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Modeling Beliefs in Computational Psychiatry

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Computational Psychiatry Unit, The University of Texas at Dallas
Advanced Imaging Research Center, UT Southwestern Medical Center

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Announcement

- **Pre-SFN workshop**: Friday-Saturday, Nov 10-11, 2017 (www.computationalpsychiatry.org/cp17)

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- **Pre-SFN workshop**: Friday-Saturday, Nov 10-11, 2017 (www.computationalpsychiatry.org/cp17)

- **SFN mini-symposium**: Sunday, Nov 12, 2017 @ 8:30 am - 11 am, Room 146a @ Walter E Convention Center

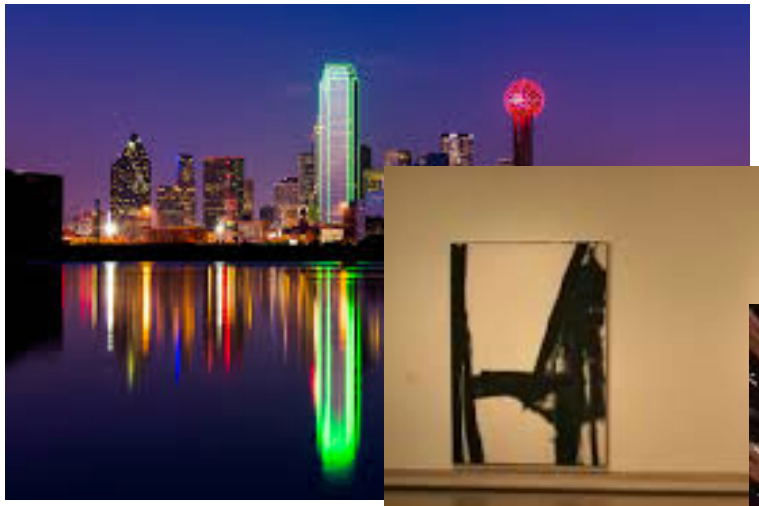
Computational Psychiatry: Multiscale Models of Mental Illnesses

Chair: Michele Ferrante, PhD
National Institute of Mental Health
Co-Chair: Xiao-Jing Wang, PhD
New York University
Date & Time: Sunday, November 12, 2017 8:30am - 11am
Location: 146A
CME: 2.5
This minisymposium will provide an in-depth introduction to the nascent and burgeoning field of computational psychiatry (CP). CP applies cutting-edge quantitative methods and theoretical models to investigate neural or cognitive phenomena relevant to psychiatric diseases. Talks will cover practical examples of theory- and data-driven computational models of cognitive deficits associated with schizophrenia, emotion regulation, anxiety, and drug addiction.

Job Opportunities (www.neurocpu.com)

One open Research Assistant position
https://jobs.utdallas.edu/postings/8431)

One PhD position open in Fall 2018
(apply through http://www.utdallas.edu/bbs/)



What is a belief?

- **Bayesian**: prior or posterior belief (probability distribution but with a psychological flavor)

- **In real life**: a state of mind in which one believes something is true
  - Stable, long-term (ideology)
  - Changeable, instantaneous, episodic

Beliefs in Psychiatry

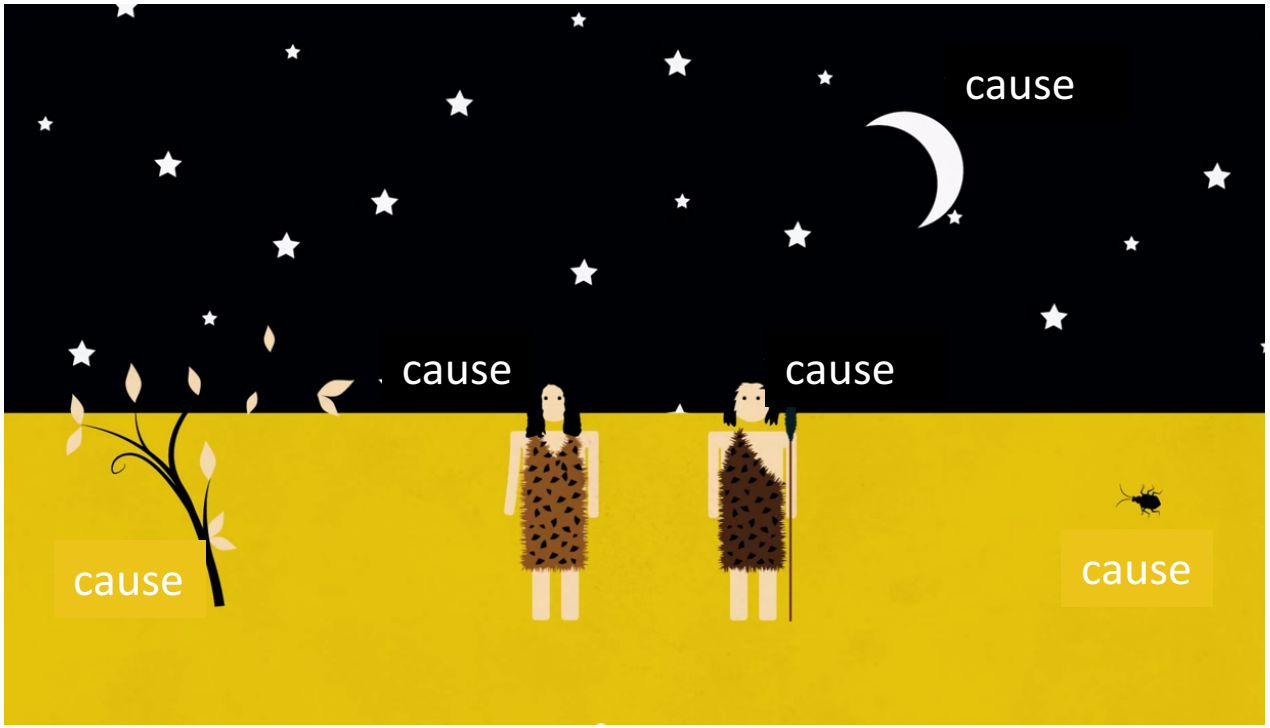
Schizophrenia
- Delusion: belief that contradicts evidence
- Hallucination: belief about (absent) sensory events

Depression
- Self-worthlessness
- Guilt
- Anhedonia: “nothing is rewarding”.

Eating disorder
- Distorted belief about body image

Broader impact of beliefs

Hidden causes, attribution, and religious beliefs



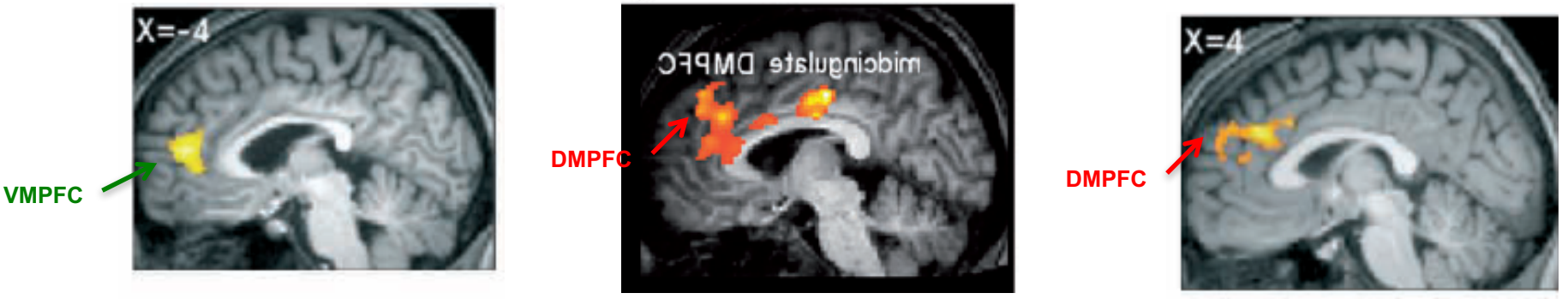
(credit: The big story: origins of religion by Yathish Dhavala)

The impact of religious beliefs on neural representations of the self

Non-religious

Buddhists

Christians



Dorsal medial prefrontal cortex (DMPFC): reappraisal and evaluation of self-related stimuli

Ventral medial prefrontal cortex (VMPFC): self-relatedness of stimuli (Northoff & Bermpohl, 2004; Northoff et al., 2006)

Han, S., Gu, X., et al. Neural substrates of self-referential processing in Chinese Buddhists. *Soc Cogn Affect Neurosci* **5**, 332-339 (2010).

Han, S., Mao, L., Gu, X. et al.. Neural consequences of religious belief on self-referential processing. *Soc Neurosci* **3**, 1-15 (2008).

Even the most abstract beliefs can be represented in the brain

Even the most abstract beliefs can be represented in the brain

Long-term belief

(e.g. religion, political ideology…)

Gene x Environment

long-term functional/ structural change neural plasticity

metabolism, magnetic field blood flow, oxygen level

action potential neurotransmission

So what?

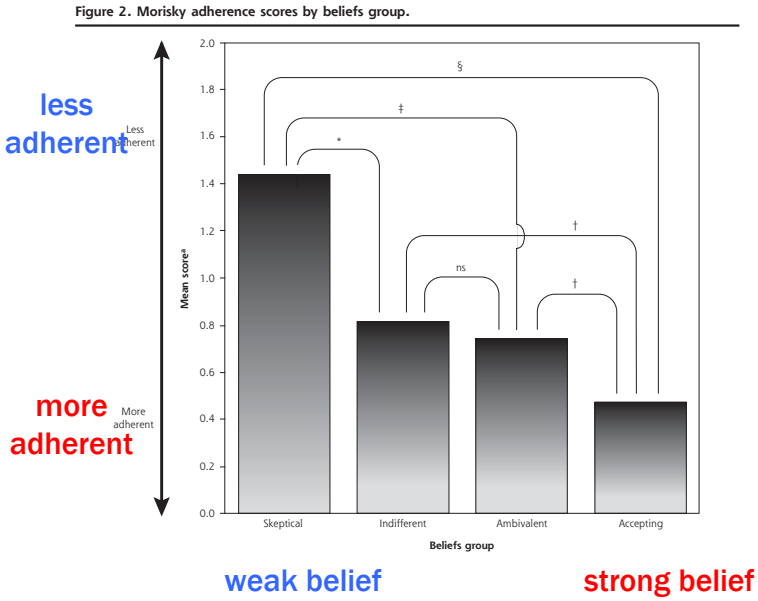
Beliefs

- Delusion: belief that contradicts evidence
- Hallucination: belief about (absent) sensory events
- Self-worthlessness
- Guilt
- Anhedonia: “nothing is rewarding”.
- Distorted belief about body image

Clinical impact

- Symptomatology
- Clinical heterogeneity / phenotypes
- Treatment strategy
- Treatment outcomes

Belief modulates treatment adherence



Aikens, J.E. et al. (2005) Adherence to Maintenance-Phase Antidepressant Medication as a Function of Patient Beliefs About Medication. The Annals of Family Medicine 3 (1), 23-30.

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(e.g. religion, political ideology…)

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long-term functional/ structural change neural plasticity

metabolism, magnetic field blood flow, oxygen level

action potential neurotransmission

Instantaneous beliefs have direct, moment-to-moment effect on behavior

Long-term belief

(e.g. religion, political ideology…)

Gene x Environment

long-term functional/ structural change neural plasticity

Instantaneous belief

(estimation about sensory information)

metabolism, magnetic field blood flow, oxygen level

sensorium

action potential neurotransmission

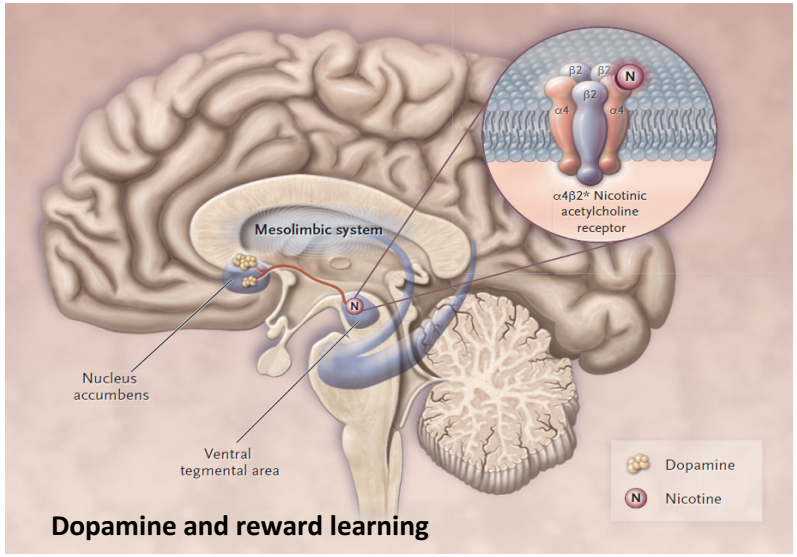
Managing beliefs

Can experimentally controlled beliefs alter neural responses to sensory experience?

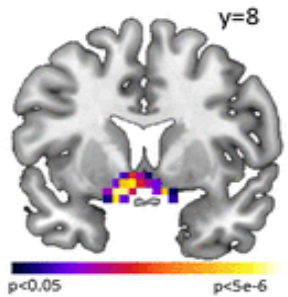
told "nicotine"

both have nicotine

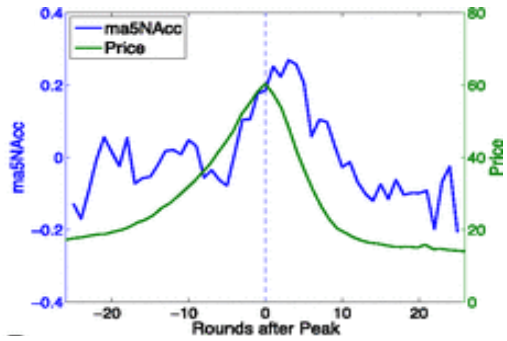
told "no nicotine"



Dopamine and reward learning



ventral striatum



Benowitz, N. L. (2010). Nicotine addiction. *The New England journal of medicine*, *362*(24), 2295.

Smith et al. *Proc Natl Acad Sci U S A* (2014)

Managing beliefs

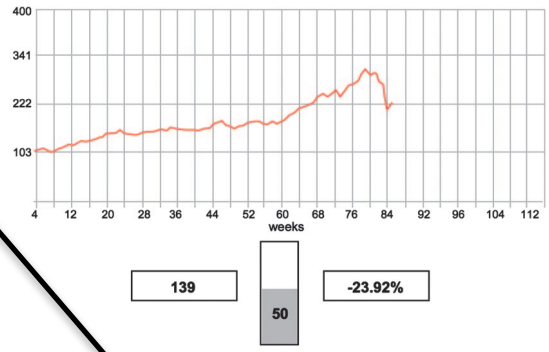
1. Measure craving and exhaled carbon monoxide

within-subject
placebo-controlled
double-blind

2. Belief + cigarette

belief “yes” nicotine “yes”
belief “yes” nicotine “no”
belief ”no” nicotine “yes”
Belief “no” nicotine “no”

3. fMRI: stock market task

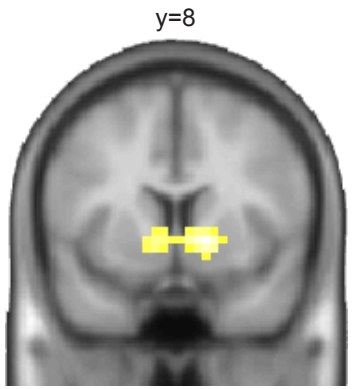


4. Measure craving and exhaled carbon monoxide

Gu, X. et al. (2015) Belief about nicotine selectively modulates value and reward prediction error signals in smokers. PNAS.

Study 1: Belief about nicotine modified ***reward learning*** in ***non-deprived*** smokers

reward-related neural activity



told “nicotine”
smoked nicotine

$P_{FWE} < 0.05$

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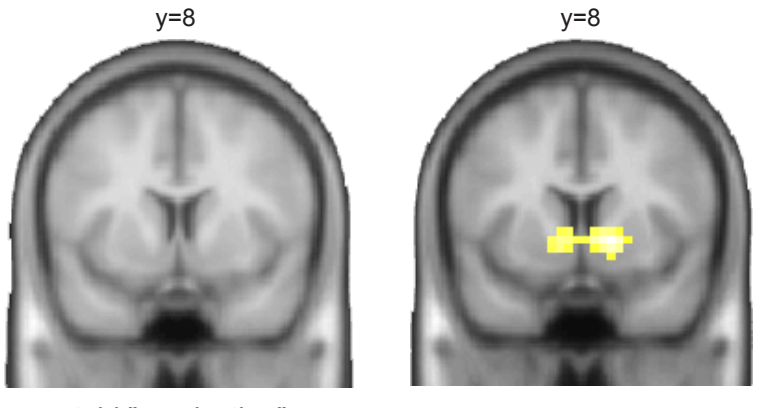

told “no nicotine”
smoked nicotine

told “nicotine”
smoked nicotine

$P_{FWE} < 0.05$

Gu, X. et al. (2015) Belief about nicotine selectively modulates value and reward prediction error signals in smokers. PNAS.

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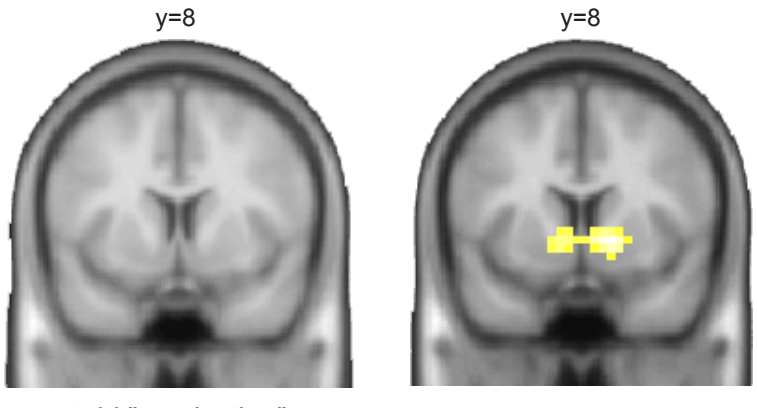
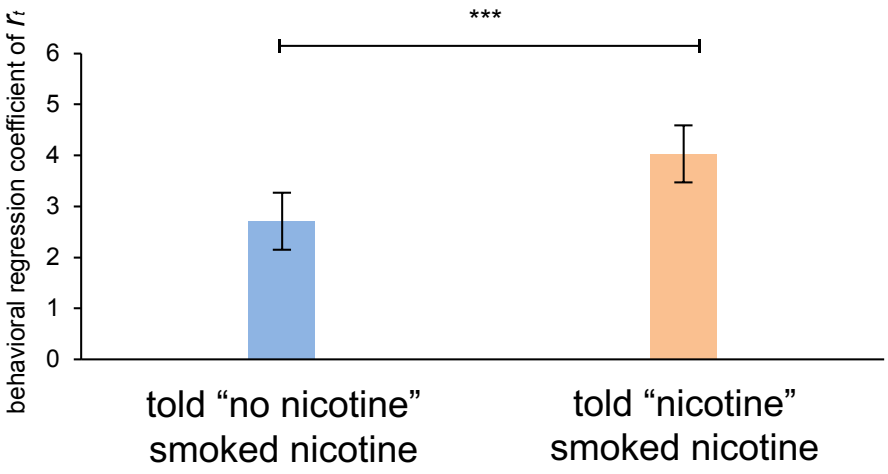


told “no nicotine”
smoked nicotine

told “nicotine”
smoked nicotine

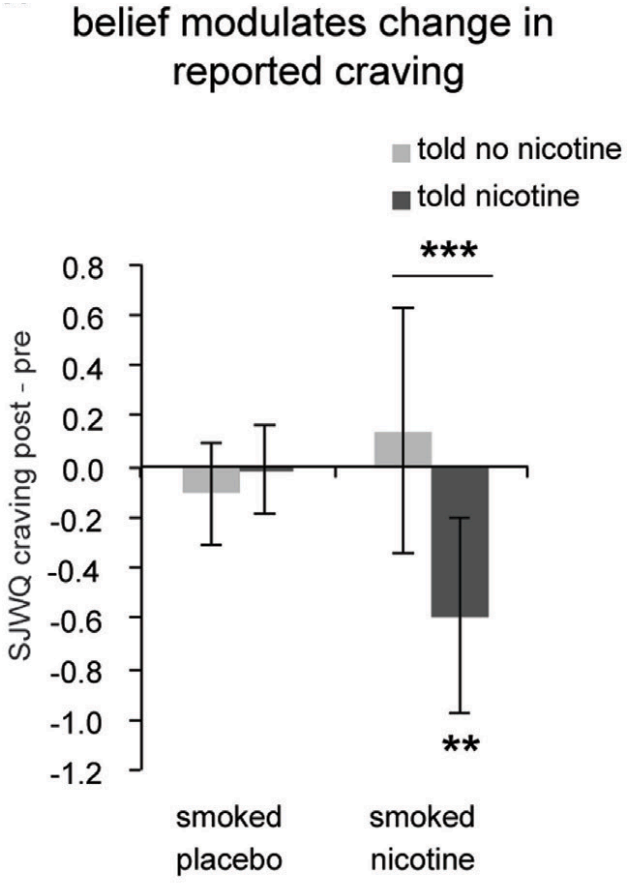
$P_{FWE} < 0.05$

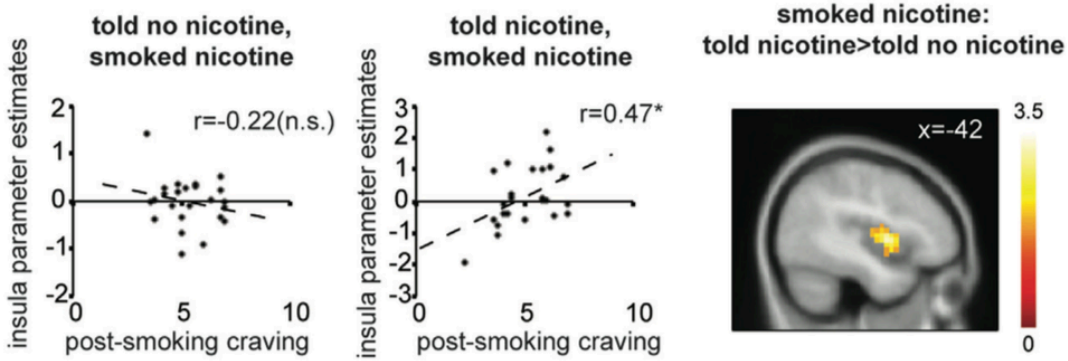
weight of *reward* on choice behavior



Gu, X. et al. (2015) Belief about nicotine selectively modulates value and reward prediction error signals in smokers. PNAS.

Study 2: Belief about nicotine modified ***craving*** in ***deprived*** smokers





Gu, X. et al. (2016) Belief about Nicotine Modulates Subjective Craving and Insula Activity in Deprived Smokers. Front Psychiatry

Choices vs. feelings

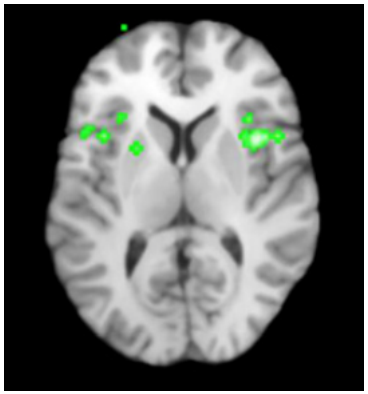
- Craving is often equated with choice behavior

- Craving: not a trivial concept
  - One of the strongest predictors of relapse
  - Treatment resistant
  - Persist for a long timm even after quitting

- Drug craving has a strong interoceptive basis
  - Faster heart beats
  - Butterflies in stomach
  - Breathing faster
  - Insula is commonly implicated

(Bergquist et al., 2010 Exp Clin Psychopharmacol)

Cigarette craving-related activation



Lesion that predicts reduction in craving

Tang, D.W. et al (2012) Physiol Behav 106 (3), 317-24.

Naqvi, N.H et al. (2007) Science 315 (5811), 531-4.

The incentive salience theory of craving

Brain Research Reviews, 18 (1993) 247–291

BRESR 90157

Full-length reviews

The neural basis of drug craving:
an incentive-sensitization theory of addiction

Terry E. Robinson and Kent C. Berridge

Department of Psychology and Neuroscience Program, The University of Michigan, Neuroscience Laboratory Building, Ann Arbor, MI 48104-1687 (USA)

Addiction (2000) 95 (Supplement 2), S91–S117

ANIMAL MODELS IN CRAVING RESEARCH

The psychology and neurobiology of addiction: an incentive–sensitization view

TERRY E. ROBINSON & KENT C. BERRIDGE

Department of Psychology (Biopsychology Program), The University of Michigan, Ann Arbor, MI, USA

- **Incentive salience** is a psychological process that transforms the perception of stimuli, imbuing them with salience, making them attractive, 'wanted', incentive stimuli" ("wanting" vs. "liking")

- Defines **craving** as "a state caused by the oversensitivity of incentive salience attributed to drugs"

Limitations of the incentive salience theory of craving

- Predicts that craving only depends on the availability of dopamine caused by drugs (wrong)

- Does not describe the computational mechanism

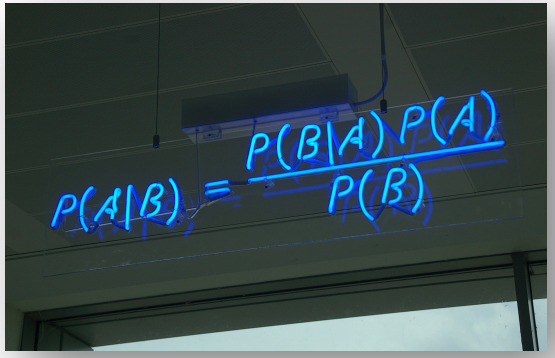
Craving as a belief

(Gu and Filbey, 2017 JAMA Psychiatry)

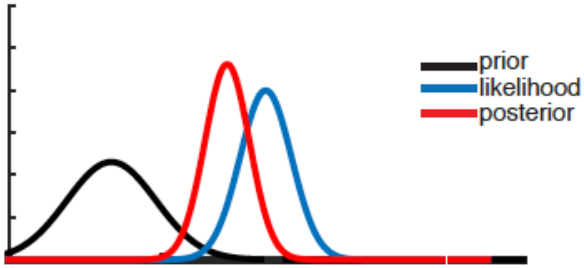
Craving as the posterior belief of the physiological states of the body

DA controls the precision of probability distributions
(Friston et al., 2012; Schwartenbeck et al., 2015)

Substances of abuse hijack this process

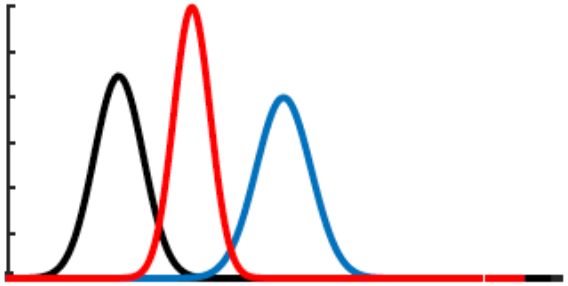


non-addicted (normal DA)

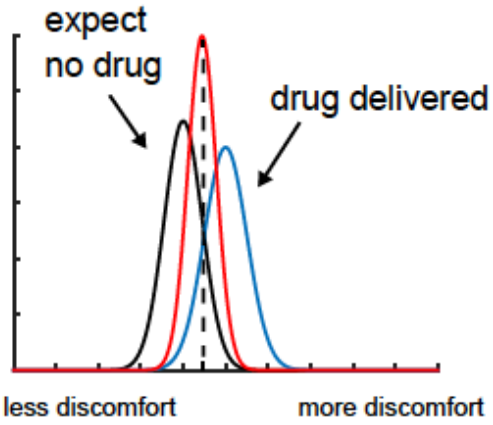


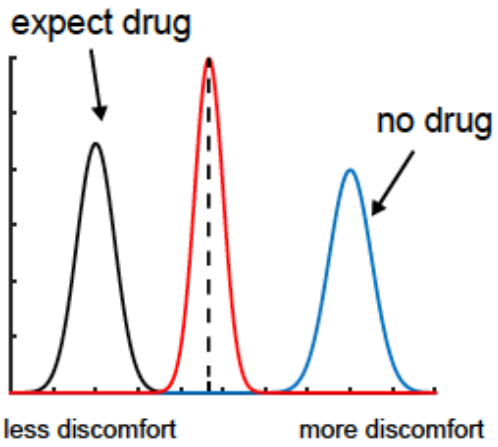
drugs

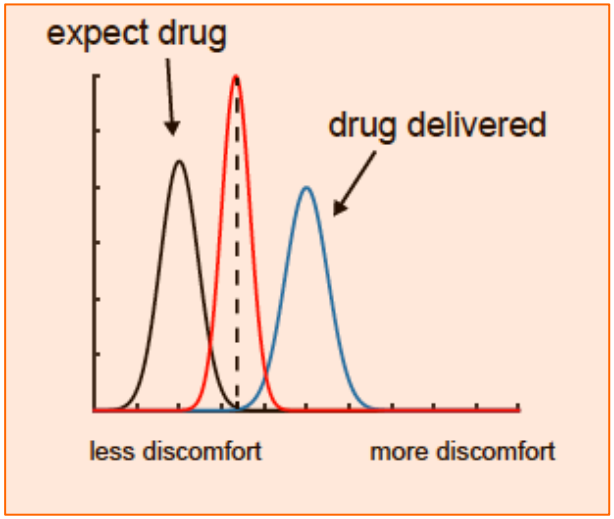
addicted (high DA)

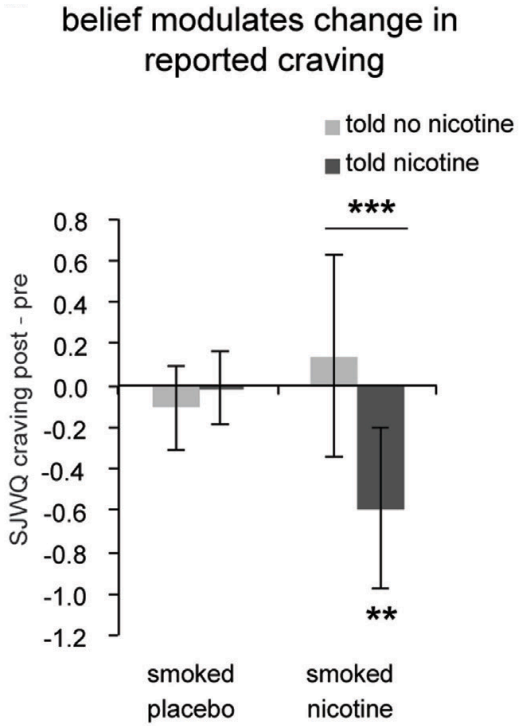


Craving as a belief









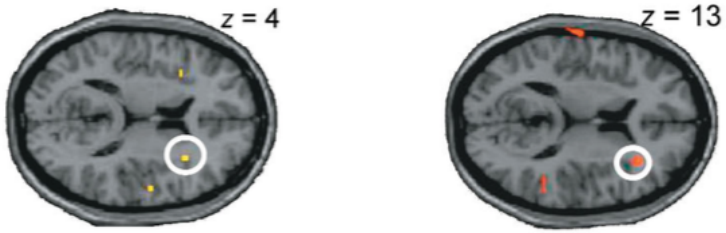
Gu and Filbey, 2007 JAMA Psychiatry

Searching for craving/feeling prediction errors (PE) in the brain

"Specialized Encoding" Hypothesis

- A specialized neural system for computing craving PE
- Candidates: "interoceptive" brain regions (e.g. insula)

Activity *Structure*



Critchley, H.D. et al. (2004) Neural systems supporting interoceptive awareness. Nat Neurosci 7 (2), 189-95.

Significance of the insula for the evolution of human awareness of feelings from the body

A. D. (Bud) Craig
Atkinson Research Laboratory, Barrow Neurological Institute, Phoenix, Arizona

Box 3 | **The insular cortex as a focus in models of interoception**

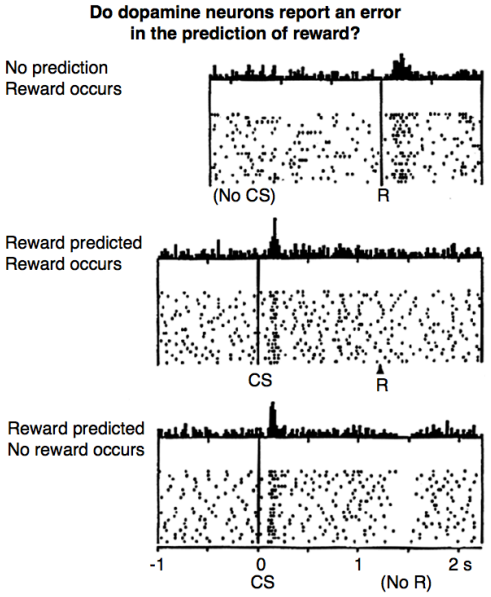
For many years, interoception has been studied as a bottom-up, sensory-driven phenomenon that is linked to the neuroanatomy of the ascending homeostatic lamina I and vagal pathways that bring interoceptive sensations to the brain[54]. Other approaches to understanding interoception have focused on the structure and function of the anterior insula, because of its importance in interoceptive awareness and sensitivity (for example, see REFS 6,140). Both lines of research reflect

Barrett, L.F. and Simmons, W.K. (2015) Interoceptive predictions in the brain. Nat Rev Neurosci.

"Common Encoding" Hypothesis

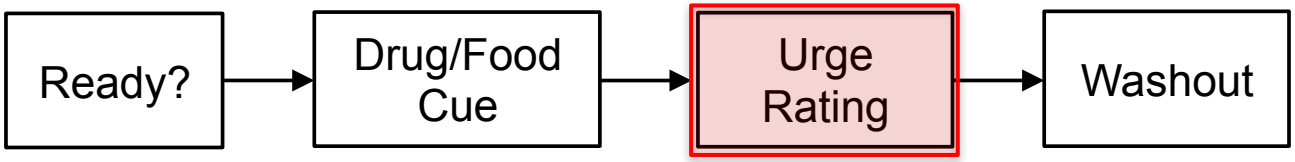
- Exteroceptive "PE" brain regions will also compute craving PE
- Candidates: the dopamine system (e.g. midbrain)

Midbrain dopamine neurons



Schultz, W., Dayan, P. and Montague, P.R. (1997) A neural substrate of prediction and reward. Science 275 (5306), 1593-9

Bayesian observer model of craving



Exp 1: Nicotine-visual (n=27)

Smokers rated continuously

Exp 2: Nicotine-olfactory (n=24)

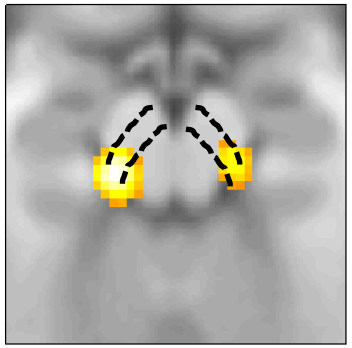
Smokers rated after each cue presentation

Exp 3: Marijuana – tactile (n=25)

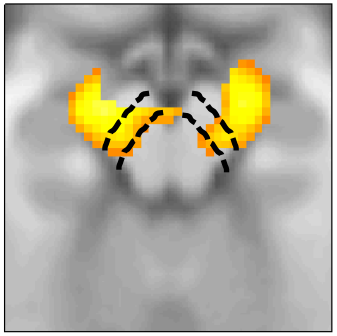
Smokers rated after each cue presentation

Craving feeling PE

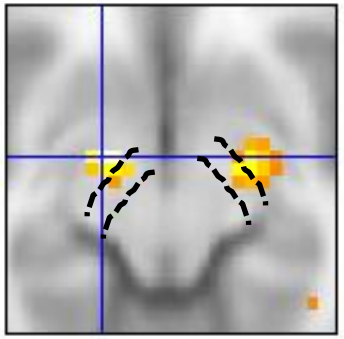
Nicotine - visual (n=27)



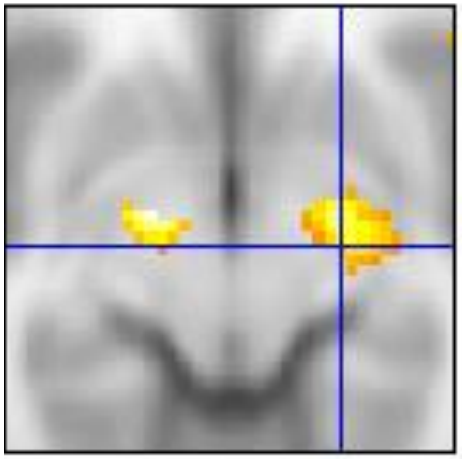
Nicotine - olfactory (n=24)



Marijuana (n=25)



Common activation



Midbrain Encodes Craving/Feeling PE Across Modalities/Groups

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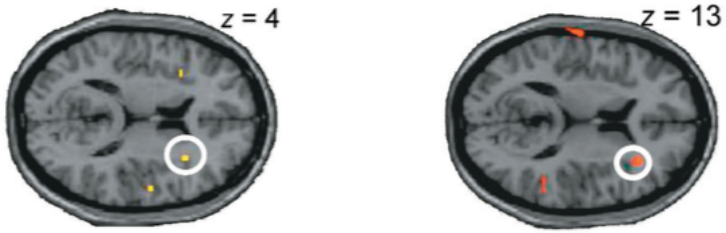
- Candidates: "interoceptive" brain regions (e.g. insula)

Activity *Structure*



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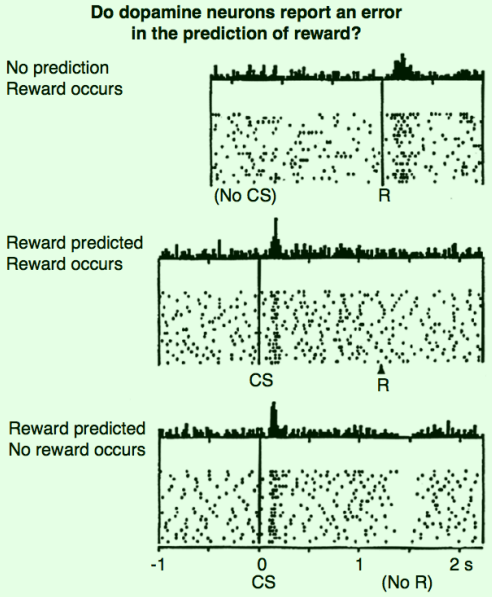

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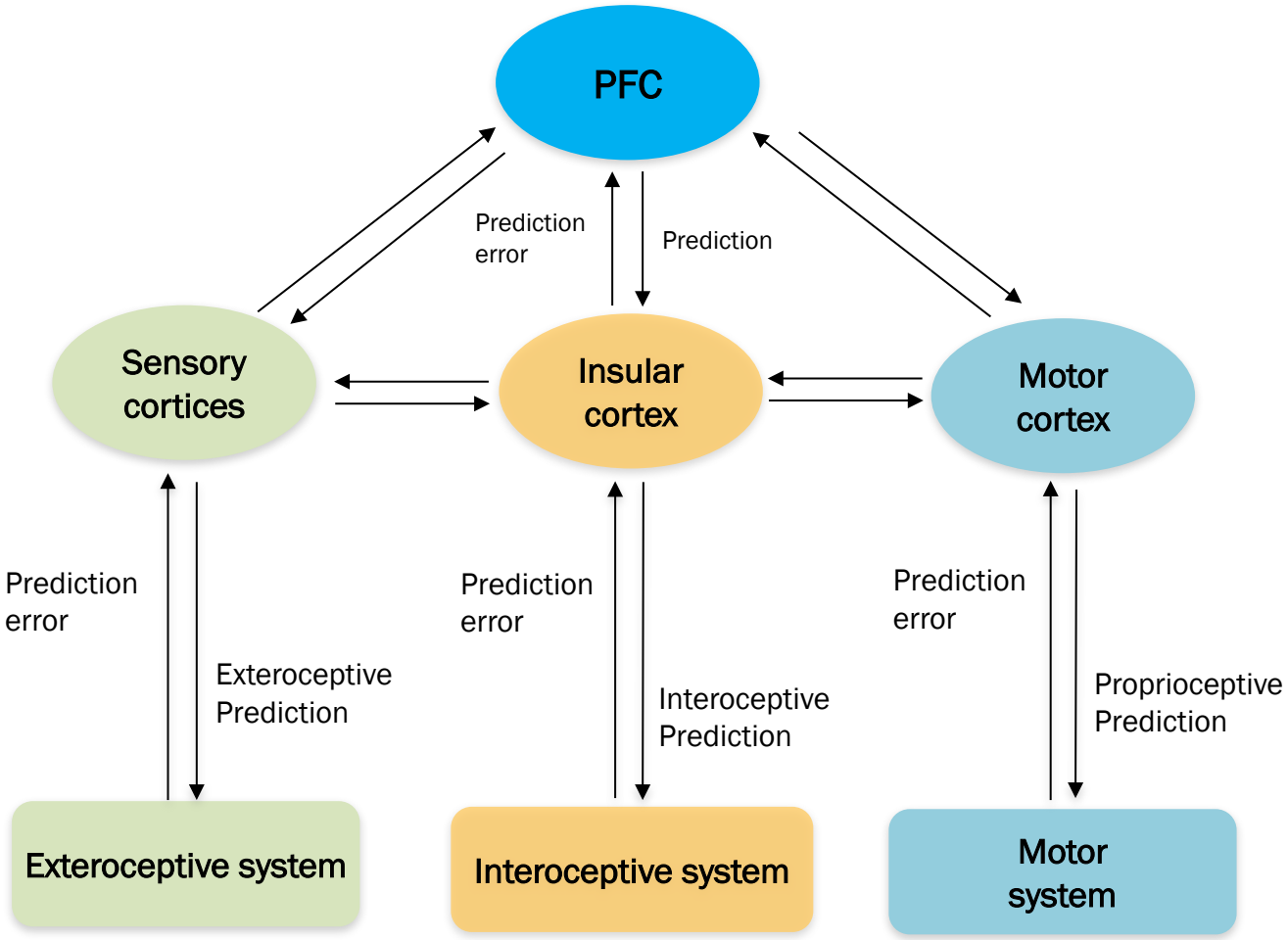
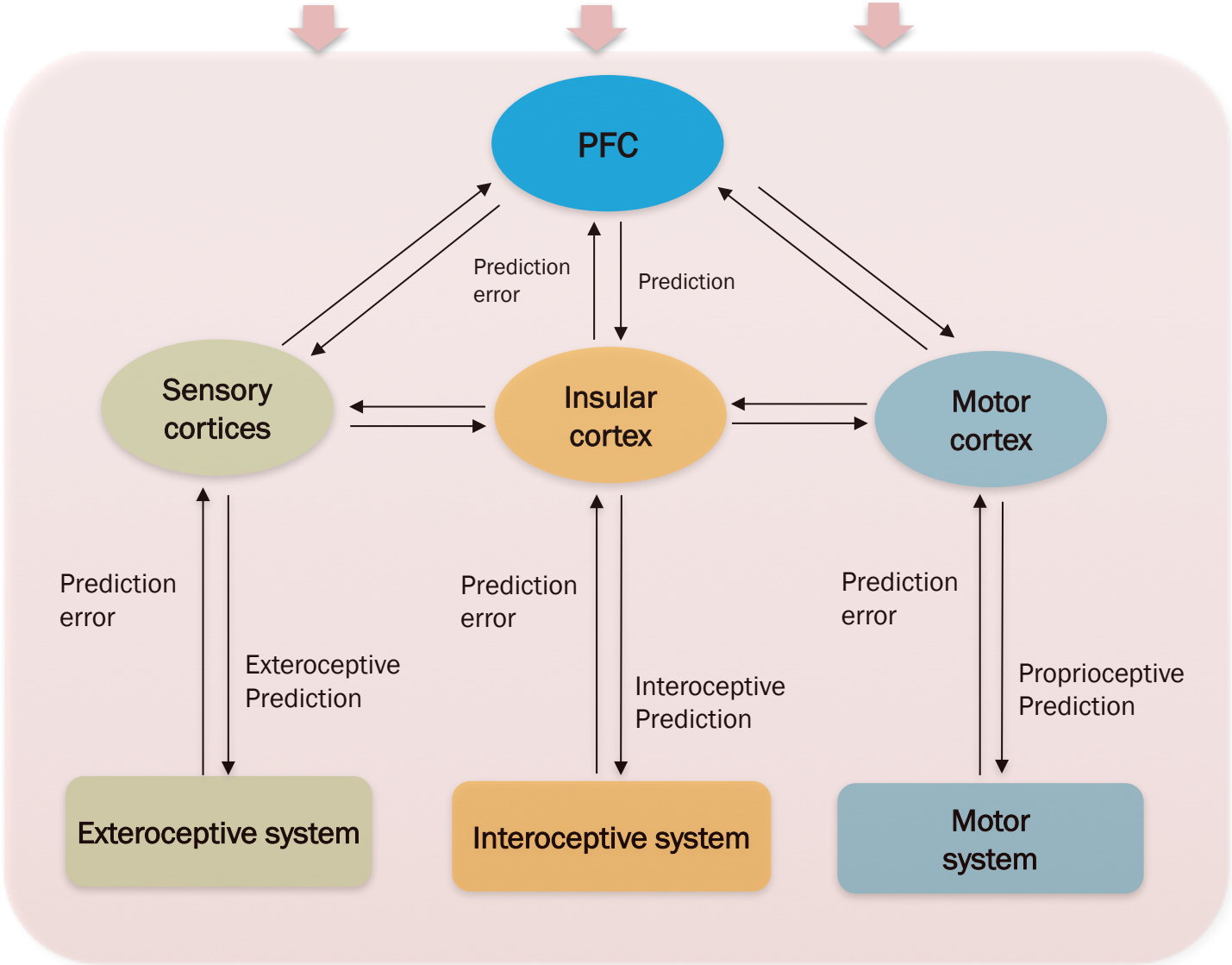
Revisiting previous models of interoceptive inference



Gu et al., 2013 J Comp Neurol.

Revisiting previous models of interoceptive inference



Gu et al., 2013 J Comp Neurol.

Summary

- Abstract beliefs can be represented in the brain.
- Feelings as beliefs (about the physiological state of the body)
- The same midbrain region that encodes reward PE also computes feeling (e.g. craving) PE across modalities and populations.
  - Evolutionarily efficient?

long-term belief

(e.g. religion, political ideology…)

Gene x Environment

long-term functional/ structural change neural plasticity

instantaneous belief

(estimation about sensory information)

metabolism, magnetic field blood flow, oxygen level

sensorium

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A Bayesian account of beliefs

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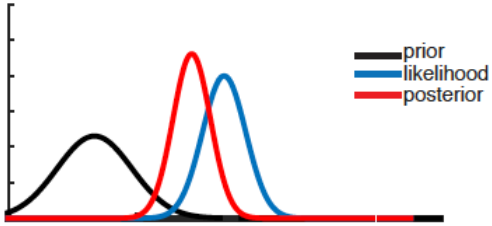

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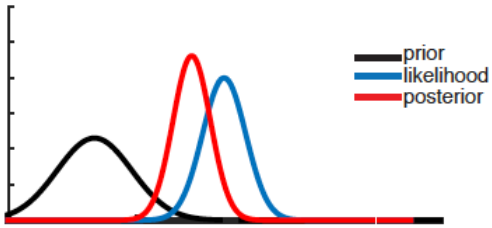

sensorium

A Bayesian account of beliefs

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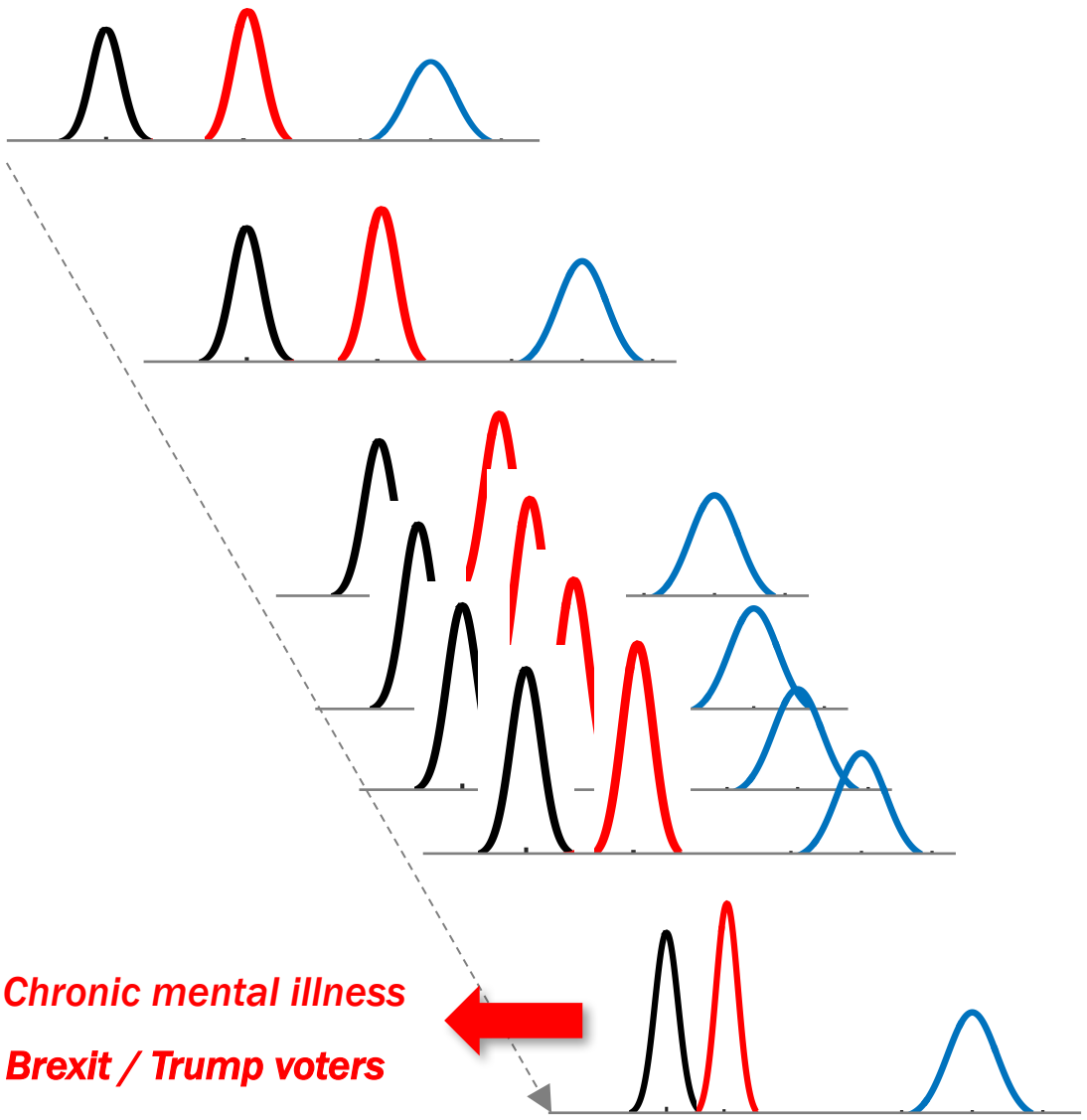
(estimation about sensory information)

sensorium



Utility of this model

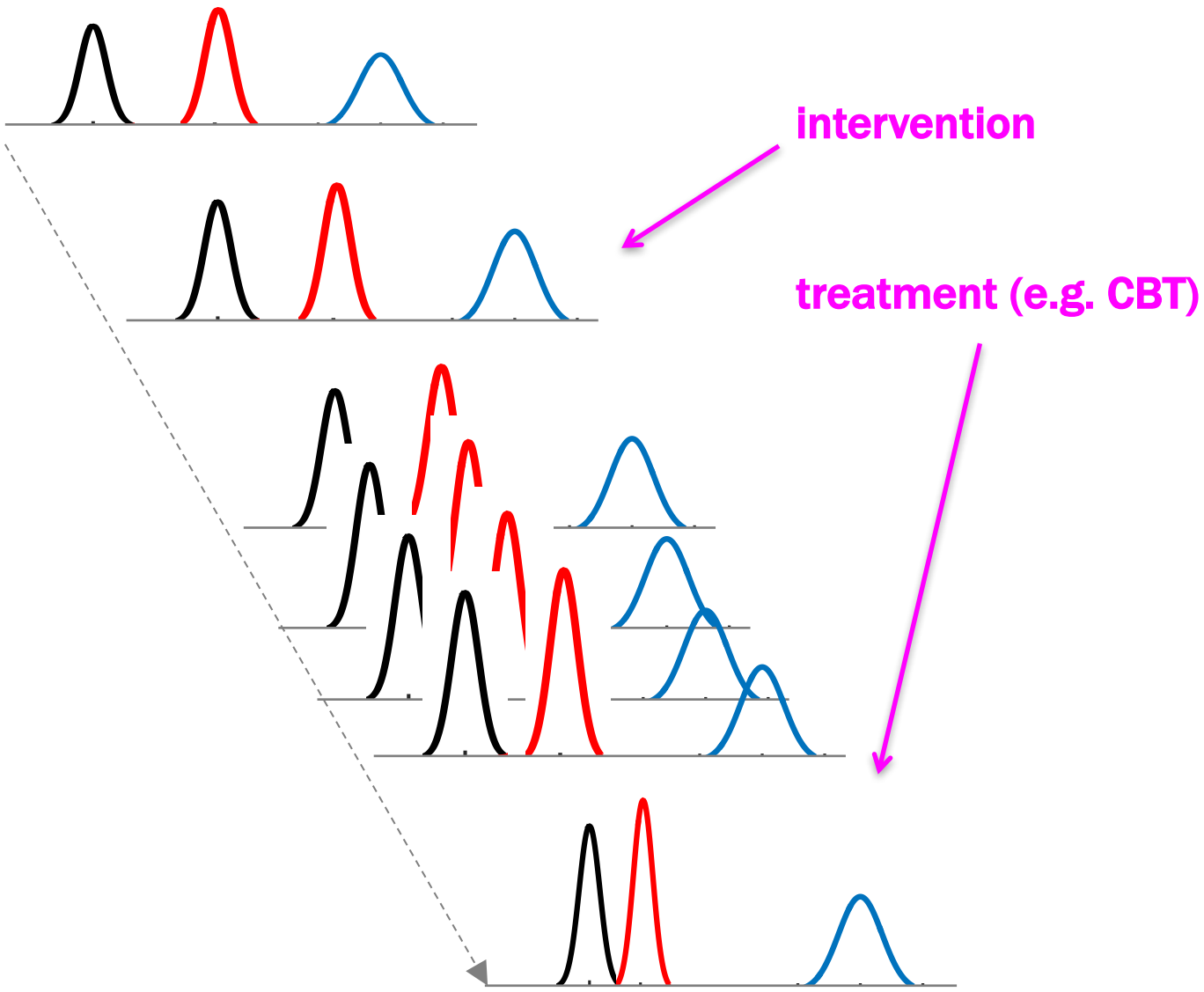
long-term belief

(e.g. religion, political ideology…)

instantaneous belief

(estimation about sensory information)

sensorium



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