Modeling Decision Making Under Risk using Neurochemistry

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Spencer Conference

Beyond Correlation in the Study of Personality

Beyond Correlation in the Study of Personality

including attitude towards economic risk

Classical Decision Theory

- Primitives based on revealed choice
- Utility specification on well defined domain
- Clean/efficient axiomatization, preferably

For examples, EU

“Behavioral” Decision Theory

- Classical decision theory + psychological considerations

“Behavioral” Decision Theory

- Classical decision theory + psychological considerations
- Prime example – prospect theory (1979):
  - Loss-gain differentiation: reference dependence, loss aversion, gain-loss differentiation of risk attitude
  - Nonlinear response to probabilistic outcomes

Valuation Function in Prospect Theory (K&T 1979)

- Weber-Fechner
- Reference point
  - Status quo
  - Endowment effect
- Loss-gain differentiatio
  - Risk averse in gain
  - Risk taking in loss
- Loss looms larger than gain
  - Loss aversion

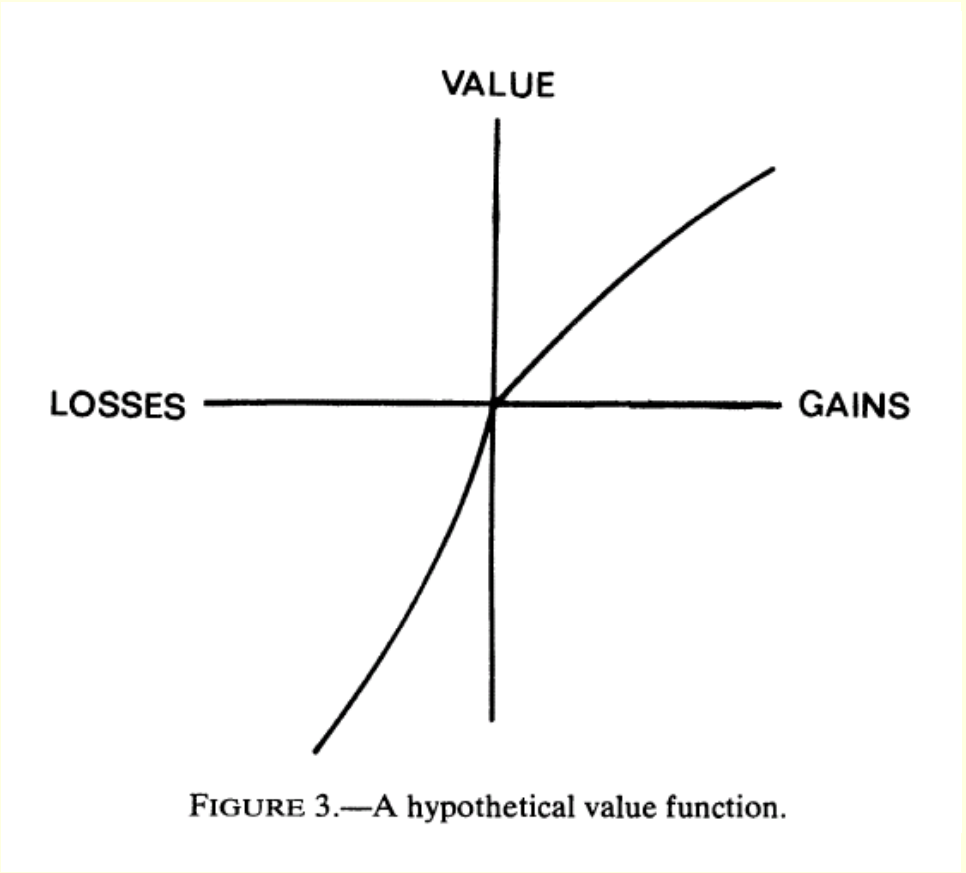


FIGURE 3.—A hypothetical value function.

Probability Weighting

- Weber-Fechner again?
- Pessimism and optimism
- Overweight small probabilities

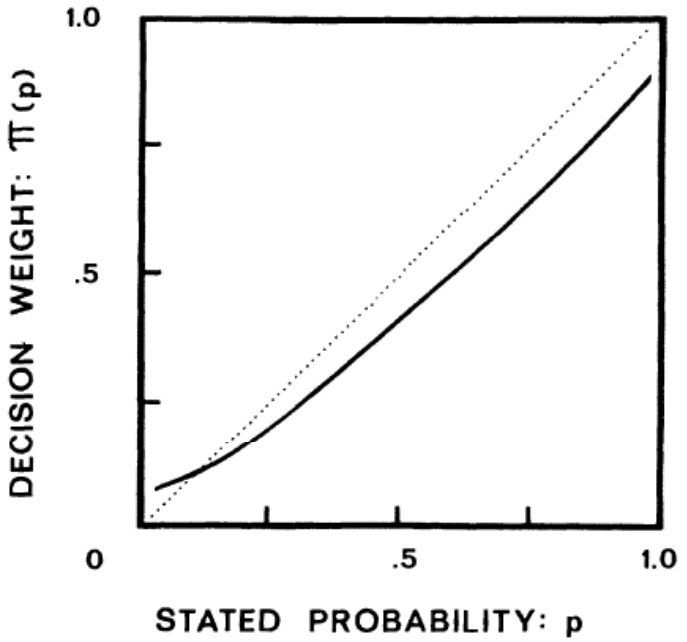


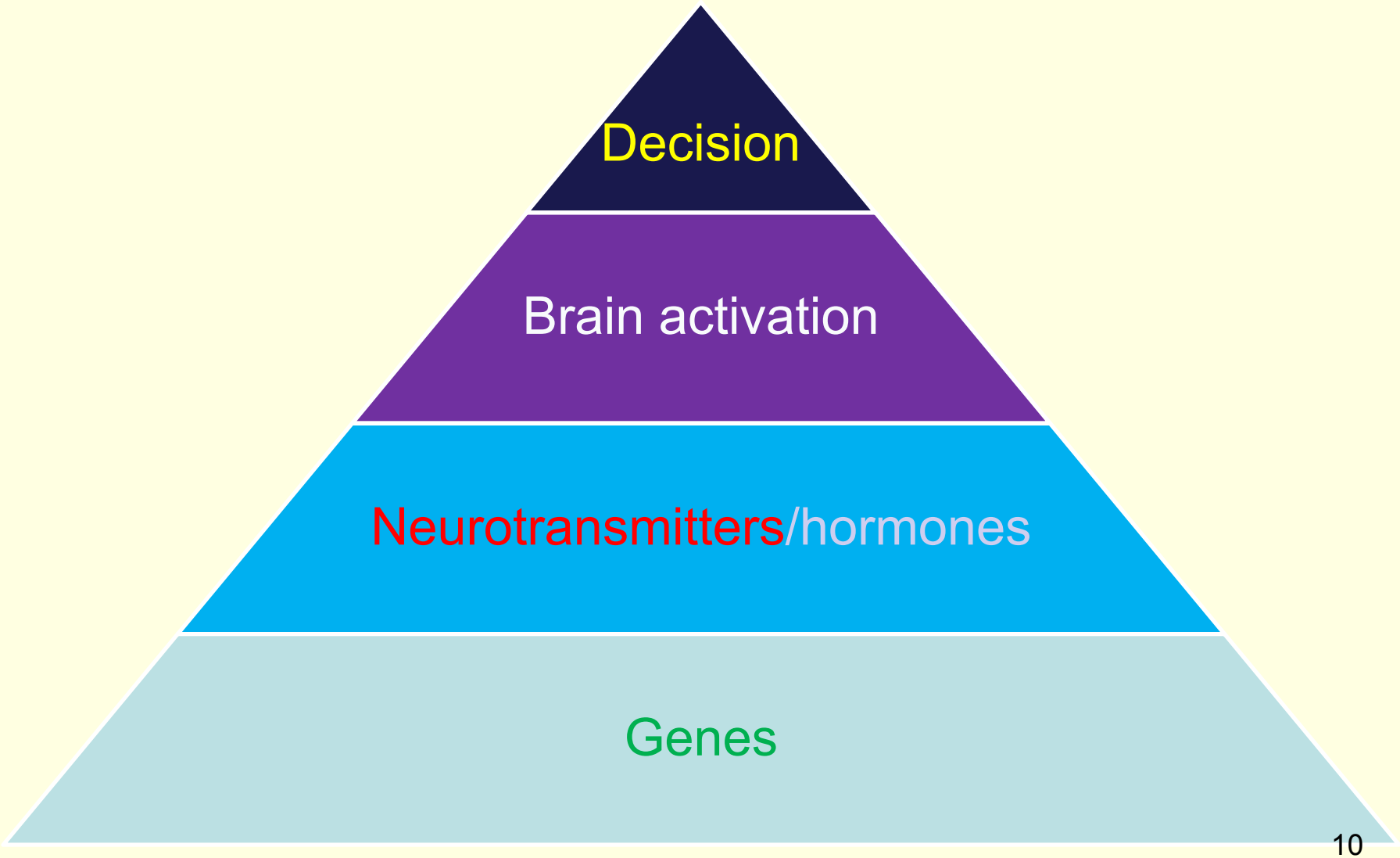
FIGURE 4.—A hypothetical weighting function.

Beyond
revealed choice

- Biomarkers (e.g., gender) and physiological variables
- Brain activation
- Genetic makeup

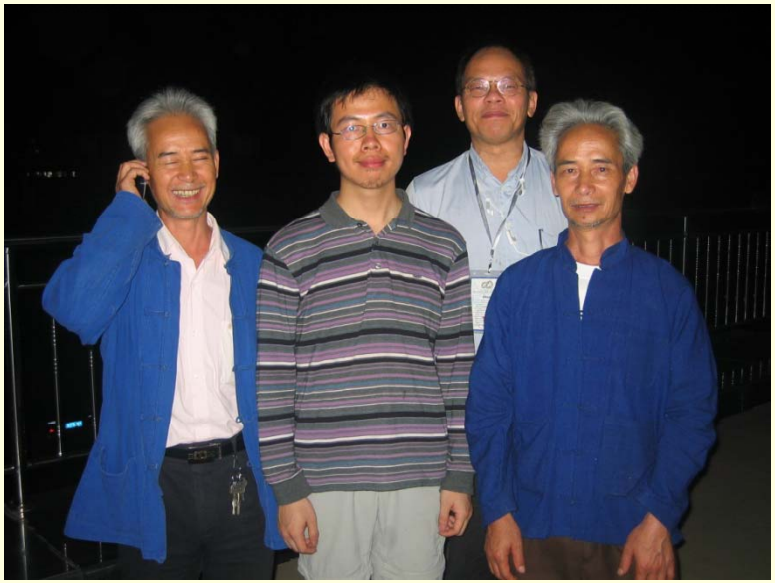
How might biology be incorporated?

Gene ←→ Decision



Heritability of Risk Attitude

- Zhong et al., 2009 a
  - Genetic effect (57%)
  - Environmental effects (43%)
- Cesarini et al., 2009
  - Genetic effect (14%)
  - Environmental effects (86%)



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Molecular Genetics of Risk Attitude

Study	N	Risk Attitude	Gene
Crisan et al	36	Loss-gain framing	5-HTTLPR
Dreber et al	94	Portfolio choice	DRD4
Kuhnen & Chiao	65	Portfolio choice	5-HTTLPR,DRD4
Roe et al	67	Multiple-price list design	CHRNA4
Roiser et al	30	Loss-gain framing with fMRI	5-HTTLPR
Zhong et al (2009b)	325	Even-chance risks over gains and losses	Stin2, DAT1
Zhong et al (2009c)	325	Longshot risks over gains and losses	MAOA
Zhong et al (2009c)	325	Longshot risks over gains and losses	MAOA

Goal

- Immediate
  - Build a model of decision making under risk linking genetic makeup with revealed choice.
- Long Term
  - Develop biologically sound approach to economic modeling
- Eventually
  - behavioral x biological economics (**B^2E**)

Two Immediate Deliverables

- Predict association between gene and decision
  - Go beyond association

Immediate Deliverables

- Predict association between gene and decision
  - Go beyond association
- Predict correlation in fourfold risk attitude
  - Share common biological factors

Attitudes towards Fourfold Risks

Moderate Hazards

Limited

Risk Preference

Moderate Prospects

Globally

Risk Averse

Skewed Hazards

Globally

Risk Averse

Skewed Prospects

Limited

Risk Preference

Moderate Prospect

- Subjects valuation (v) of risky option (50% of getting 60 Yuan; 50% of getting nothing)
  - V>35
  - 30<V<35
  - 25<V<30
  - V<25

Moderate Hazard

- Subjects valuation (v) of risky option (50% of losing 10 Yuan; 50% of losing nothing)
  - V>-4
  - -4<V<-5
  - -5<V<-6
  - V<-6

Longshot Prospect

- Longshot preference (1% chance of getting 200 Yuan $\succ$ 10% chance of getting 20 Yuan $\succ$ 2 Yuan for sure).
  - Yes
  - No

Longshot Hazard

- Insurance (Losing 2 Yuan for sure $\succ$ 0.1% chance of losing 2000 Yuan).
  - Yes
  - No

Correlations among Fourfold Risks?

	Moderate Prospect	Longshot Prospect	Moderate Hazard
Longshot Prospect	?		
Moderate Hazard	?	?	
Longshot Hazard	?	?	?

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Prediction of most models limited to:

	Moderate Prospect	**Longshot Prospect**	**Moderate Hazard**
Longshot Prospect	+		
Moderate Hazard	NA	NA	
Longshot Hazard	NA	NA	+

Concave (convex) valuation function in gain (loss) would predict positive correlation between MP and LP (MH and LH).

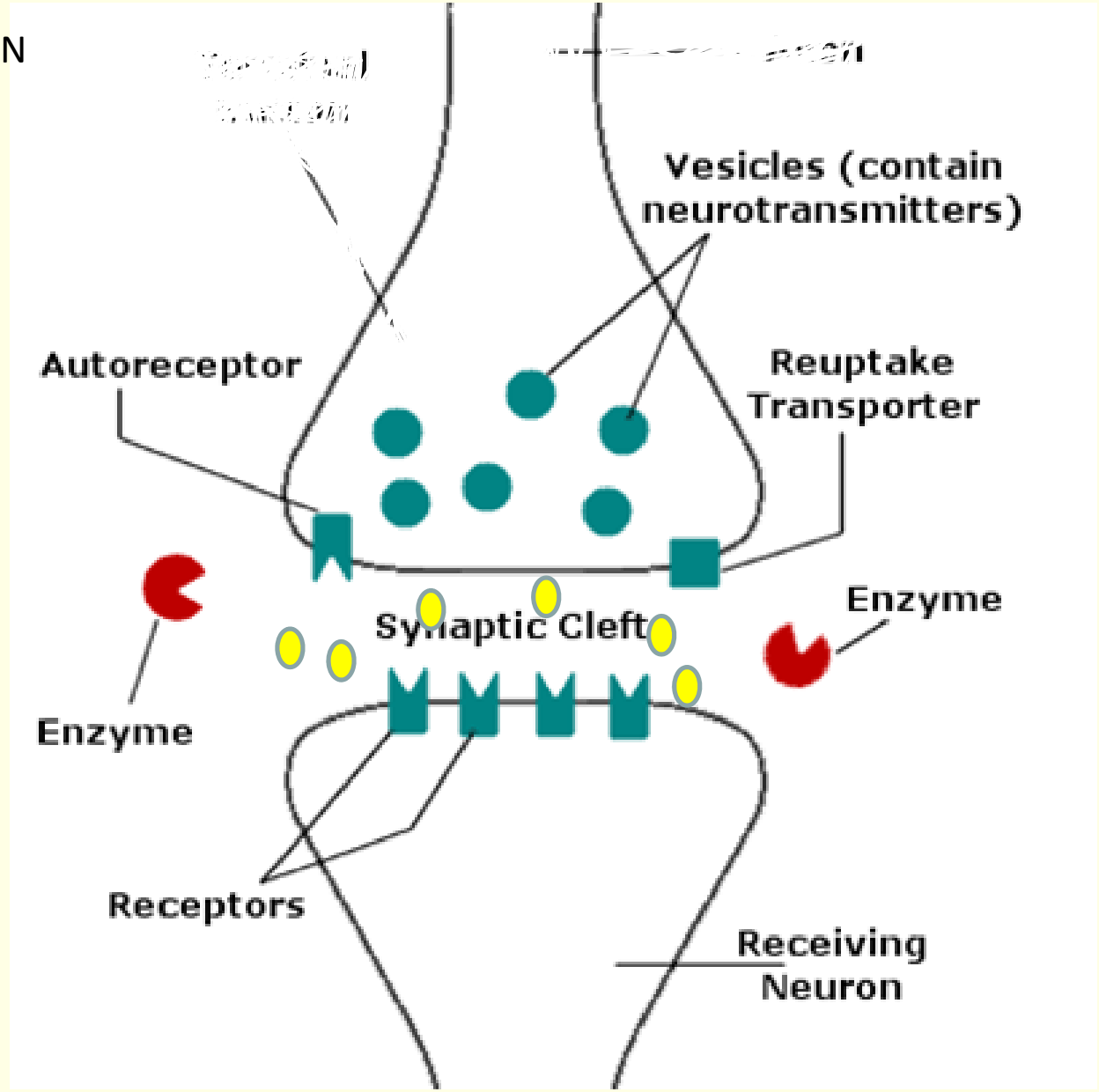
New Behavioral Evidence: Correlations among Four-fold Risks

	Moderate Prospect	**Longshot Prospect**	**Moderate Hazard**
Longshot Prospect	0.160**		
Moderate Hazard	0.297***	0.137*	
Longshot Hazard	– 0.070	0.034	0.031

Table 1. Spearman correlation between different pairs of attitude towards fourfold risks (N=325). Estimated correlation with two-tails significance indicated by * for 5%, ** for 1%, and *** for 0.1%.

Neurochemistry without Tears

INFORMATION FLOW



Neurochemistry without Tears

Dopamine (DA)

- **Gain**
  - reward as well as reward prediction errors (Schultz, Dayan, and Montague, 1997)
  - novelty seeking (Cloninger, 1986; Ebstein et al., 1996)
  - expected reward (Preuschoff, Bossarts and Quartz, 2005)
- **Not loss**
  - does not produce negative prediction error (Fiorillo, Tobler, and Schultz, 2003).
  - administration of DA drugs affects risky decision making under gains but not under losses (Pessiglione et al 2006)

Neurochemistry without Tears

Serotonin (5HT)

- Harm avoidance (Cloninger, 1986)
- Anxiety-related personality traits (Lesch *et al* 1996)
- Amygdala activation and loss-gain framing (Roiser *et al* 2009)

DA and 5HT Opponent Partnership Hypothesis

- Opponency between reward and punishment is fundamentally asymmetric (*Daw, et al, 2002; Dayan and Huys, 2009)*
- Losses loom larger than gains

Neurochemistry without Tears

Saliency – salient stimuli (e.g., tones and light) that are not inherently reward related (see Ungless, 2004 for review).

- novelty of an unexpected physical stimulus (Ljungberg, Apicella, and Schultz, 1992).
- unexpected novel sound interferes, even in the absence of reward (Zink et al, 2006).

Neurochemistry without Tears

Tone

- low-level background firings in slow, irregular single-spike mode.
- Polymorphic genes modulate available neurotransmitter/receptor numbers that contribute to their background firing.

Fourfold pattern of risk attitude

Task 1: Moderate Prospect (G, ½)
(*61%* *exhibits risk tolerance for longshot prospects*)
Task 2: Longshot Prospect (G, p)
(*80%* *exhibits risk aversion for moderate prospects*):
Task 3: Moderate Hazard (L, ½)
(*69%* *exhibits risk tolerance for moderate hazards*)
Task 4: Longshot Hazard (L, q)
(*69%* *exhibits risk aversion for longshot hazards*)

Biology of Fechner-Weber Law

– Beyond psychophysics

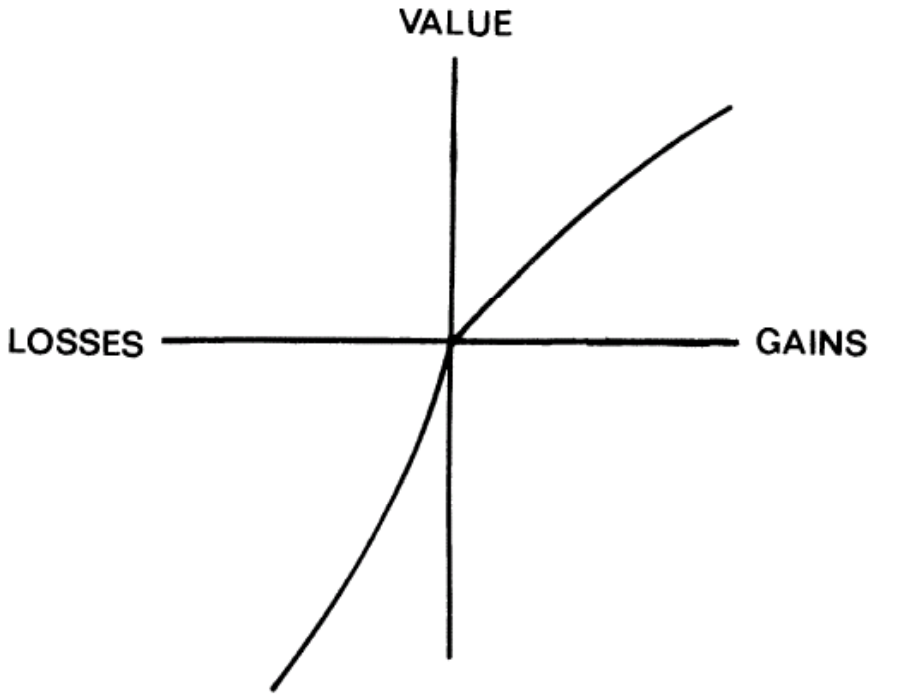


FIGURE 3.—A hypothetical value function.

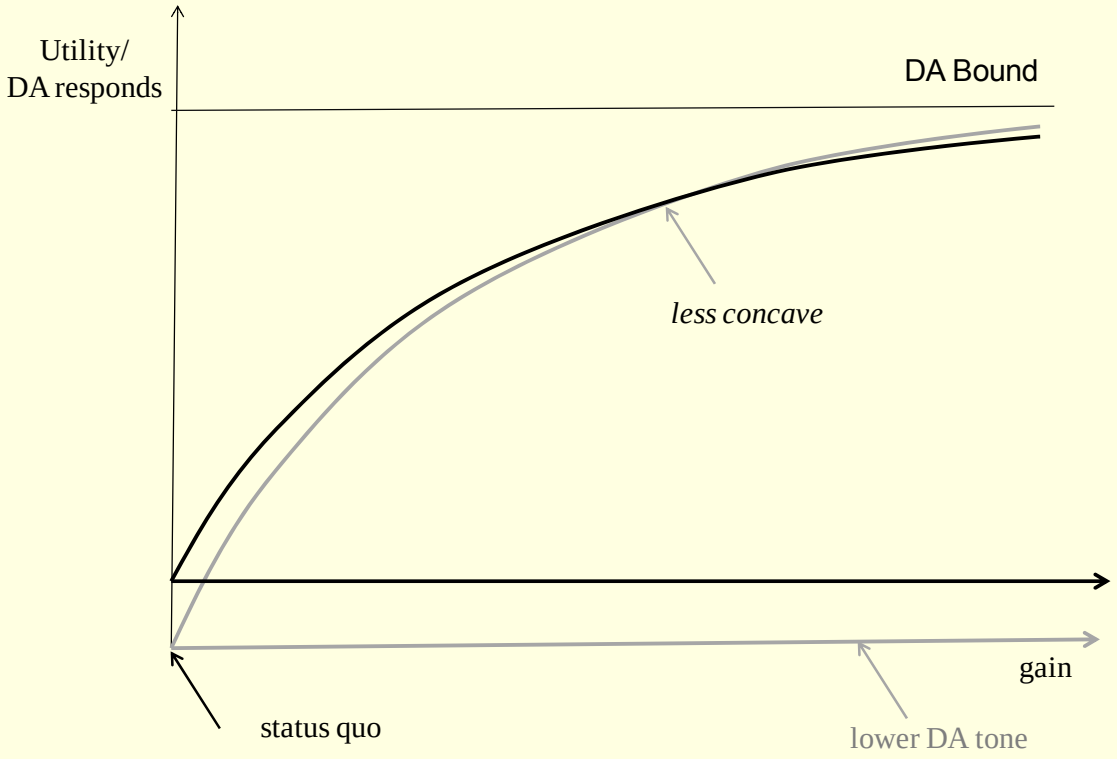
Berns' Biological Bound Hypothesis

- Noting that DA are in limited supply in the brain, they lead naturally to bounds to the value function in both gains and loss domains
- This value function would be convex over losses besides being concave over gain
- Implication re "kink" at status quo
- Biological basis for the psychophysics of valuation sensitivity

Biological Bound Hypothesis + Tone

Bound + Tone Hypothesis for DA

- **Bound**: limited availability
- **Tone:** low-level background firings
- Higher DA tone, lower capacity, more concave in gain



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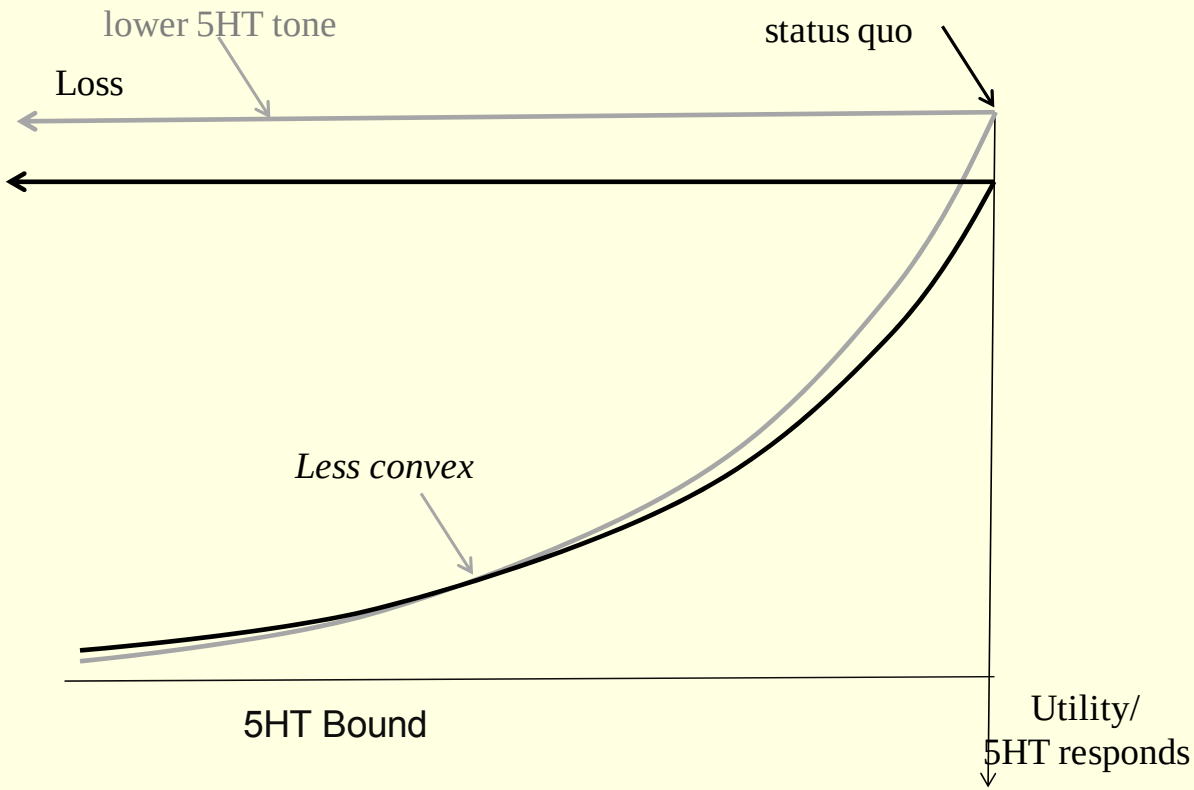
Bound + Tone Hypothesis for 5HT

- **Tone:** low-level background firings
- **Bound**: limited availability
- Higher 5HT tone, lower capacity, more convex in loss



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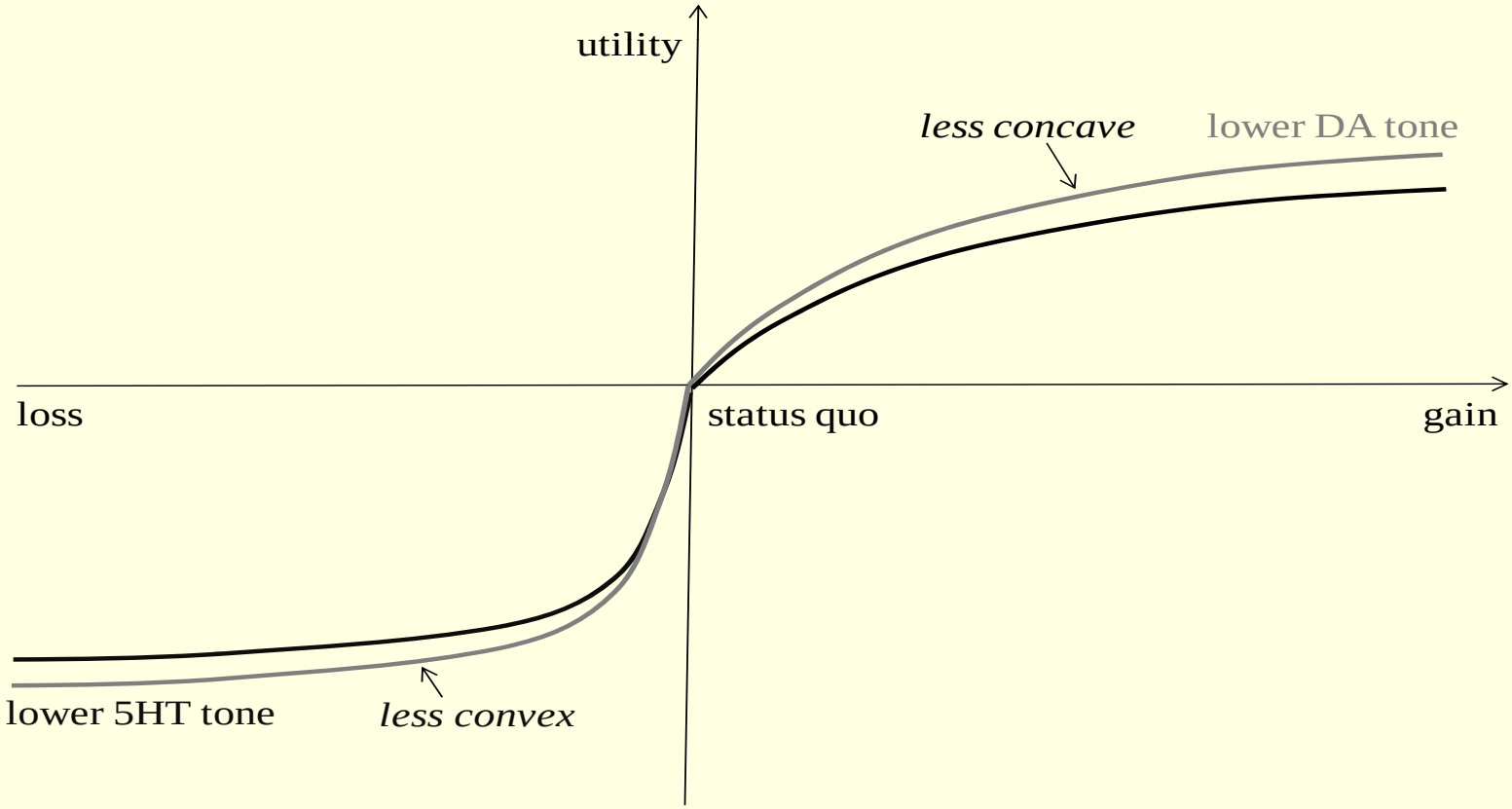
Hypothesis V (Dual System)

- *Higher DA (5HT) tone associates with a more concave (convex) valuation function over gains (losses).*



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Candidate Genes ↓↑= **TONE**

- **Dopamine** transporter
  – (9 ↓, 10 ↑)
- **Serotonin** transporter – 2 polymorphisms
  –**5HTTLPR** (short ↑ , long ↓)
  –**STiN2** (10 ↑, 12 ↓)

Corroborating Dual System Hypothesis (Zhong et al., 2009 b)

- 325 subjects
- Risk attitude for gain and loss
- Candidate Gene – Dopamine transporter DAT
  - midbrain activation (Schott et al., 2006)
  - in vivo transporter availability (van Dyck et al., 2005)
    - (9 ↓, 10 ↑)
- Candidate Gene – Serotonin transporter
  - 5HTTLPR (short ↑ , long ↓)
  - STiN2 (10 ↑, 12 ↓)

↓↑= TONE

Finding Corroborating Dual System Hypothesis

	Gene	*OR*	*CI*		*z-value*	*p-value*
Gain	DAT1	1.77	1.04	3.04	2.07	0.035*
	STin2	1.22	0.96	1.54	1.63	0.104
	5-HTTLPR	1.21	0.86	1.68	1.12	0.264
Loss	DAT1	1.63	0.88	2.99	1.56	0.118
	STin2	1.36	1.03	1.79	2.18	0.029*
	5-HTTLPR	1.36	0.97	1.9	1.78	0.075

Nonlinear Probability Weighting

- $p^c/[p^c+(1-p)^c]^{1/c}$ (Tversky and Kahneman, 1992)
- $sp^c/[sp^c+(1-p)^c]$ (Lattimore, Baker, and Witte, 1992)
- $exp\{-[-\ln p]^a\}$ (Prelec, 1998)
- $1/\{1+(1-p)/ps\}$ (Rachlin et al 1991)

Outcome Dependence

- Overweighting of small probabilities depends on the size of outcomes such that large outcomes engender greater curvature than smaller outcomes. (Camerer, 1992; Tversky and Kahneman, 1992)
- People tend to be more pessimistic when facing large losses (Etchart-Vincent, 2004)
- Reflecting affect salience and echo the suggestion that they can depend on the underlying outcome *x* (Rottenstreich and Hsee, 2002)

Nonlinear Probability Weighting

- $p^c/[p^c+(1-p)^c]^{1/c}$ (Tversky and Kahneman, 1992)
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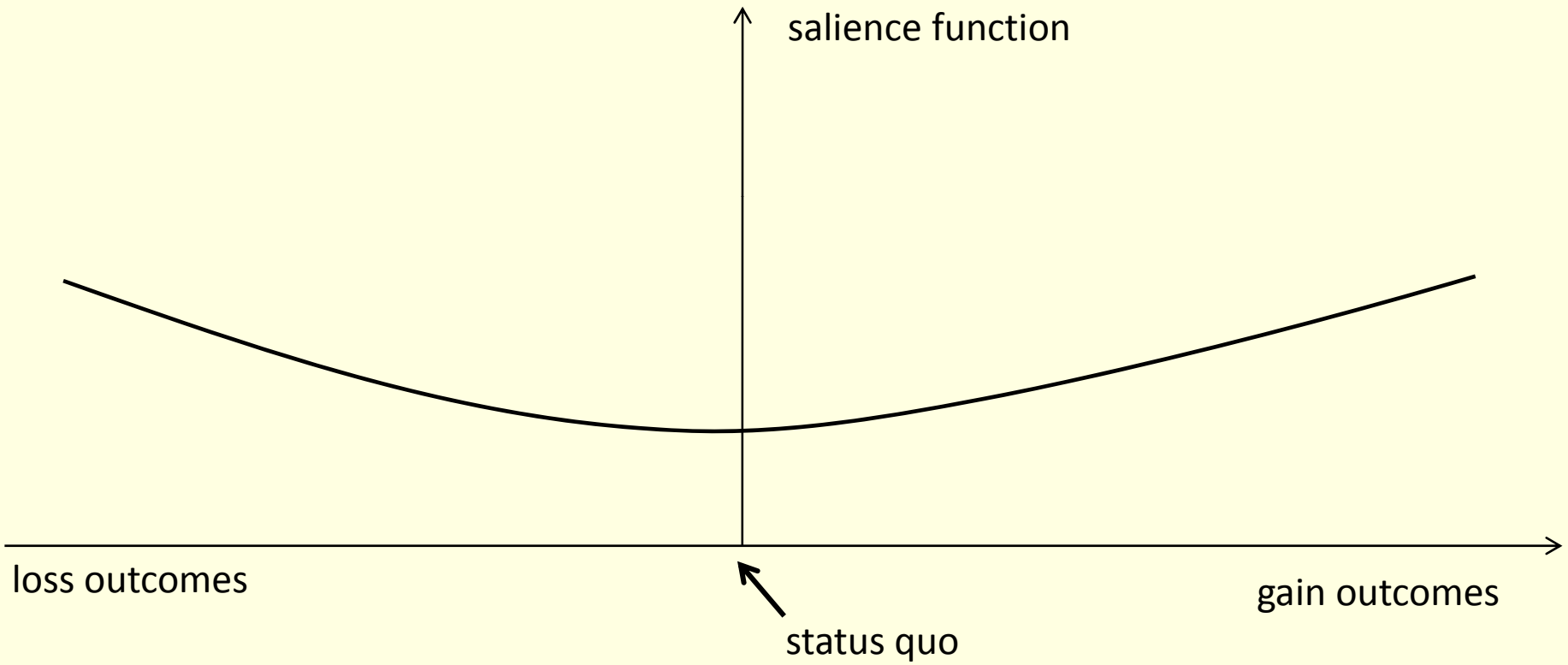
- $exp\{-[-\ln p]^a\}$ (Prelec, 1998)
- $1/\{1+(1-p)/ps\}$ (Rachlin et al 1991)

Incorporating outcome dependence

$$ps(x)/[ps(x)+1-p]$$

Salience function s(x)



Proposition A

- Under a loss-averse utility function *v* with v(0) = 0 and a U-shaped salience function *s* which is minimized at 0, the decision maker exhibits
  - aversion towards *(G,½)*

    if $v(G/2)/v(G) > [1+s(0)/s(G)]^{-1}$,
  - tolerance towards *(L,½)*

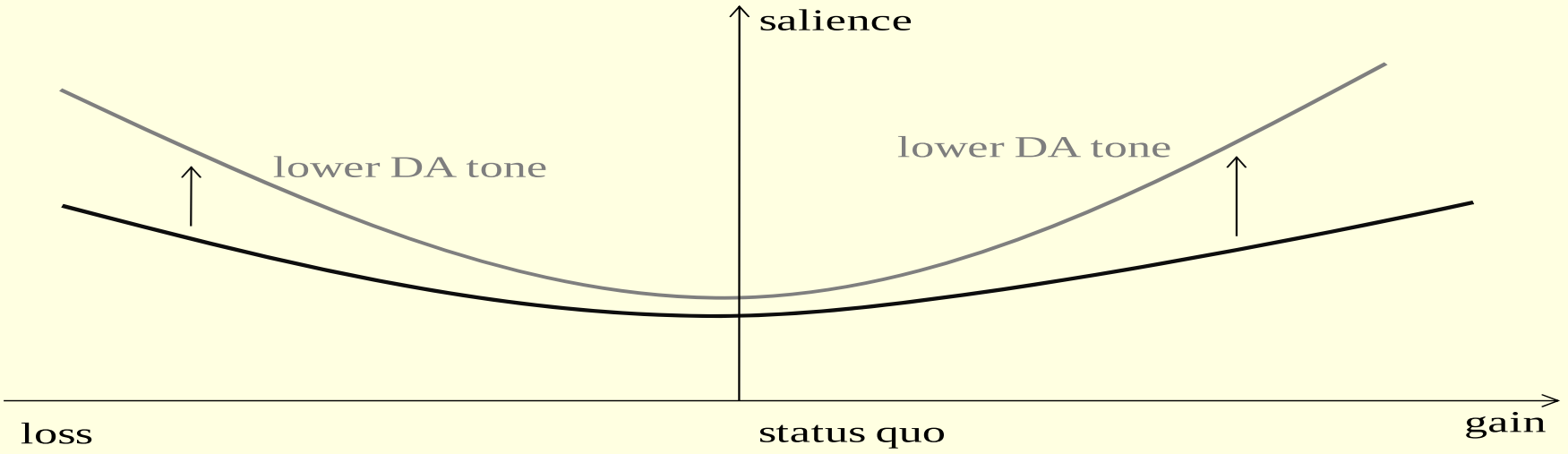
    if $v(L/2)/v(L) < [1 + s(0)/s(L)]^{-1}$,
  - tolerance towards *(G, p)* with *p* sufficiently small

    if $s(G)/G > v'(0)s(0)/m$
  - aversion towards *(L, q)* with *q* sufficiently small

    if $s(L)/|L| > v'(0)s(0)$

Hypothesis S – DA

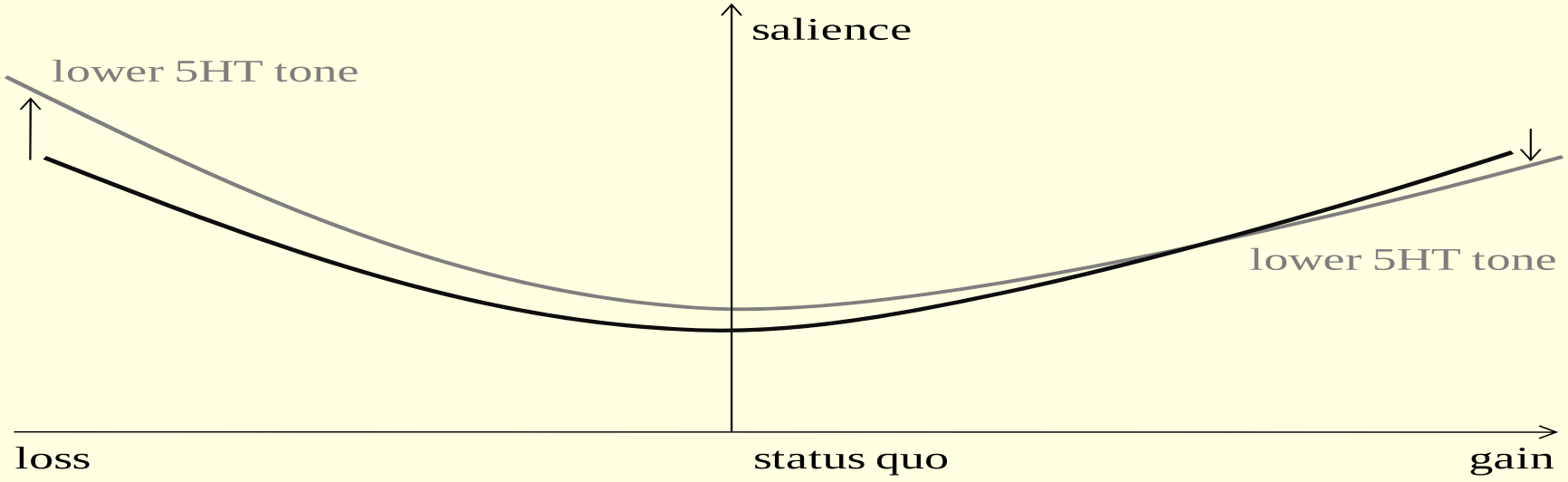
- Lower DA tone engenders a salience function *s* that increases faster over gains and decreases faster over losses relative to the case for higher DA tone.



(A) Saliency of outcomes and DA tone

Hypothesis S – 5HT

- Lower 5HT tone engenders a salience function *s* that decreases faster over losses as well as gains relative to the case for higher 5HT tone.
  - Attention focus and emotional salience



(B) Saliency of outcomes and 5HT tone

Proposition B

- Relative to the case of low DA tone, a decision maker with high DA tone will tend to be
  - D(i) more averse towards moderate prospects.
  - D(ii) more averse towards longshot prospects.
  - D(iii) less averse towards longshot hazards.
- Relative to case of low 5HT tone, a decision maker with high 5HT tone will tend to be
  - S(i) less averse towards moderate hazards.
  - S(ii) less averse towards longshot hazards.
  - S(iii) less averse towards longshot prospects.

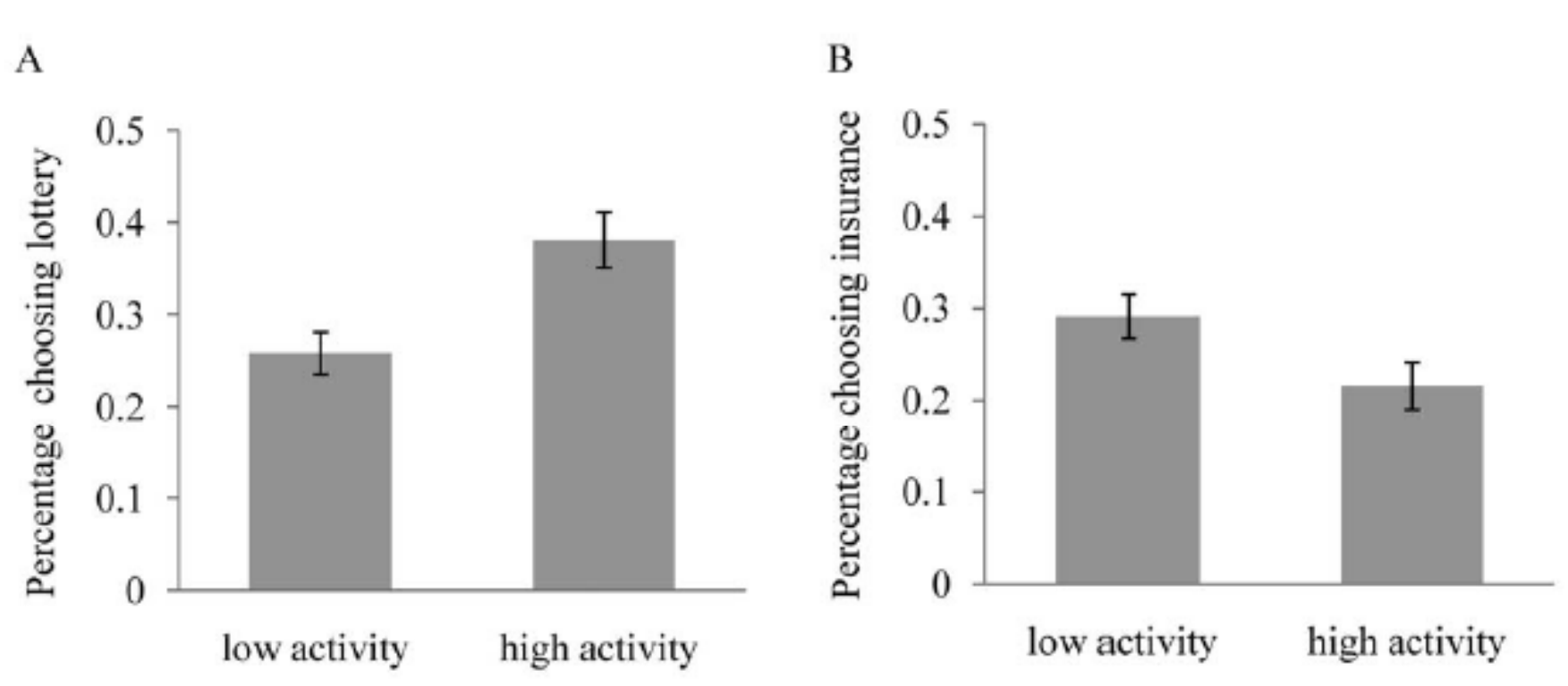
Correlation among Fourfold Risks

	Moderate Prospect	Longshot Prospect	Moderate Hazard
Longshot Prospect	*Positive: D(i) & D(ii)* 0.160**		
Moderate Hazard	*Positive#* 0.297***	*Positive: S(i) & S(iii)* 0.137*	
Longshot Hazard	*Negative: D(i) &D(iii)* – 0.070	*No implication* 0.034	*Positive: S(i) & S(ii)* 0.031

Table 1. Spearman correlation between different pairs of attitude towards fourfold risks (N=325). Estimated correlation with two-tail significance indicated by * for 5%, ** for 1%, and *** for 0.1%.

#Interaction between dopamine and serotonin transmitters

Association Results for Longshot Risks



Final Slide

- One small step in incorporating biology to model decision making under uncertainty
  - Neurochemical tones as reference points
  - Dual-system model: Is an individual a group?

- Consilience of biology (beyond psychology) and economics, especially decision theory

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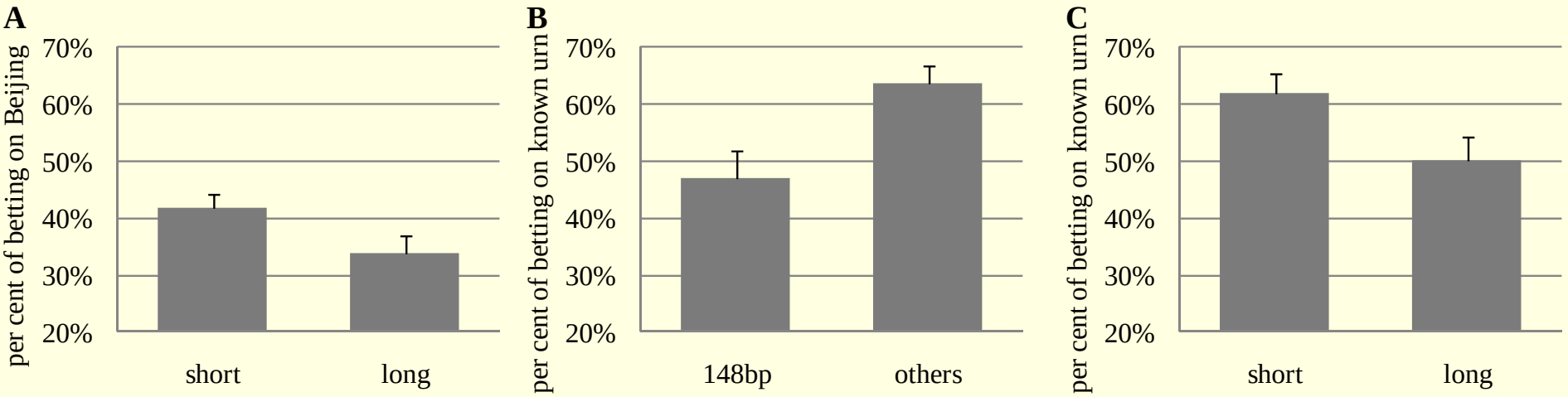
Source Dependence via Saliency

- "Known" uncertainty is more salient than "less known" uncertainty
  - Two decks of cards
- "Familiar" uncertainty is more salient than "less familiar" uncertainty
  - Two cities in China

s is more salient than s if s/s* is nondecreasing*

Ambiguity Aversion and Familiarity Bias



(A) 5-HTTLPR and familiarity bias. Subjects with short allele tend to bet on Beijing.

(B) (B) *DRD5 and ambiguity aversion in female.* Female subjects without 148bp allele tend to bet on known deck.

(C) *ESR2 and ambiguity aversion in female.* Subjects with short allele tend to bet on known deck.