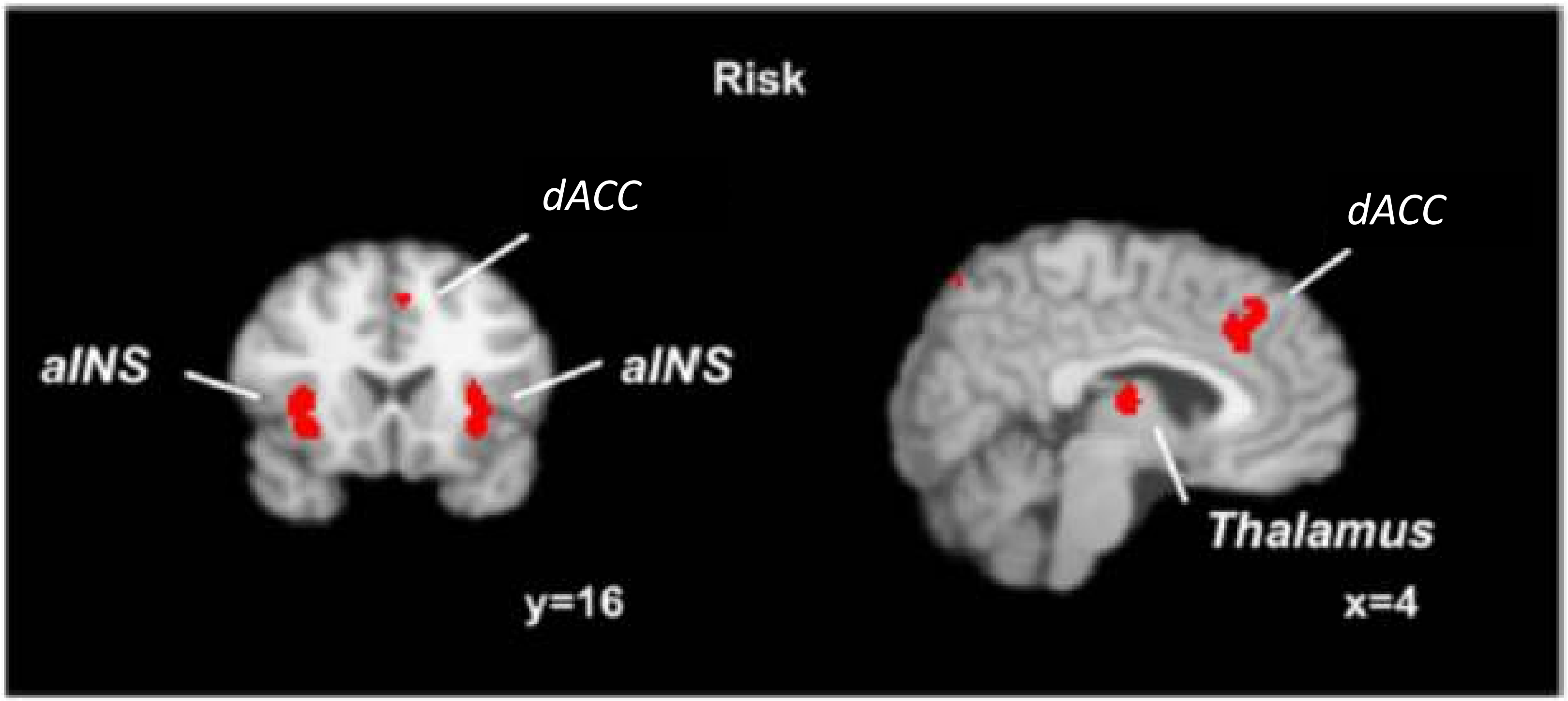
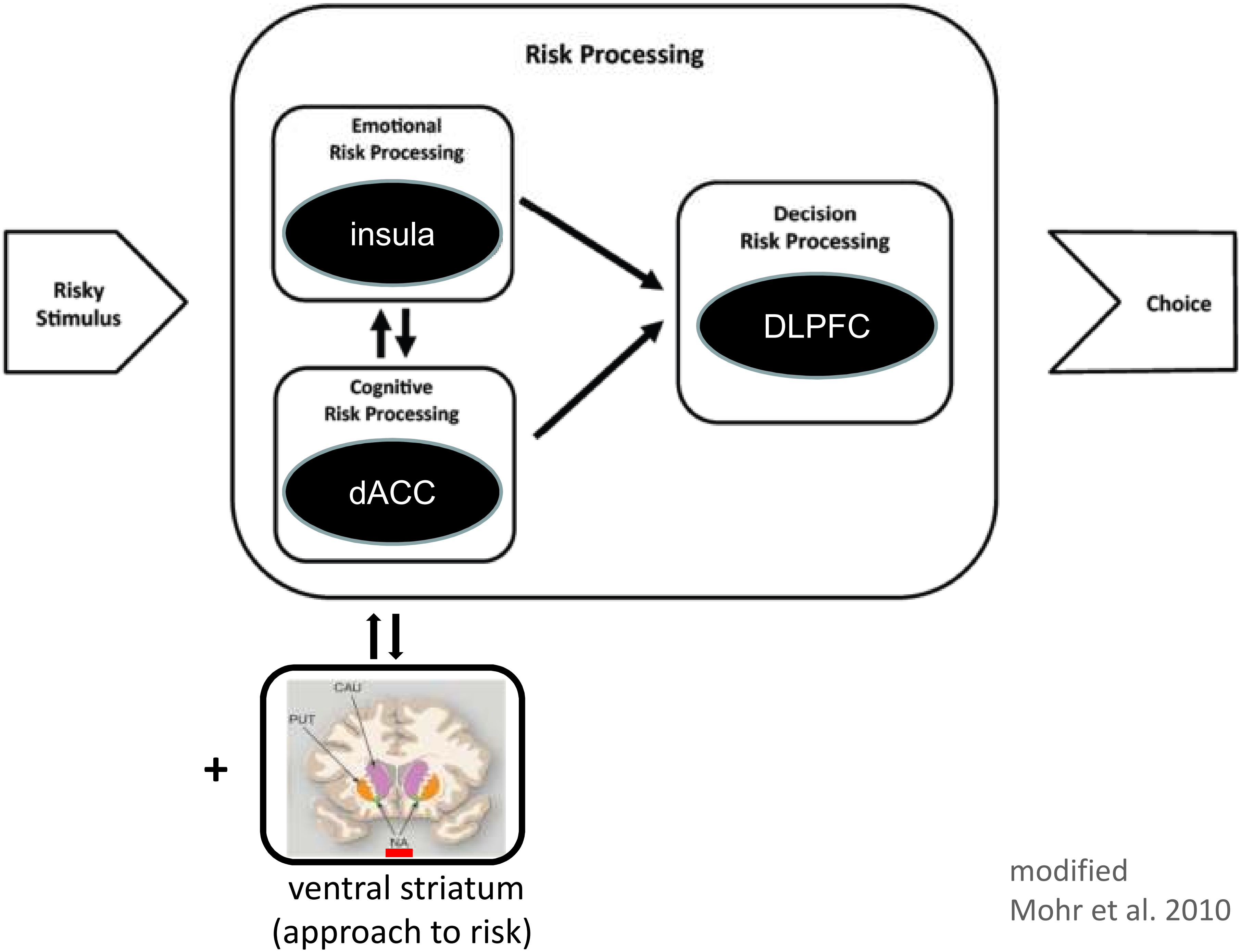


Figure 1. Neural representations of risk. Results from an ALE meta-analysis on risk independent of the context (decision risk or anticipation risk) and the domain (gains + losses or only gains in which risk was investigated). Activated clusters included bilateral aINS, DMPFC, and thalamus (FDR of <0.05; cluster size of $>200\ mm^3$).

aINS –anterior insula
dACC – dorsal anterior cingulate cortex

modified
Mohr et al. 2010



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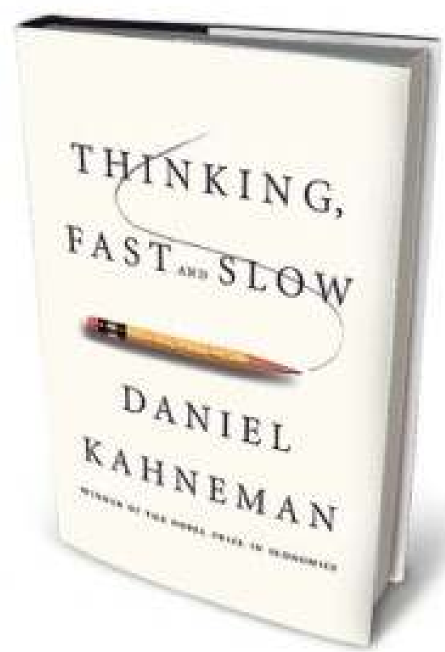
Mohr et al. 2010

- Standard decision theory predicts that people should never buy lotteries.
- But in fact they do!

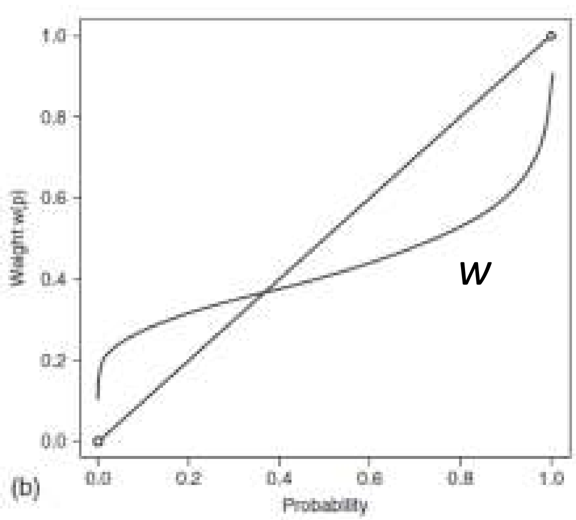


Prospect Theory

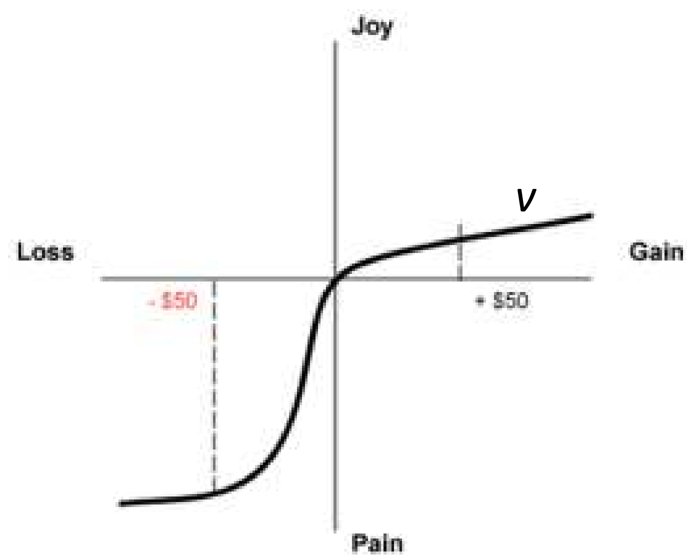
$$U = \sum_{i=1}^{n} w(p_i)v(x_i)$$

U - expected utility.
w - a probability weighting function, that captures the idea that people tend to overreact to small probability events, but under react to large probabilities.
v - a function that assigns a value to an outcome. The value function is s-shaped and asymmetrical. Losses hurt more than gains feel good (loss aversion).

w – probability weighting function



v - value function



Prospect theory

- People apply nonlinear “decision weights” to objective probabilities.
- An inverse S-shaped nonlinear function was first suggested experimentally (Preston and Baratta, 1948), is a central feature of prospect theory (Kahneman and Tversky, 1979), and has been replicated in subsequent experimental and field studies.
- Small probabilities are typically overweighed while high probabilities are underweighted.

1. Expected Utility Theory

$$EU(X) = \sum_{x} p(x)u(x),$$

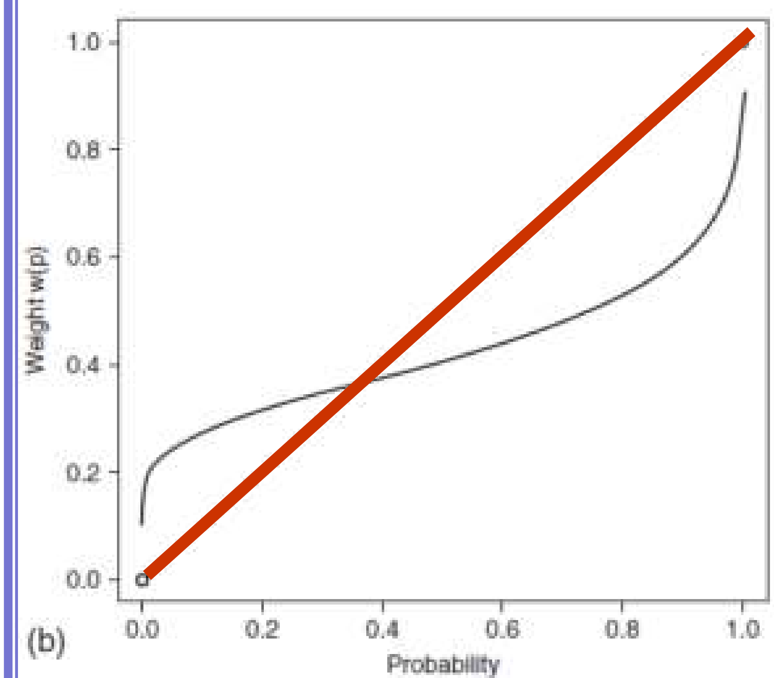
2. Prospect Theory

$$U = \sum_{i=1}^{n} w(p_i)v(x_i)$$

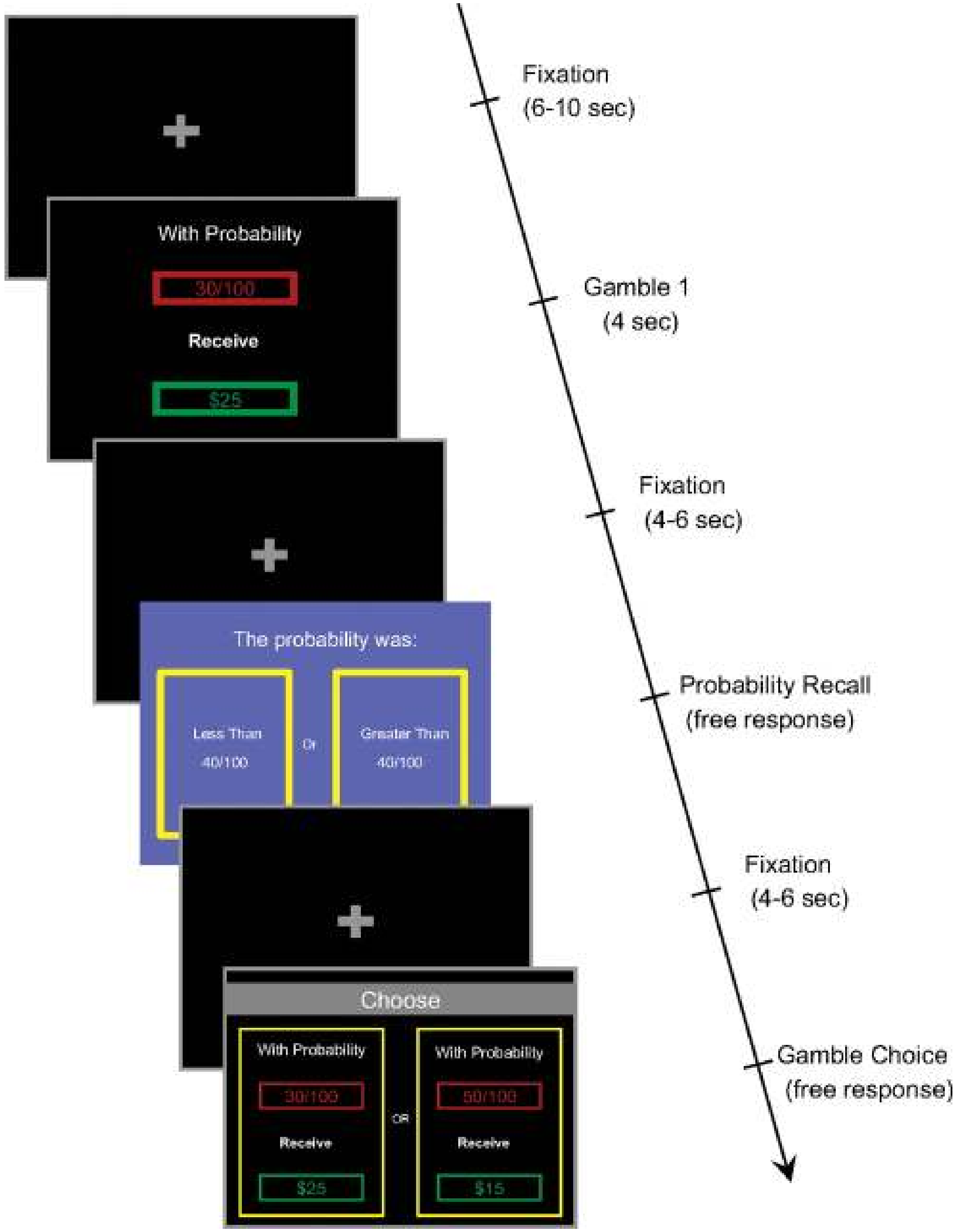
U - expected utility.

w - a probability weighting function.

v - a value function that assigns a value to an outcome

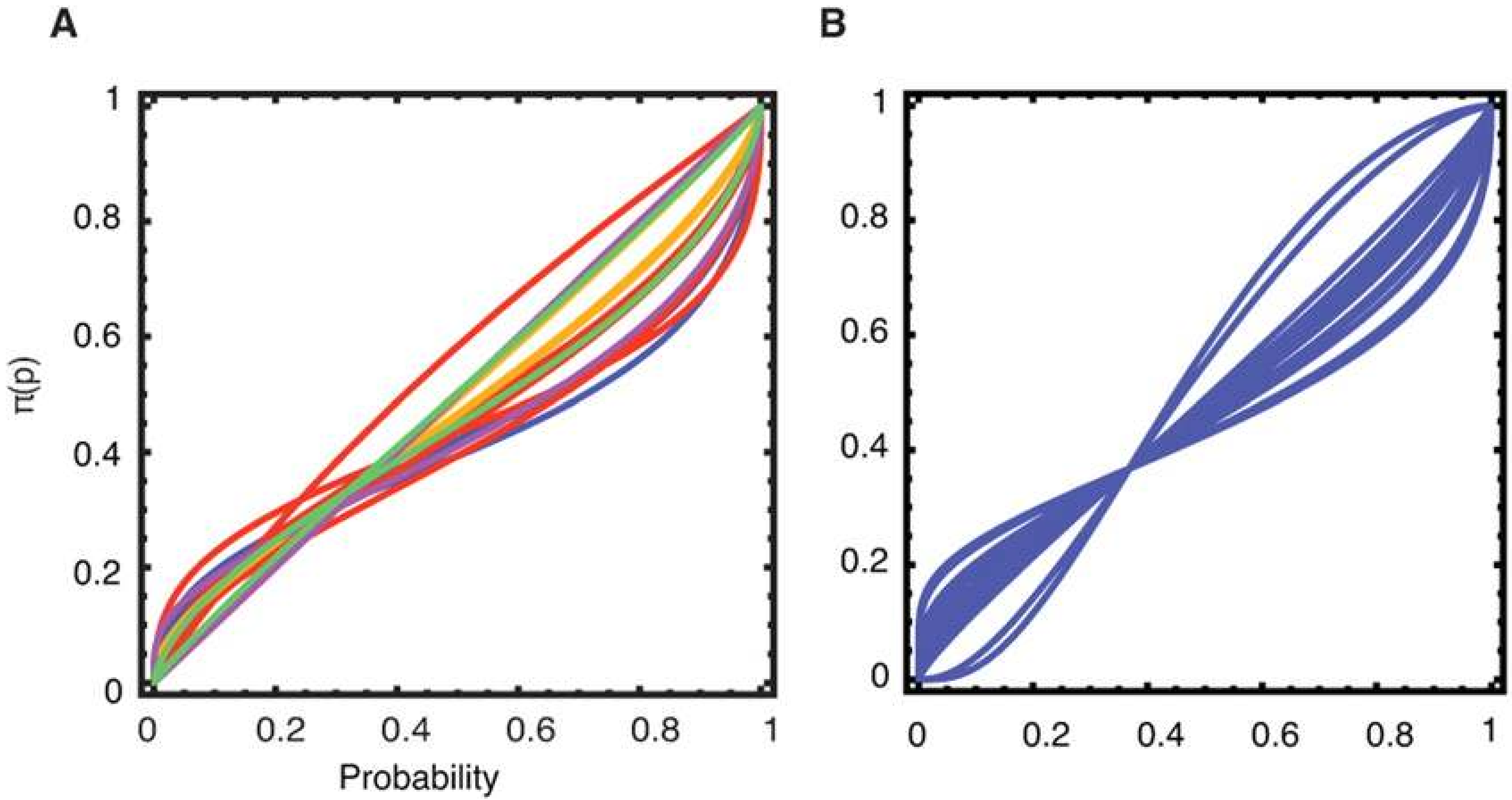


Prospect theory (PT; Kahneman and Tversky, 1979) **decision weight function** π (*p*). PT suggests a subjective transformation of objective probabilities, *p*, into subjective decision weights, *π (p)* , which indicates the impact the event has on the decision. Formalized empirical observations show that small probability events receive more weight than they should, based on their likelihood of occurrence, while large probabilities receive too little weight.



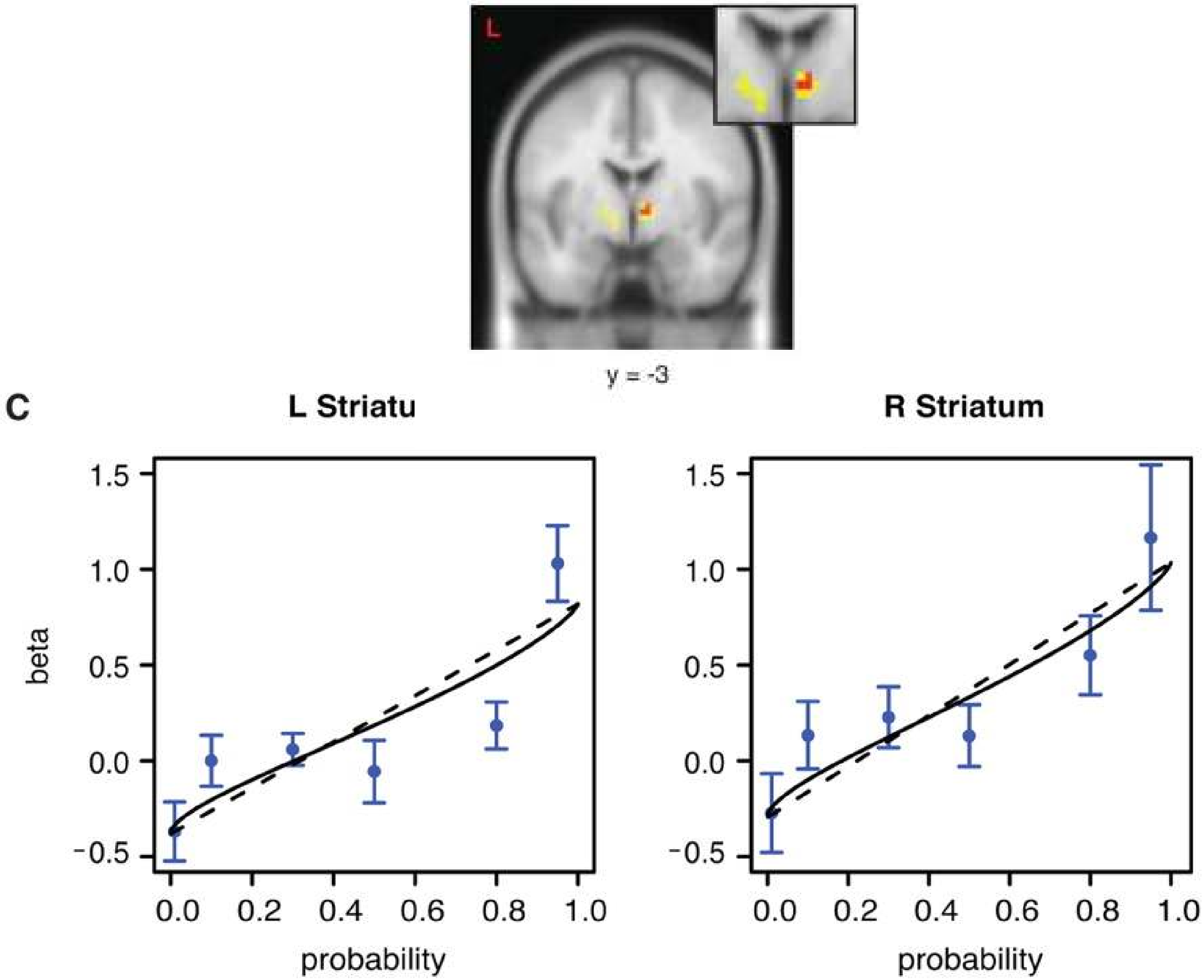
1. (1) A single gamble, consisting of the probability *p*1 of receiving some dollar amount $*x* (or 0 otherwise).
2. (2) In 12 of the 120 trials, subjects are then asked to indicate whether the probability in the previous screen was greater or less than 40/100 (to engage attention to screen 1).
3. (3) Subjects see a choice screen showing the gamble shown in 1 and a new gamble. Weighted expected utility of the new gamble is close to that of the first gamble.

Hsu et al. 2009



Nonlinear weighting of probability inferred from choices.
A, Fits of the weighting function π(*p*) from many previous behavioural studies.
B, Fits from individual subjects in the current experiment.

Hsu et al. 2009



Expected reward responses: activation for extracted voxels (blue dots) in the left and right striatum

Hsu et al. 2009

- Activity in the striatum during valuation of monetary gambles is nonlinear in probabilities, in the pattern predicted by Prospect Theory.

- The degree of nonlinearity reflected in individual subjects' decisions is also correlated with striatal activity across subjects.

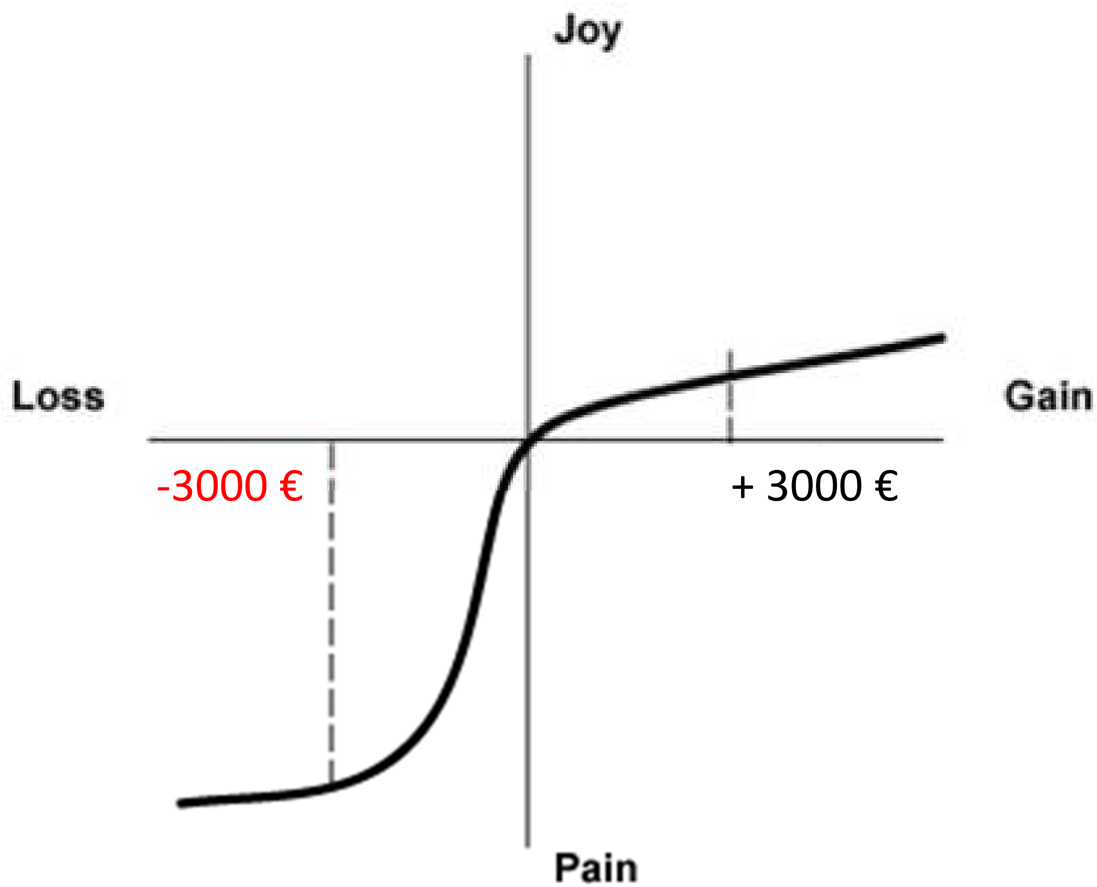
Hsu et al. 2009

How do people feel about pure gain and pure loss lotteries?

- Kahneman and Tversky have shown that people are risk averse in the gain domain and risk seeking in the loss domain.
- Consider a choice:
  - Get 3000 € for sure or win 4000 € with probability 0.8: <u>80% of people choose 3000 € for sure</u>

  - Get -3000 € for sure or lose -4000 € with probability 0.8: <u>92% of people choose a lottery now</u>

v - value function



Problem 1—The Asian Disease

Imagine that the United States is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed.

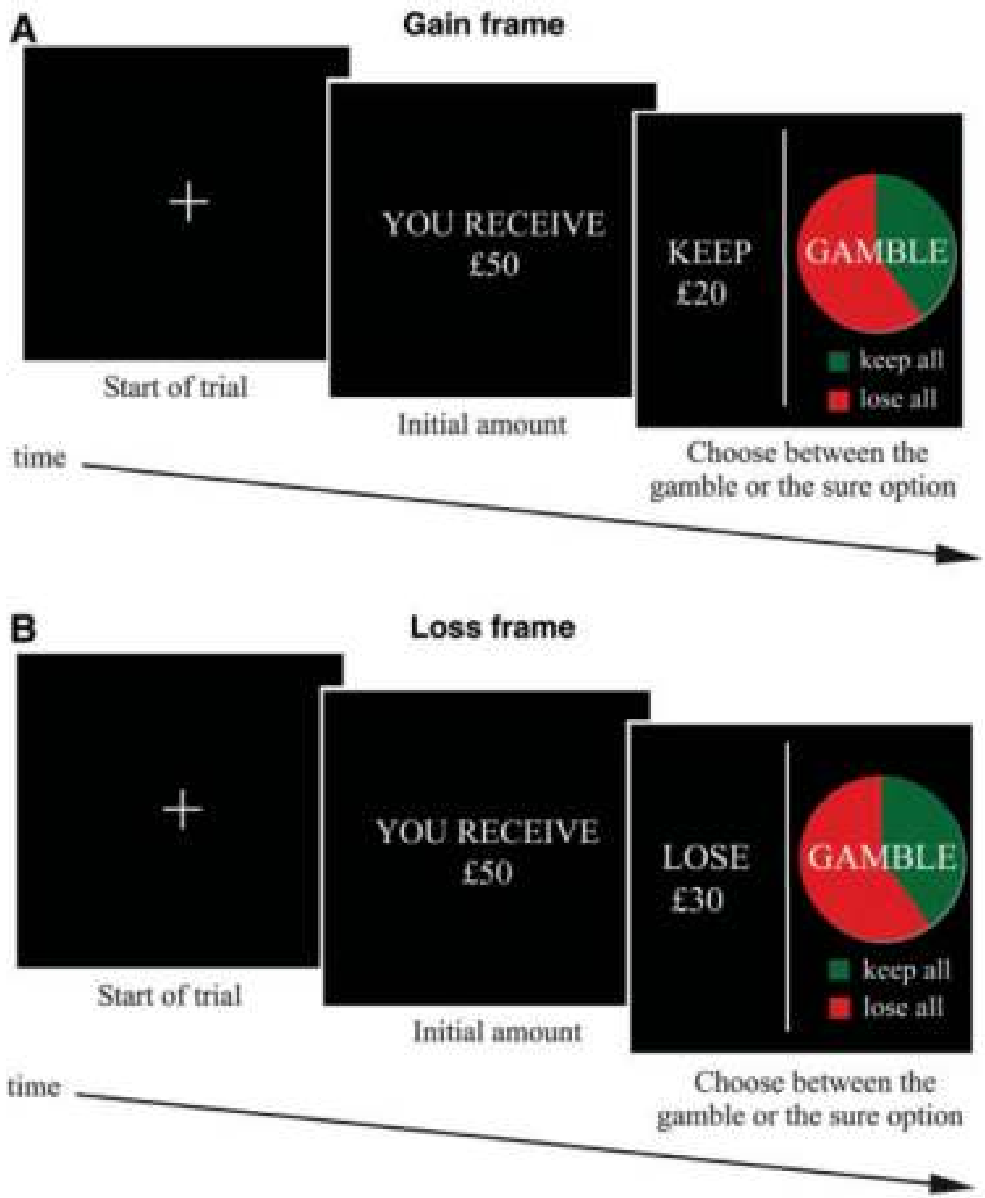
If Program A is adopted, 200 people will be saved.

If Program B is adopted, there is a one-third probability that 600 people will be saved and a two-thirds probability that no people will be saved.

Which one of the two programs would you favor?

If Program A′ is adopted, 400 people will die.

If Program B′ is adopted, there is a one-third probability that nobody will die and a two-thirds probability that 600 people will die.

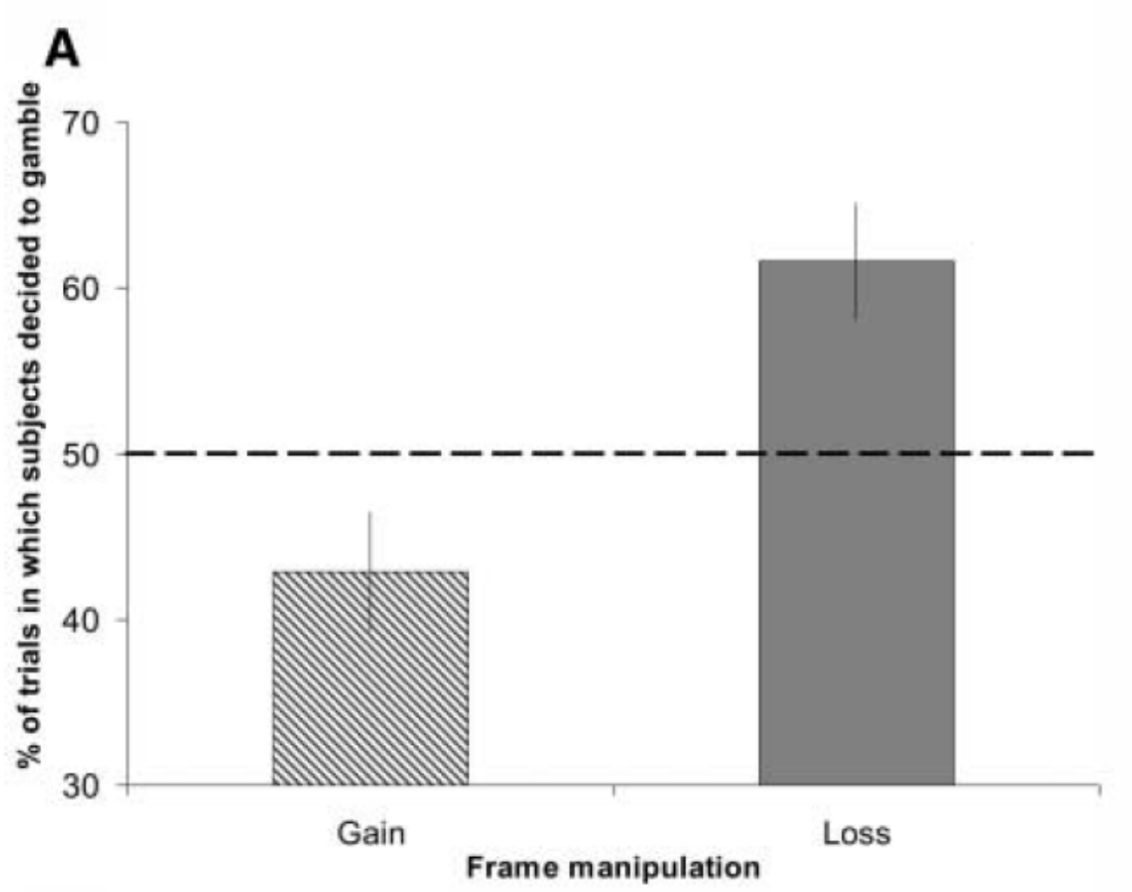


Condition 1

Condition 2

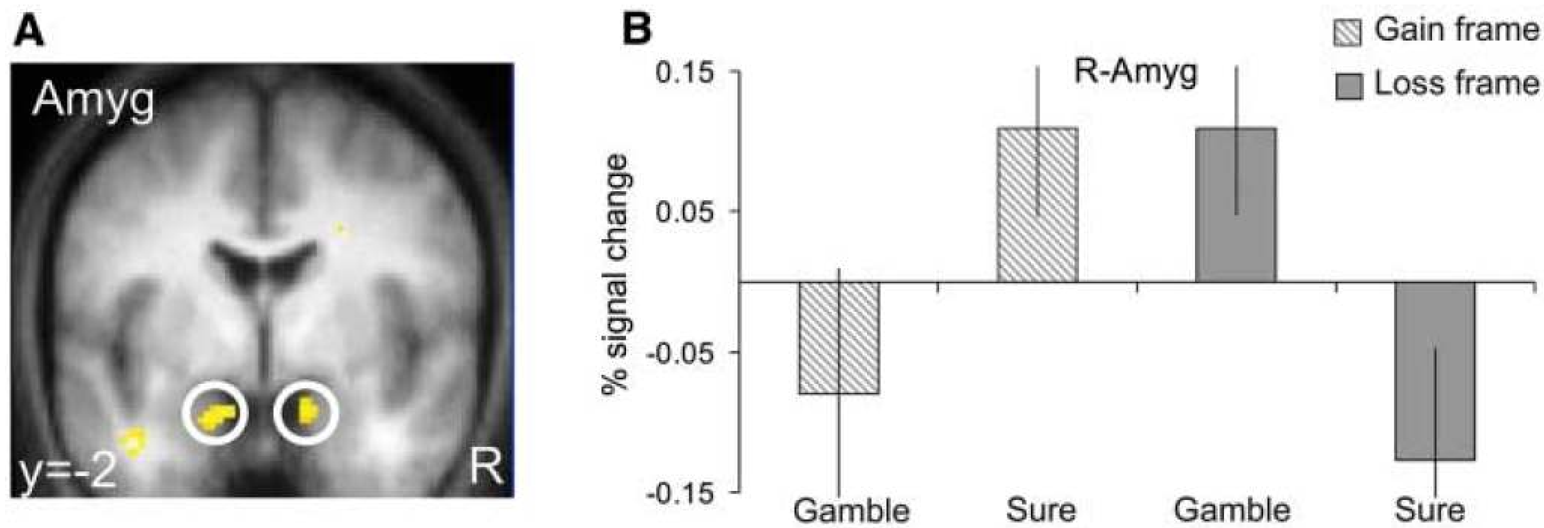
De Martino et al. 2006

Percentages of trials in which subjects chose the gamble option in the Gain and in the Loss frame



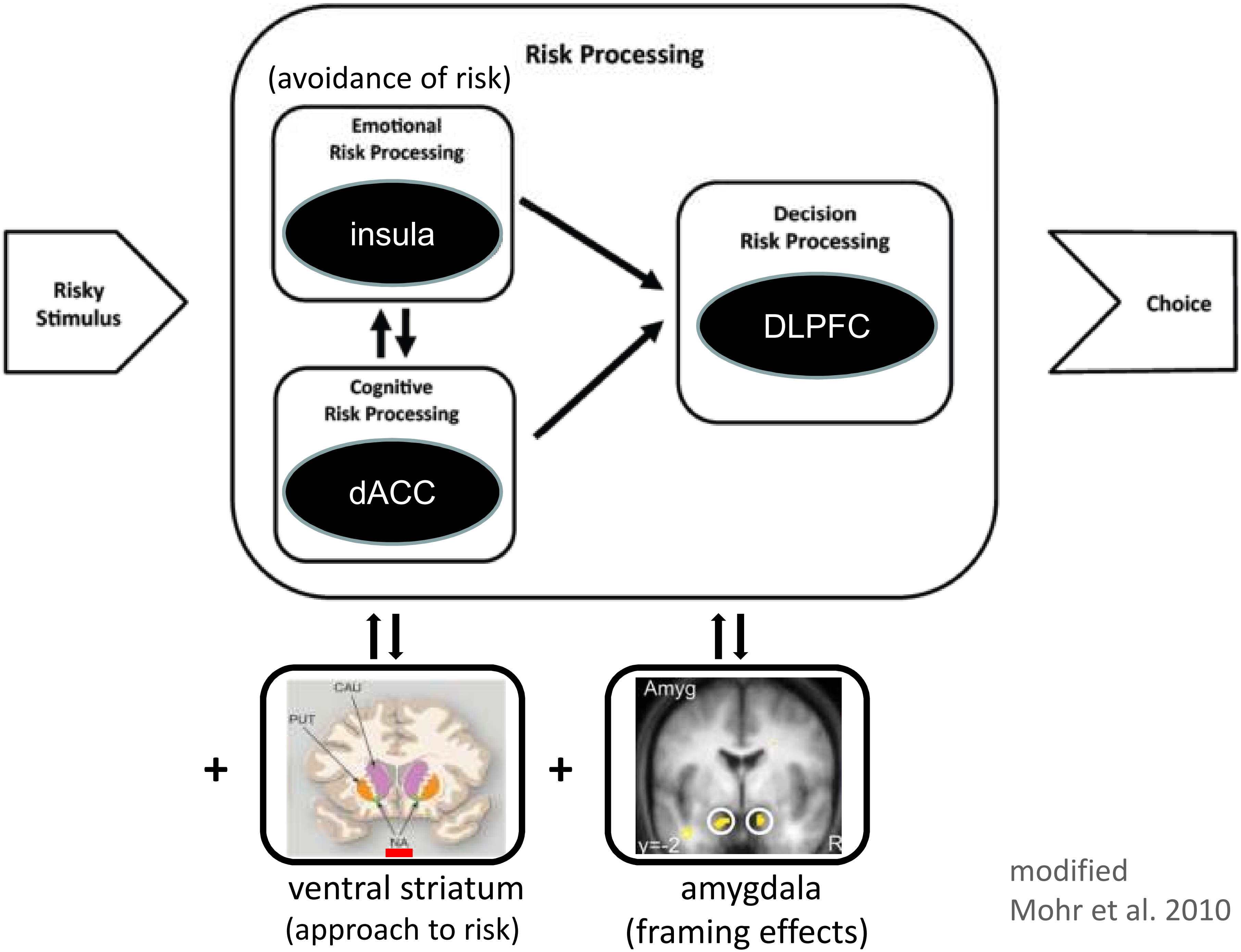
De Martino et al., 2006

Brain activations reflecting subjects' behavioral tendency to choose the sure option in the Gain frame and the gamble option in the Loss frame



The framing effect was specifically associated with amygdala activity, suggesting a key role for an emotional system in mediating decision biases.

De Martino et al., 2006



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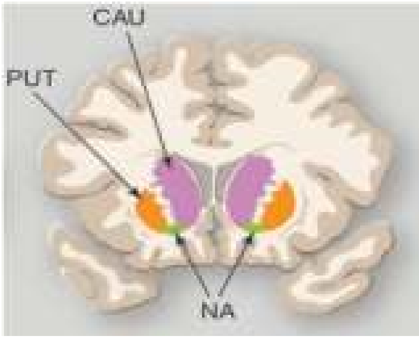
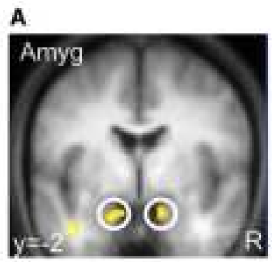
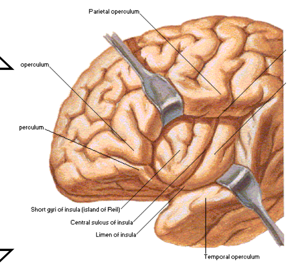
Mohr et al. 2010



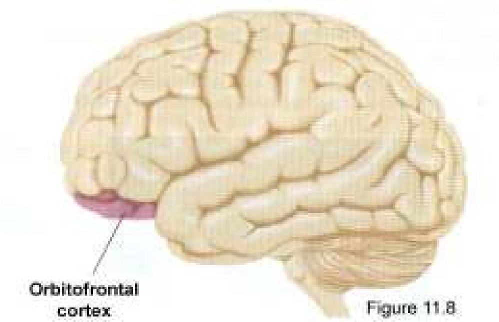
Nucleus accumbens (NAc) – subjective value / anticipated gain magnitude. Approach to risk.



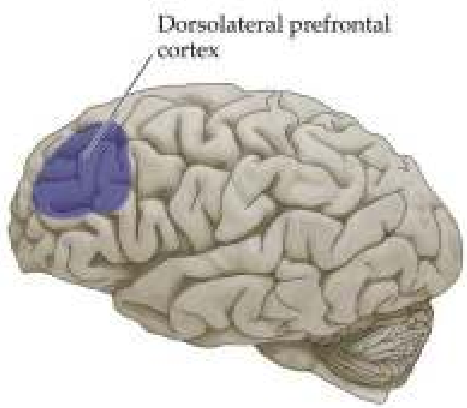
Amygdala – costs estimation, learning & framing.



Insula – emotions & risk evaluation.



Orbitofrontal cortex (OFC) – compares / integrates multiple information regarding the reward outcome.



Dorsolateral prefrontal cortex (DLPFC) – cognitive control & planning.

Thank you for your attention!