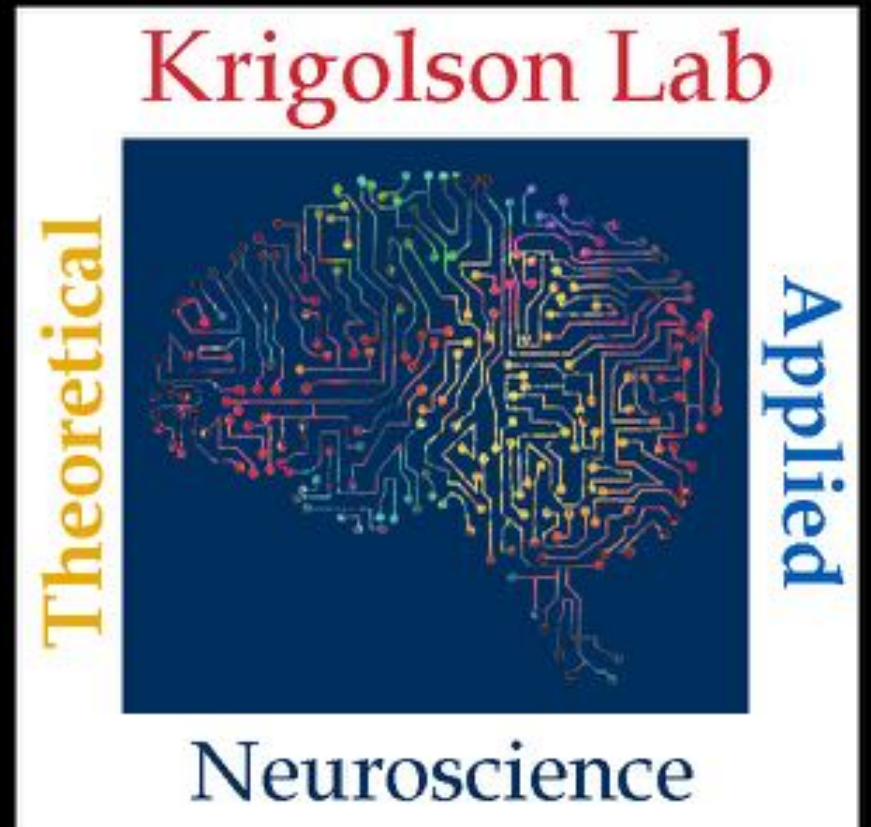


# The Neuroscience of Human Decision Making

Dr. Olav E. Krigolson  
Associate Director  
Centre for Biomedical Research  
University of Victoria



# Course Outline

The Neuroscience of Human Decision Making

ASHI726 2018F C01

Dr. Olav E. Krigolson, PhD

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## Course Overview

~~Week I: Decision Making Theory September 12th, 2018~~

~~Week II: Neural Evidence for Value September 19th, 2018~~

~~Week III: Neural Decision Systems September 26th, 2018~~

~~Week IV: System I and System II October 10th, 2018~~

~~Week V: Emotional Decisions October 17th, 2018~~




Week VI: Current Research in Decision Making October 24th, 2018

# Study 1

The Journal of Neuroscience, October 26, 2016 • 36(43):10935–10948 • 10935

Neurobiology of Disease

## Behavioral and Neural Signatures of Reduced Updating of Alternative Options in Alcohol-Dependent Patients during Flexible Decision-Making

 Andrea M.F. Reiter,<sup>1,2,7</sup>  Lorenz Deserno,<sup>1,3,4</sup> Thomas Kallert,<sup>5</sup> Hans-Jochen Heinze,<sup>1,4,6</sup>  Andreas Heinz,<sup>3</sup> and Florian Schlagenhauf<sup>1,3</sup>

# The Idea

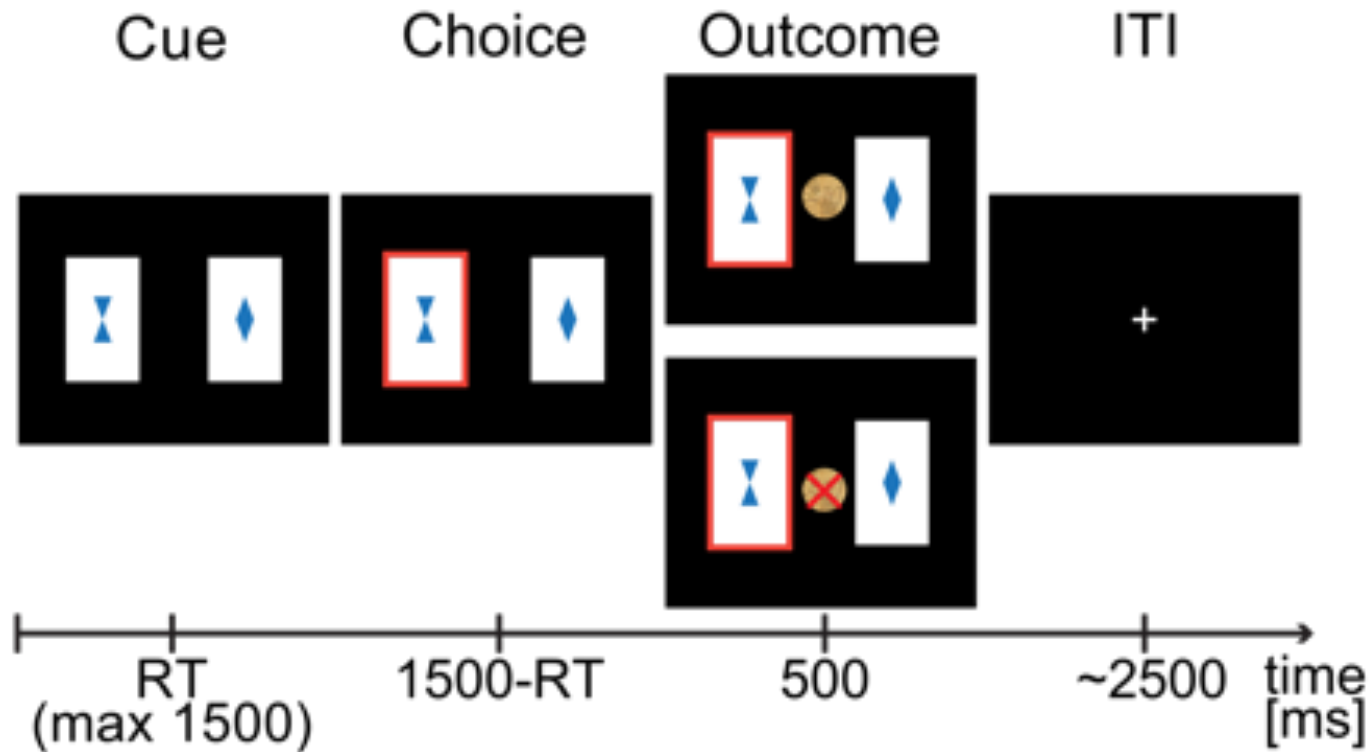
Addicted individuals continue substance use despite knowledge of harmful consequences

Why? Potentially a difficulty in considering alternative choices.  
(failure to explore)

Participants

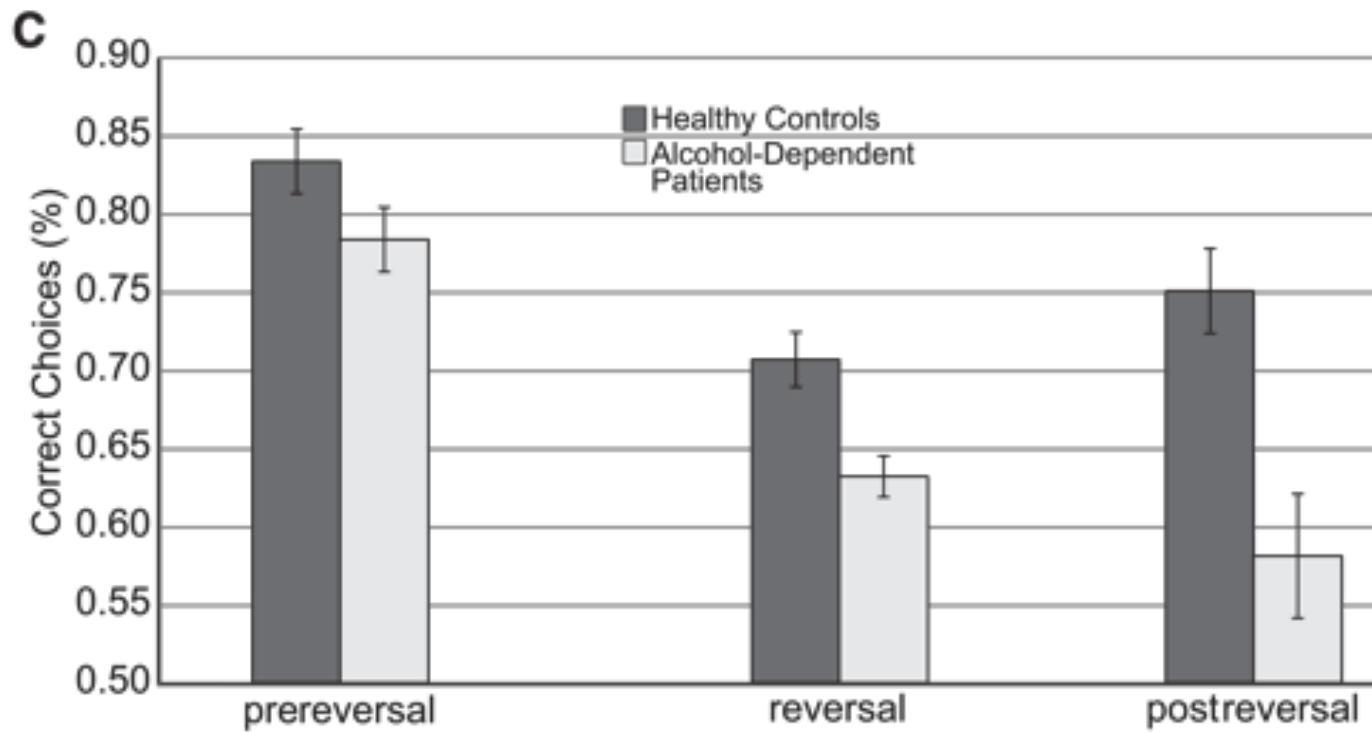
n = 43 alcohol dependent patients

n = 35 healthy control volunteers

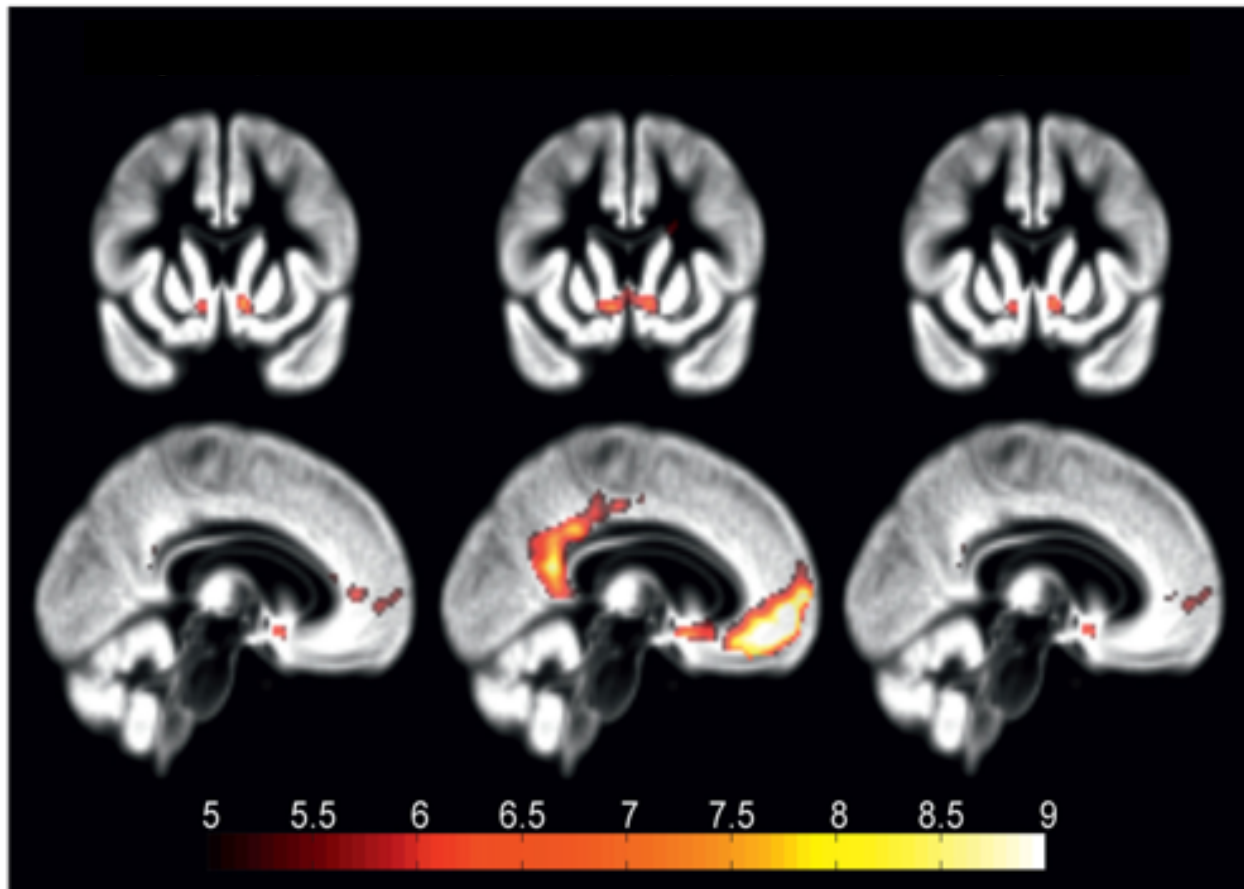


Key manipulation: The reward contingencies changed halfway through the experiment forcing participants to learn the new stimulus – reward mappings.

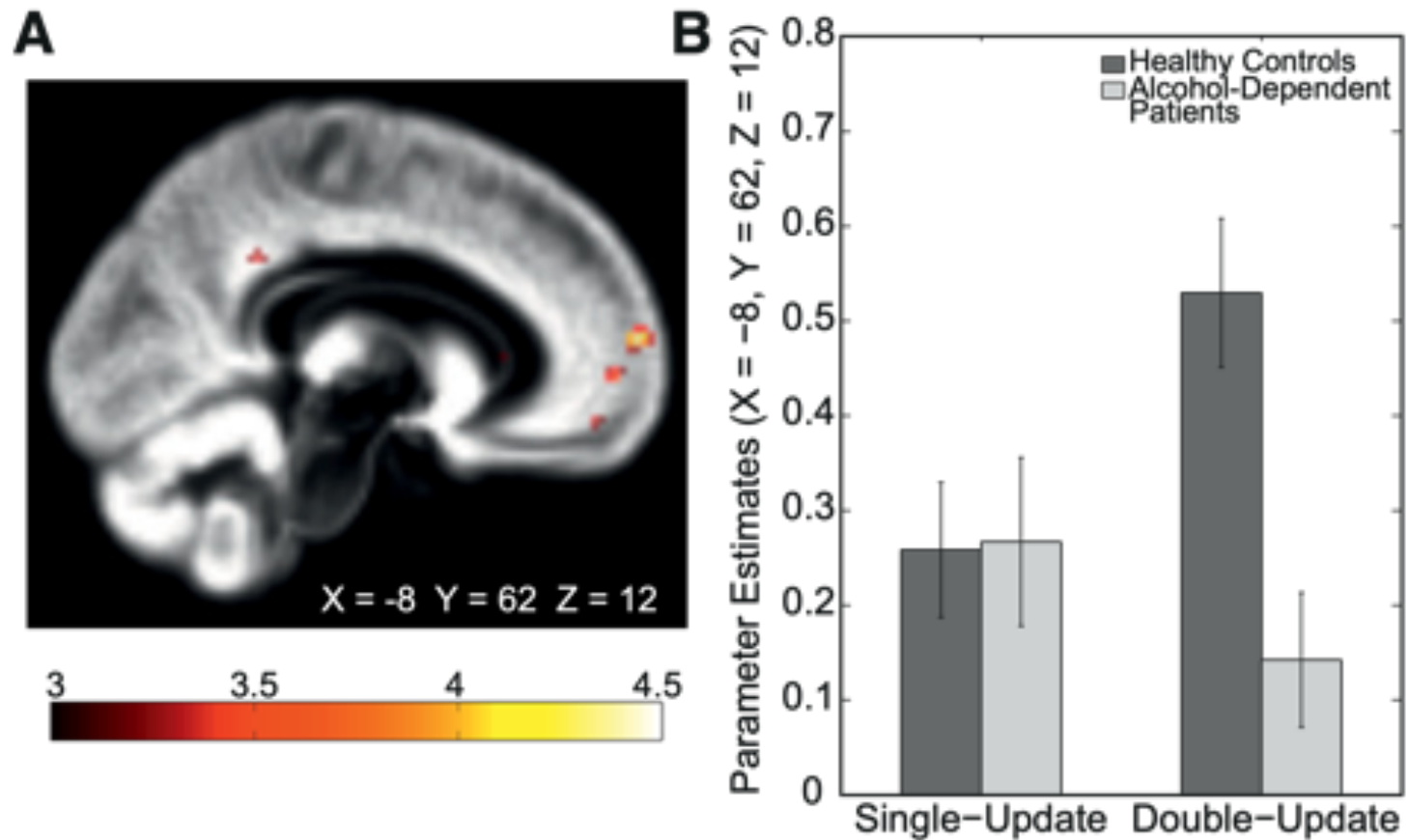
Key manipulation: The outcomes were anti-correlated – if one door was good the other was bad and vice versa.



Alcohol dependent patients were not able to process the reversal of outcome probabilities

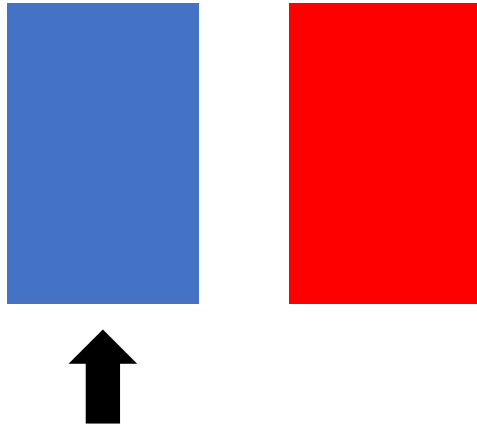


All patients processed the rewards in all conditions (i.e., were able to compute prediction errors)



However, alcohol dependent patients were not able to process the “double-update”, the “what if” associated with evaluating the other outcome and necessary to make the post reversal switch.





Choice of  $V_{\text{blue}}$  or  $V_{\text{red}}$

WIN!

Compute  $PE = \text{Outcome (reward)} - \text{Expectation } (V_{\text{blue}})$

Update value of  $V_{\text{blue}}$

Outcomes are anti-correlated:  
Thus, also update value of  $V_{\text{red}}$

However...

Alcohol-dependent patients can still learn the initial task configuration.  
(Initially acquire value that drinking is rewarding)

However, after the reversal the values are set so they cannot update the value of the alternative choice.

(However, once drinking is a problem cannot update the values for alternative choices, e.g., not drinking)

## Study 2



Research

### Original Investigation

# Impaired Functional Connectivity Within and Between Frontostriatal Circuits and Its Association With Compulsive Drug Use and Trait Impulsivity in Cocaine Addiction

Yuzheng Hu, PhD; Betty Jo Salmeron, MD; Hong Gu, PhD; Elliot A. Stein, PhD; Yihong Yang, PhD

# The Idea

Cocaine use tends to make individuals more impulsive and more compulsive.

Why? Possible disruption of normal neural connections between different brain regions.

Participants

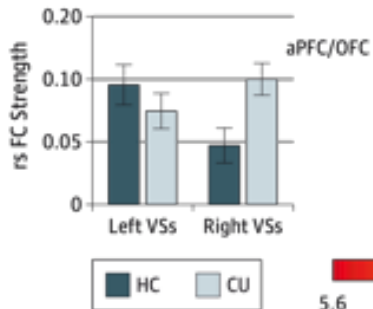
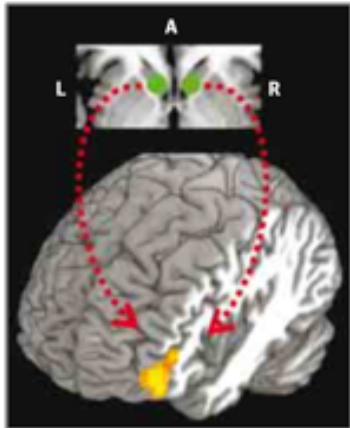
n = 56 cocaine users

n = 56 healthy control volunteers

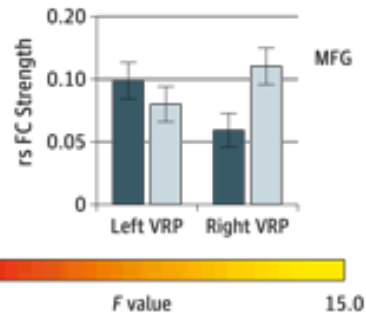
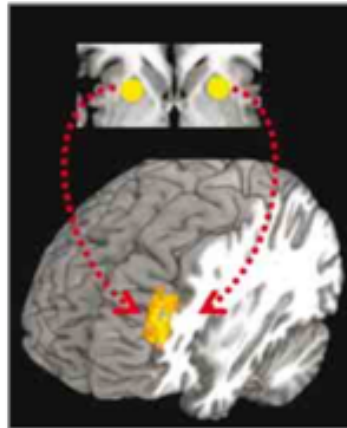
Table. Participant Demographics and Behavioral Assessments				
Characteristic	HC Group (n = 56)	CU Group (n = 56)	Difference	P Value
Sex, No. (%)				
Female	17 (30)	13 (23)	$\chi^2 = 0.73$	.39
Male	39 (70)	43 (77)	$\chi^2 = 0.73$	.39
Age, mean (SD), y	38.70 (7.82)	39.86 (6.71)	$t = -0.84$	.40
Formal education, mean (SD), y	13.21 (1.66)	12.87 (1.36)	$t = 1.22$	.23
WAIS vocabulary score, mean (SD)	55.79 (8.00)	54.66 (8.97)	$t = 0.70$	.49
Smoking, cigarettes/d, No. (%)				
Nonsmoker	23 (41)	18 (32)	$\chi^2 = 1.39$	.71
<10	9 (16)	13 (23)		
10-19	14 (25)	14 (25)		
≥20	10 (18)	11 (20)		
Race, No. (%)				
African American	45 (80)	45 (80)	$\chi^2 = 1.22$	.54
White	10 (18)	8 (14)		
Mixed	1 (2)	3 (6)		
Cocaine use assessment, mean (SD)				
Duration, y		12.64 (6.40)		
Current use, \$/wk		246.70 (168.94)		
Drug dependence <sup>a</sup>		4.50 (1.58)		
Severity of loss control over drug use <sup>b</sup>		3.46 (1.29)		
Cocaine urine test result, No. (%)				
Positive		23 (41)		
Negative		32 (57)		
Missing		1 (2)		
fMRI motion, mean (SD)				
FD	0.15 (0.09)	0.13 (0.08)	$t = 1.08$	.28
Censoring rate <sup>c</sup>	0.02 (0.05)	0.02 (0.05)	$t = 0.32$	.75
BIS-11 score, mean (SD) <sup>d</sup>	53.78 (9.95)	67.33 (10.30)	$t = -4.58$	<.001
Attention	12.33 (3.40)	15.13 (3.64)	$t = -2.75$	.009
Motor	20.50 (2.81)	24.92 (5.00)	$t = -3.77$	.001
Nonplanning	21.17 (5.64)	27.29 (4.22)	$t = -4.23$	.001



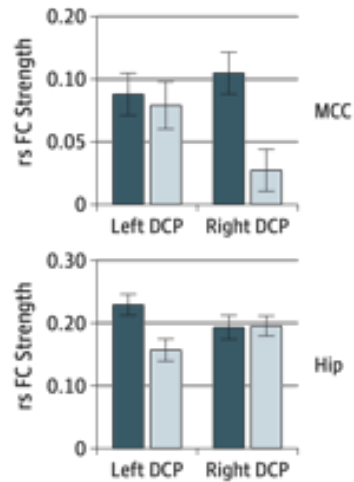
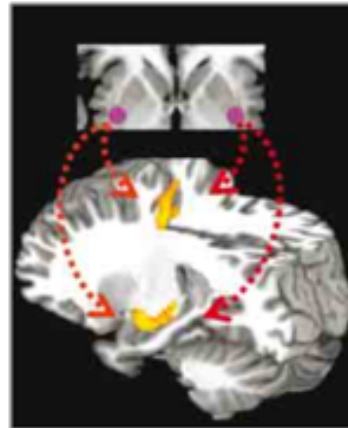
A



B



C



### Cocaine Users

Increased connectivity between:

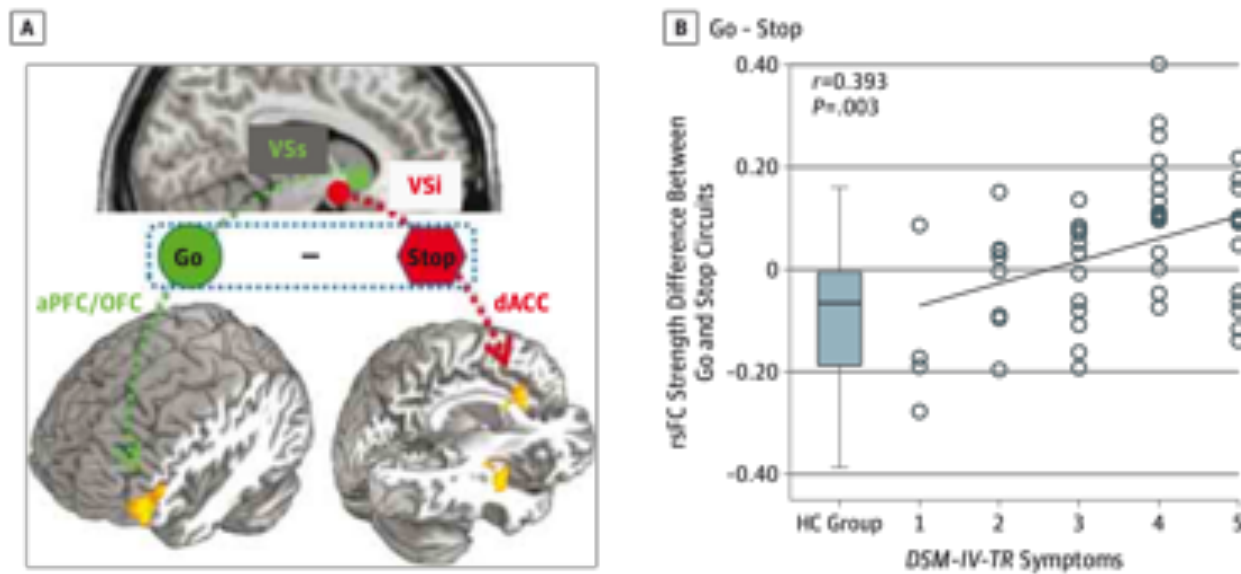
Right Ventral Striatum and PFC, OFC

Right Rostral Putamen and Middle Frontal Gyrus

Decreased connectivity between:

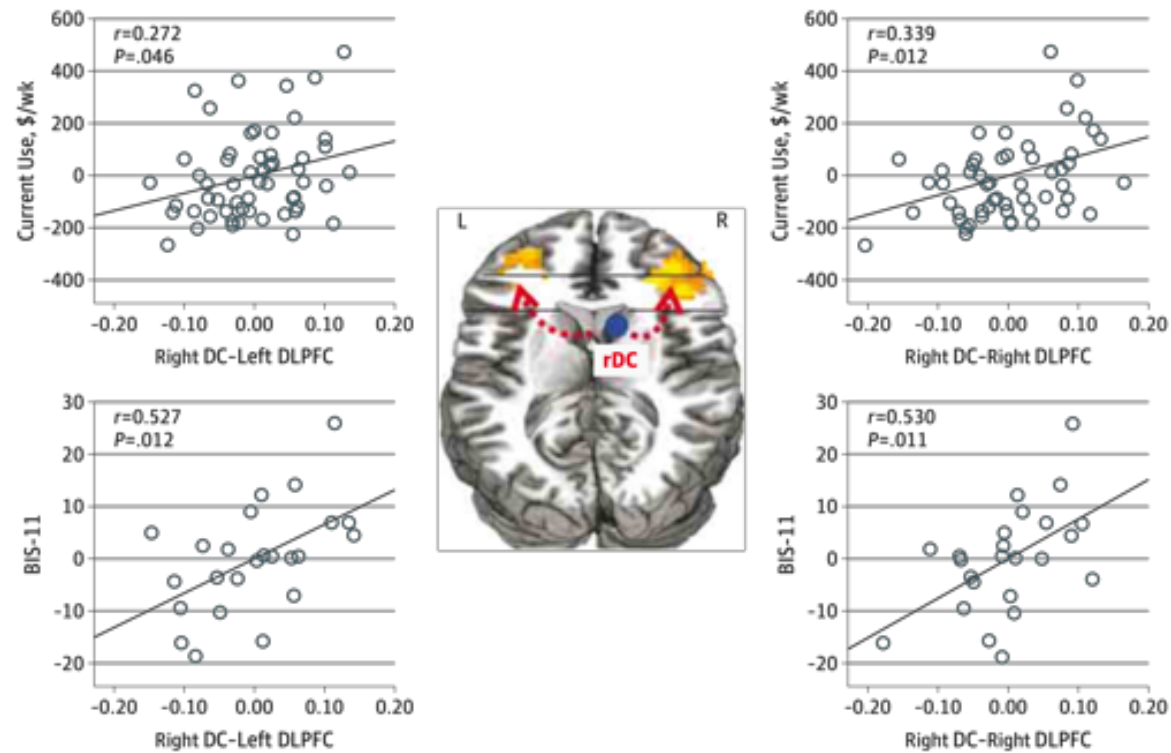
Right Caudal Putamen and Middle Cingulate Cortex

Right Caudal Putamen and Hippocampus



Difference between go pathway (Ventral Striatum to PFC/OFC) and stop pathway (Ventral Striatum to ACC) correlates with symptoms of cocaine use.





Correlation between Current Use (\$ per week) and BIS-11 score and connections between Dorsal Caudate and Left and Right DLPFC

# Conclusions

Impulsivity and compulsivity might not originate from a specific brain region but instead be reflected as differences in the connectivity between brain regions.

These connectivity's are disrupted by cocaine use.

## Study 3



Contents lists available at [ScienceDirect](#)

### Behavioural Brain Research

journal homepage: [www.elsevier.com/locate/bbr](http://www.elsevier.com/locate/bbr)

Research report

## Theory of mind and decision-making processes are impaired in Parkinson's disease

Chunhua Xi<sup>a,b</sup>, Youling Zhu<sup>b</sup>, Yanfang Mu<sup>b</sup>, Bing Chen<sup>c</sup>, Bin Dong<sup>b</sup>, Huaidong Cheng<sup>a</sup>, Panpan Hu<sup>a</sup>, Chunyan Zhu<sup>a,\*</sup>, Kai Wang<sup>a,\*</sup>

<sup>a</sup> Neuropsychology Laboratory, Department of Neurology, The First Affiliated Hospital of Anhui Medical University, Jixi Road, Hefei 230022, Anhui Province, China

<sup>b</sup> Department of Neurology, The Third Affiliated Hospital of Anhui Medical University, Huaihe Road 390, Hefei 230061, Anhui Province, China

<sup>c</sup> Department of Neuroimaging, The Third Affiliated Hospital of Anhui Medical University, Huaihe Road 390, Hefei 230061, Anhui Province, China

# The Idea

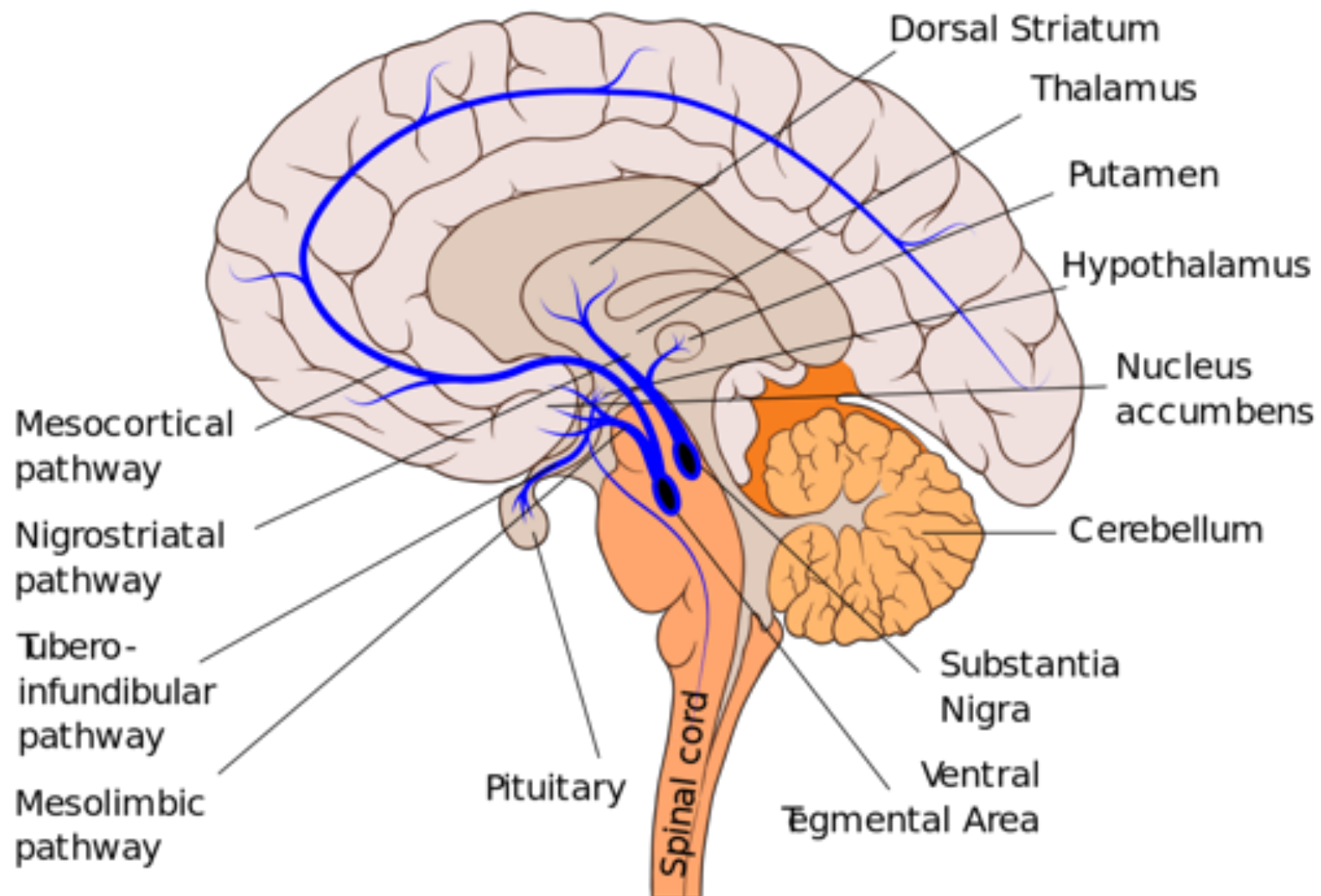
People with Parkinson's Disease can have trouble with decision-making in a variety of conditions.

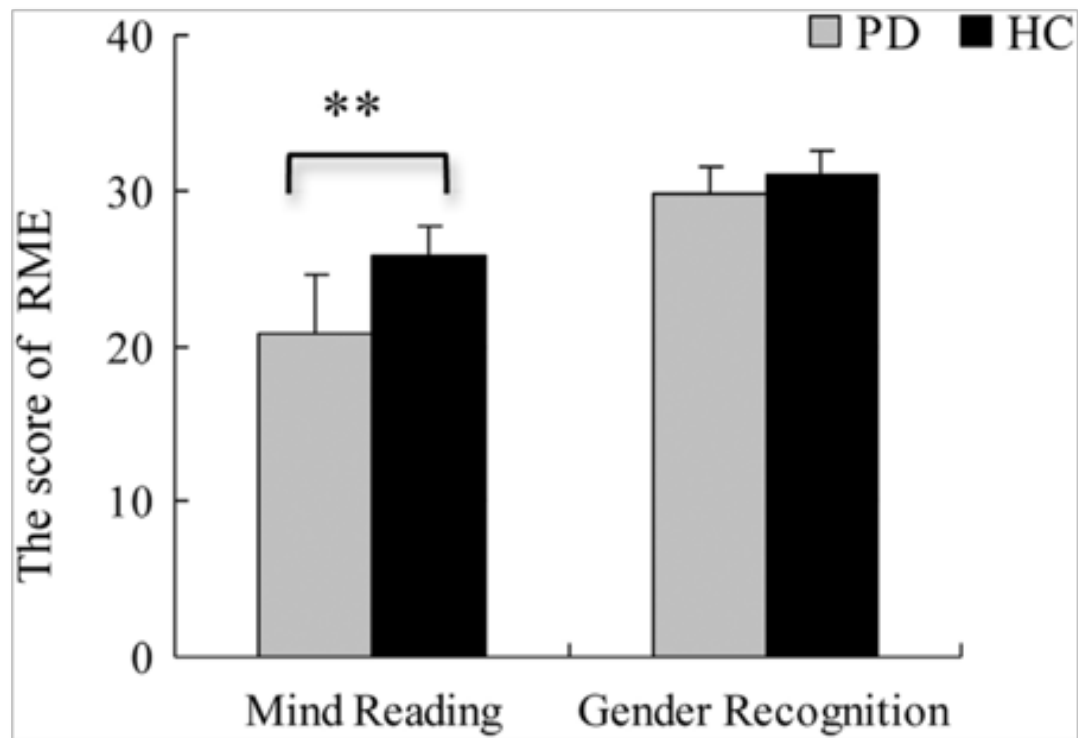
Why? Possible disruption of decision-making circuitry, especially dopamine dependent pathways.

Participants

n = 15 PD patients

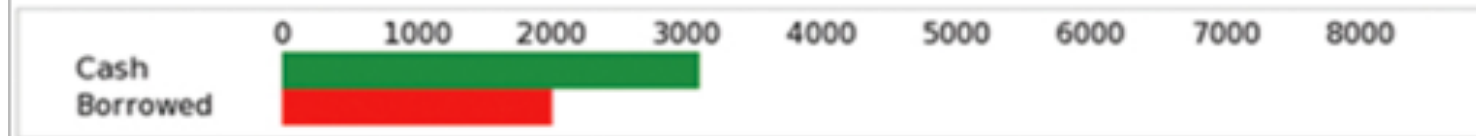
n = 15 healthy control volunteers





View faces and determine the emotion present and the gender of the person.

## Winnings:



You have won \$100!

A



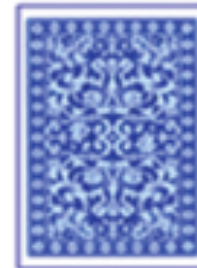
B



C

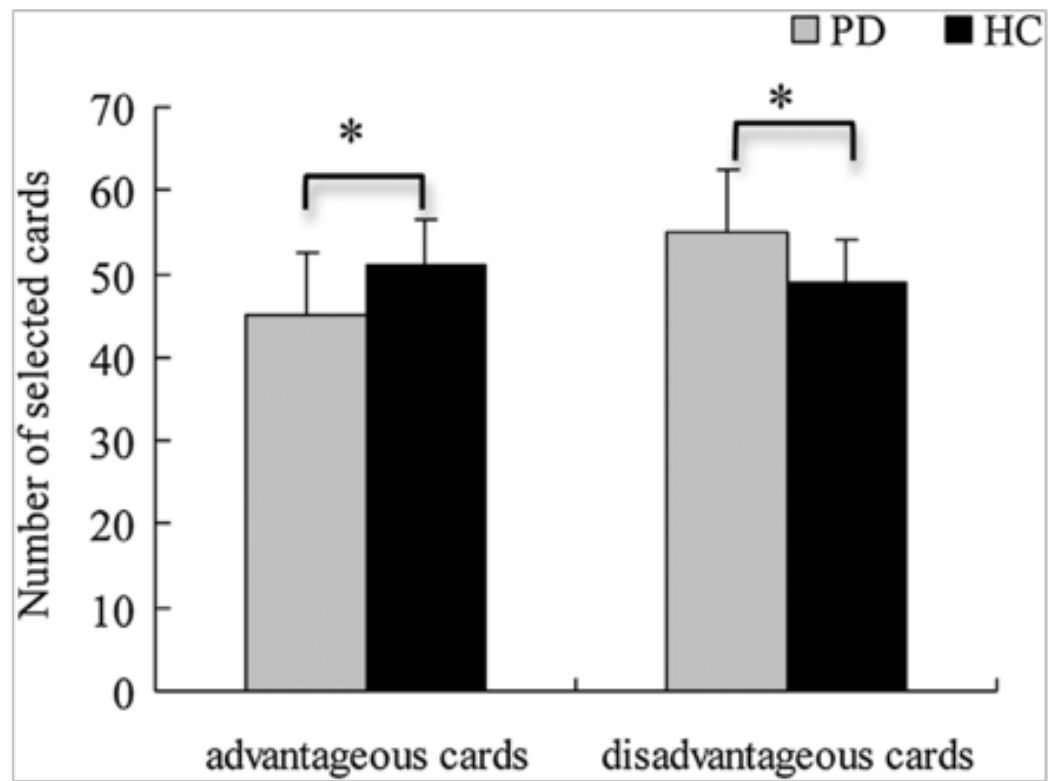


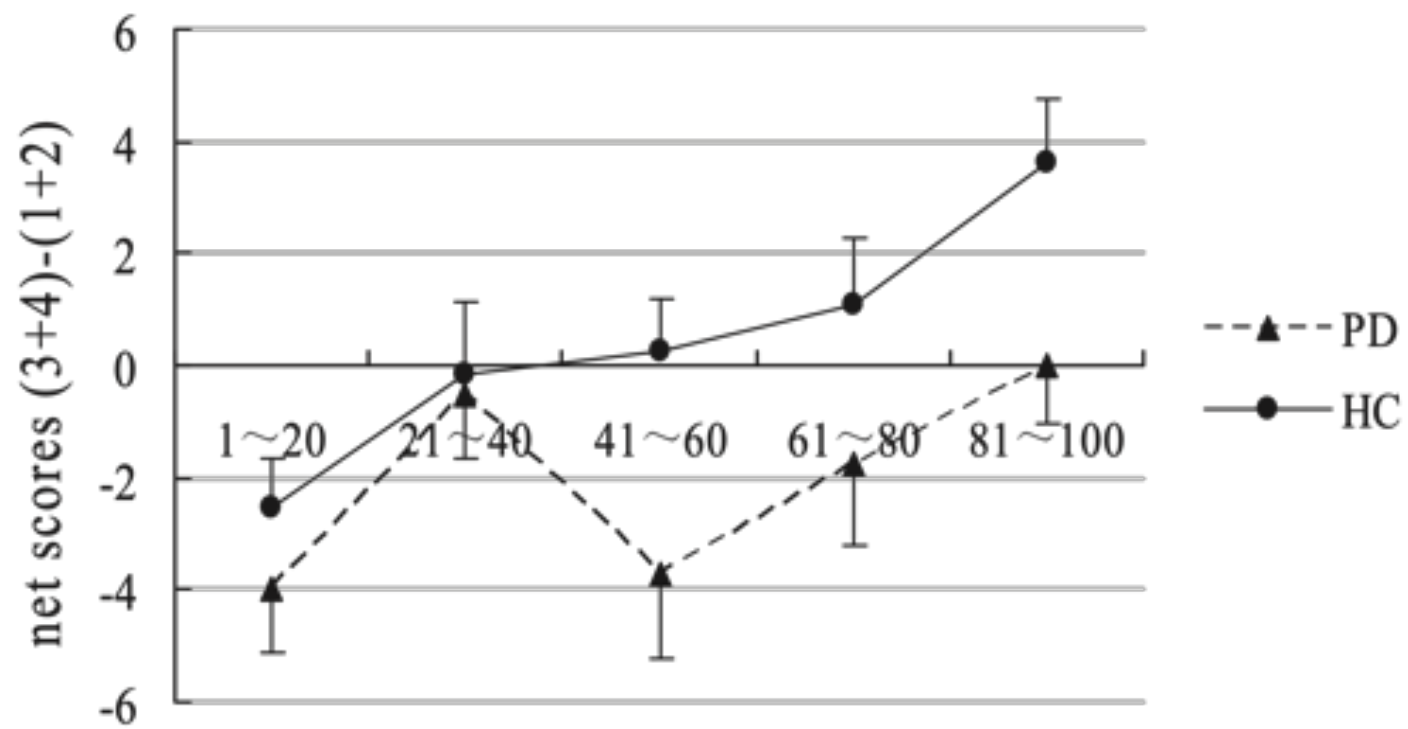
D



	<b>Deck A</b>	<b>Deck B</b>	<b>Deck C</b>	<b>Deck D</b>
Gain	\$100	\$100	\$50	\$50
Loss	\$150–\$350	\$1250	\$50	\$250
Gain/loss frequency (10 trials)	5:5	9:1	5:5	9:1
Number of net losses (10 trials)	5	1	0	1
Long-term outcome (10 trials)	–\$250	–\$250	\$250	\$250



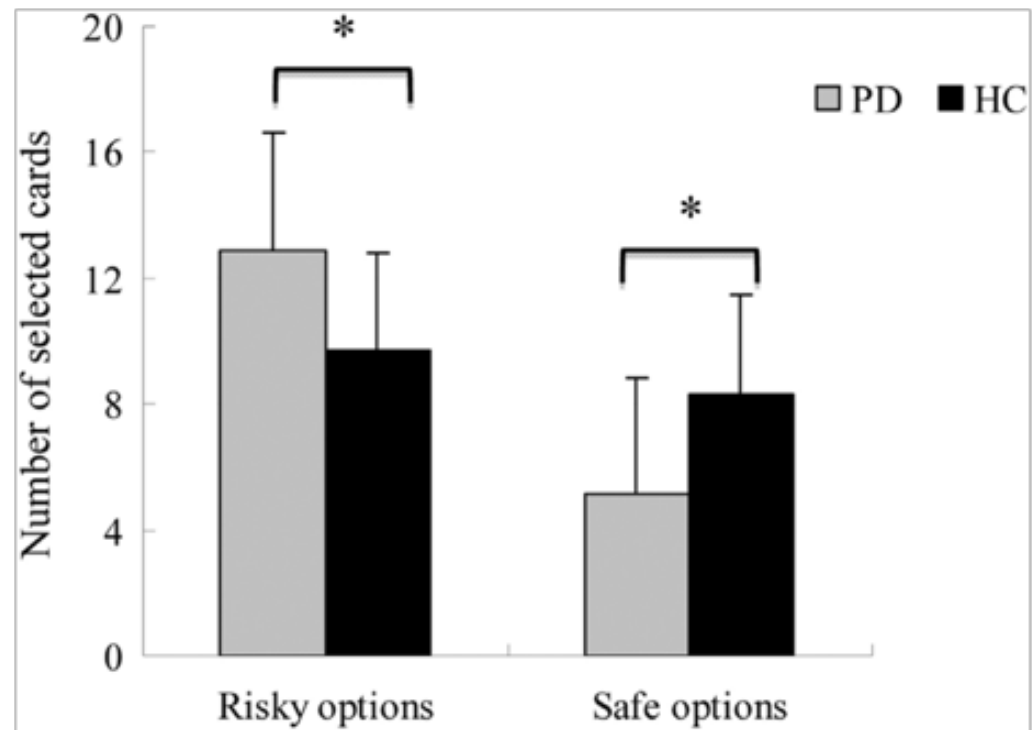




Performance on the IOWA Gambling Task

### Game of Dice Task

Players can place bets on  
“risky” or “safe” gambles.



# Conclusions

Disruptions of decision-making circuitry, especially dopamine dependent pathways, underlies impaired decision-making in people with PD.

## Study 4

doi:10.1093/brain/awv315

BRAIN 2016; 139; 204–216 | 204

**BRAIN**  
A JOURNAL OF NEUROLOGY

# **Fair play: social norm compliance failures in behavioural variant frontotemporal dementia**

**Claire O'Callaghan,<sup>1,2</sup> Maxime Bertoux,<sup>3</sup> Muireann Irish,<sup>1,4,5</sup> James M. Shine,<sup>1,6</sup>  
Stephanie Wong,<sup>1,5</sup> Leonidas Spiliopoulos,<sup>7</sup> John R. Hodges<sup>1,2,5</sup> and  
Michael Hornberger<sup>1,2,3,5</sup>**

# The Idea

People with dementia have trouble processing social norms which can then impair decision-making.

Why? Our ability to evaluate social norms seems to be related to intact function of a network between frontal (PFC) and sub-cortical (VS) regions. This network is disrupted by dementia.

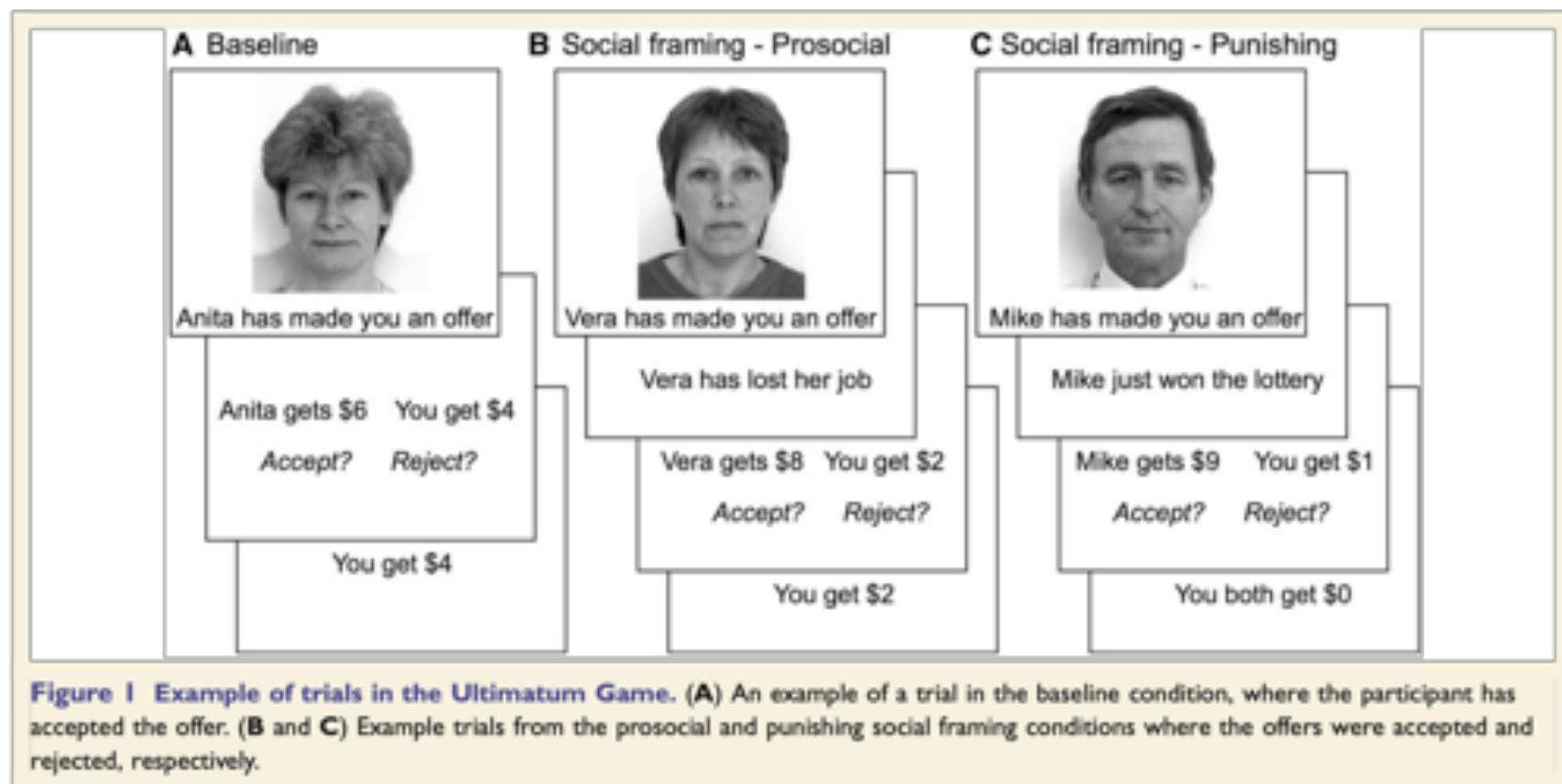
## Participants

n = 22 frontotemporal dementia

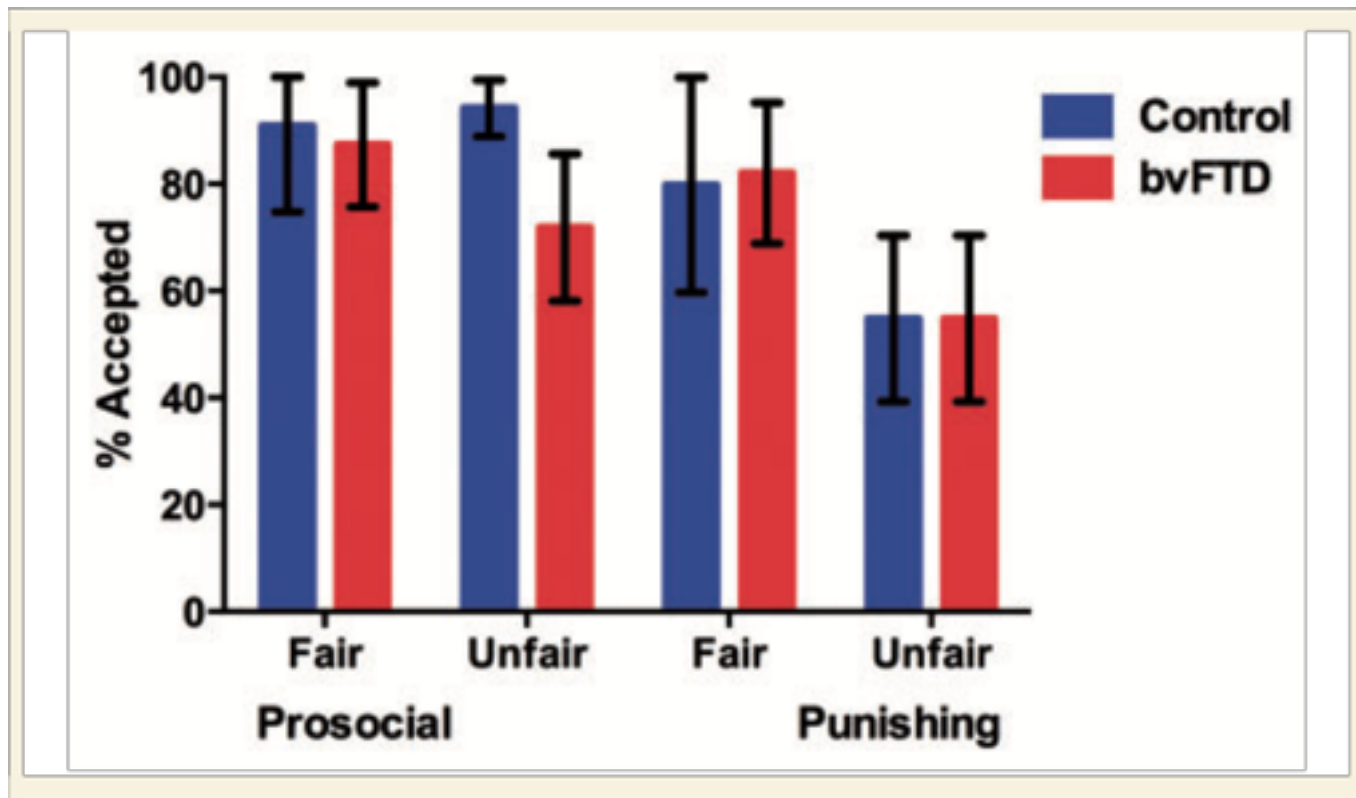
n = 22 healthy control volunteers

**Table 1** Scores on demographics, behavioural symptoms and background neuropsychology for patients with behavioural variant FTD and control subjects

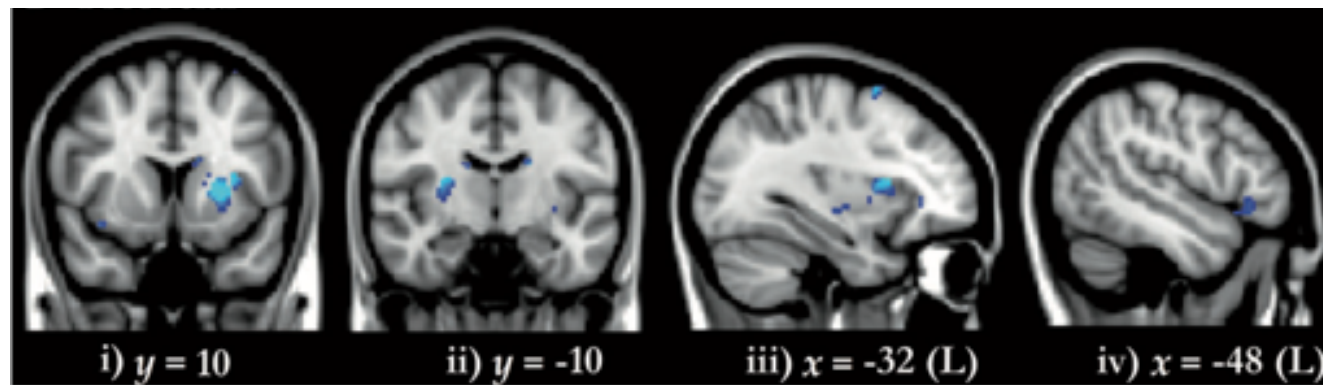
Demographics, clinical characteristics and empathy	Control	Behavioural variant FTD	P-values
<i>n</i>	22	22	–
Sex (M:F)	11:11	18:4	–
Age	64.8 (11.1)	64.8 (8.8)	n.s.
Education	13.8 (1.9)	12.0 (1.8)	n.s.
MMSE (max. 30)	29.4 (1.1)	26.3 (1.9)	<0.001
Duration (years diagnosed)	–	2.3 (2.0)	–
<b>Behavioural symptoms</b>			
FRS staging % score	–	38.8 (17.2) <sup>a</sup>	–
CBI-R Total score (max. 180)	–	73.1 (25.5)	–
Empathy item (max. 4)	–	3.0 (1.5)	–
<b>Neuropsychology</b>			
Digit span total	20.5 (2.5)	14.7 (3.5)	<0.001
TMT-A (s)	31.2 (14.2)	52.8 (36.7)	<0.05
TMT-B (s)	53.2 (14.2)	174.6 (97.5)	<0.001
RAVLT (trials 1–5)	54.2 (8.2)	31.8 (10.2)	<0.001
RAVLT delay	11.0 (3.2)	4.4 (3.7)	<0.001
Rey Figure Copy	34.2 (2.1)	26.3 (8.1)	<0.01
Rey Figure 3-minute delay	17.9 (5.8)	10.9 (7.3)	<0.01







Opponents were framed as “pro-social” (down on their luck, poor) or “punishing” (rich / well to do)



People with dementia has decreased neural activity in dorsal putamen, anterior insula, lateral orbitofrontal cortex.

# Conclusions

The putamen and orbito-frontal cortex play a role in evaluating social norms relative to decision-making.

## Study 5

*Psychological Medicine* (2015), 45, 1241–1251. © Cambridge University Press 2014  
doi:10.1017/S0033291714002347

ORIGINAL ARTICLE

# Abnormal brain responses to social fairness in depression: an fMRI study using the Ultimatum Game

V. B. Gradin<sup>1,2\*</sup>, A. Pérez<sup>1</sup>, J. A. MacFarlane<sup>3</sup>, I. Cavin<sup>3</sup>, G. Waiter<sup>4</sup>, J. Engelmann<sup>5</sup>, B. Dritschel<sup>6</sup>,  
A. Pomi<sup>7</sup>, K. Matthews<sup>2</sup> and J. D. Steele<sup>2</sup>

# The Idea

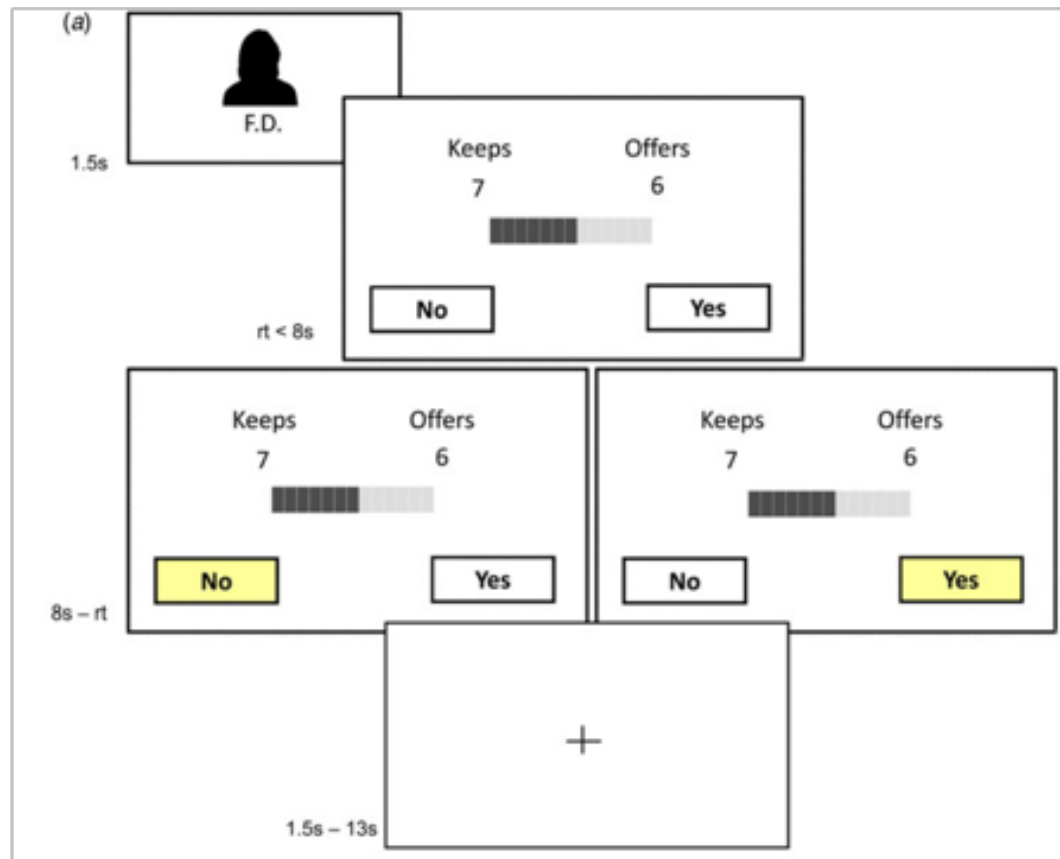
People with depression can have impaired decision-making ability.

Why? This could possibly be due to differences in neural processing – in particular in reward evaluation parts of the brain.

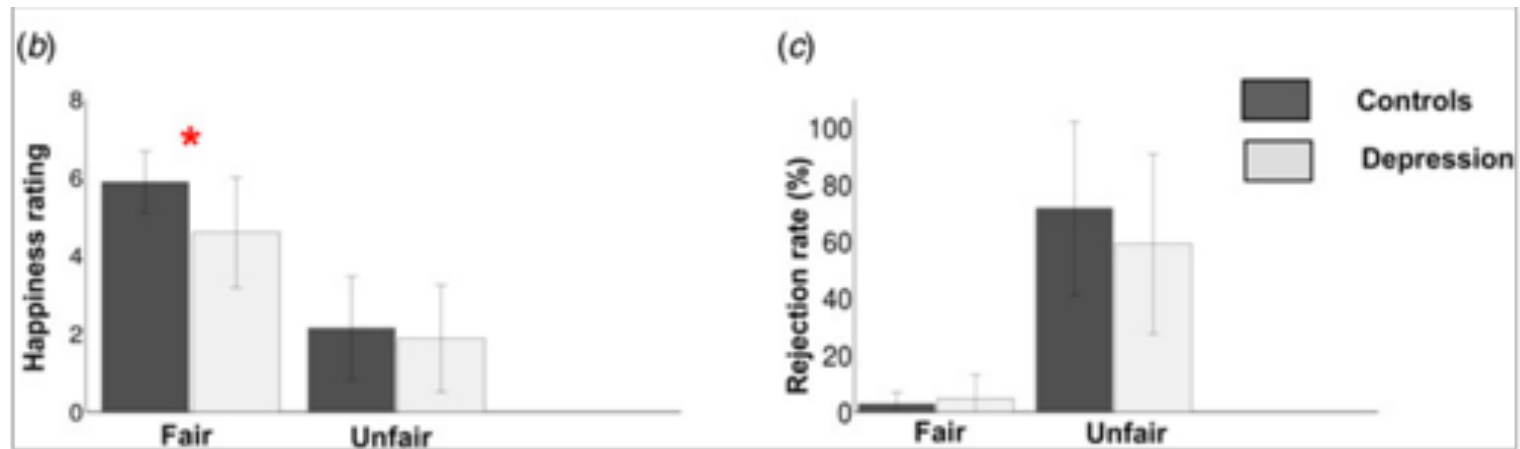
## Participants

n = 25 depressed patients

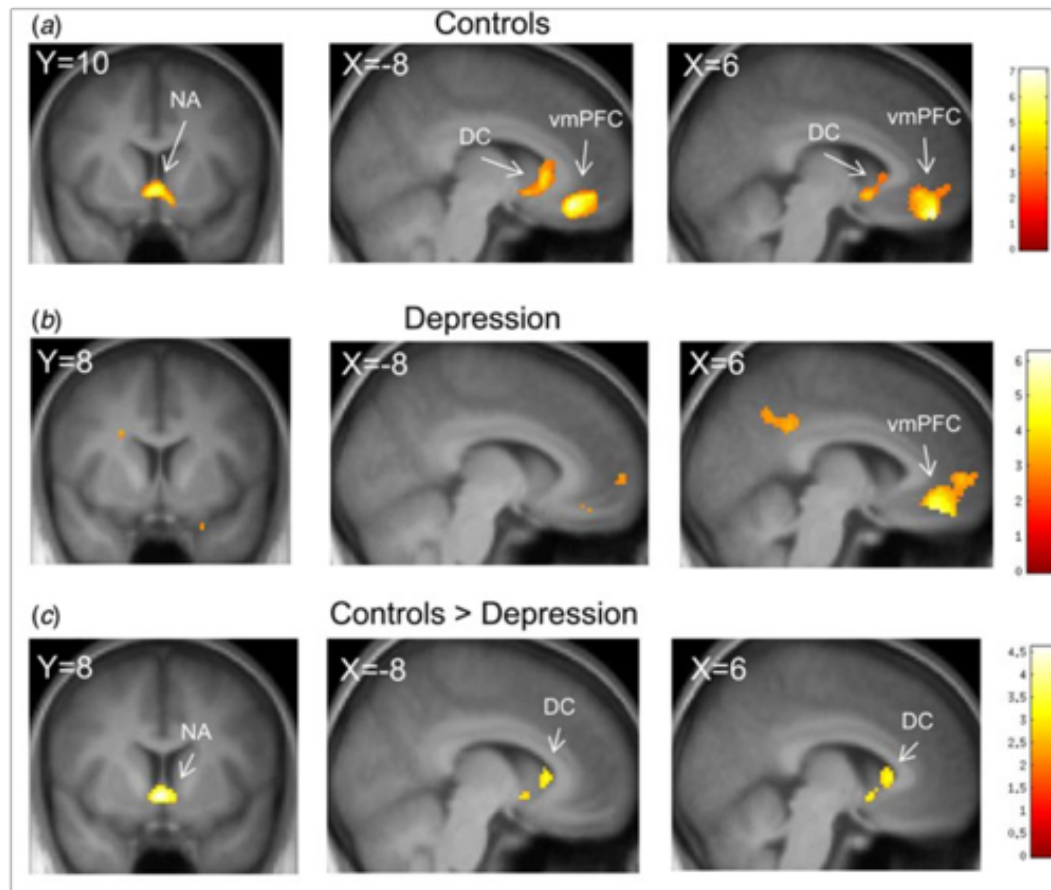
n = 25 healthy control volunteers



Key Manipulation: Hidden patterns of increasing or decreasing fairness of offers.

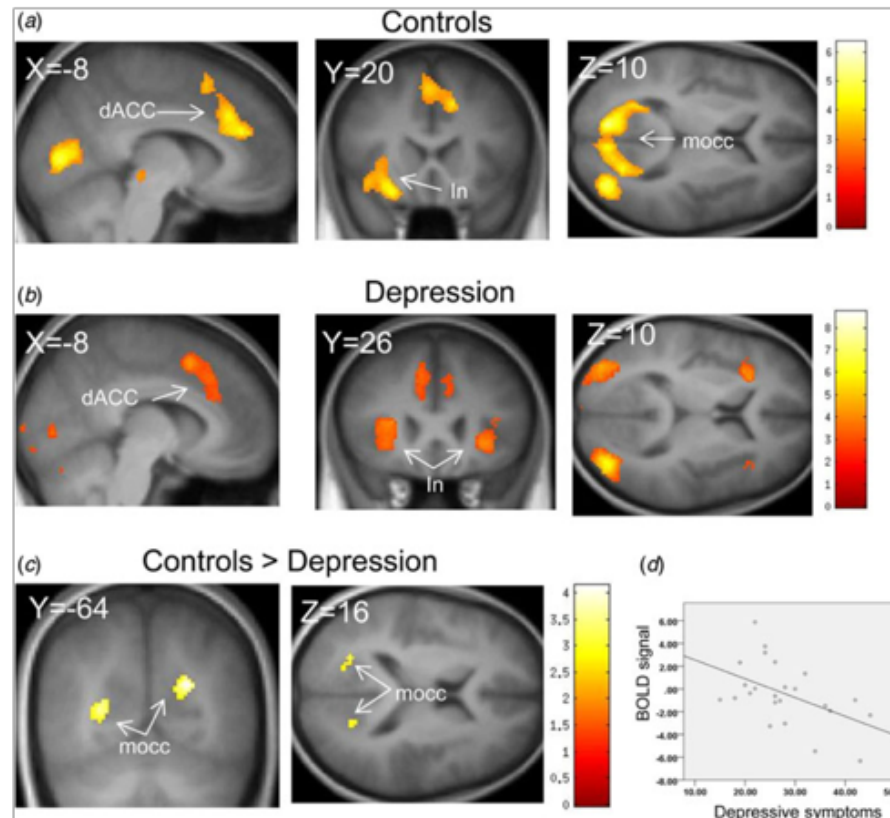


Depressed participants performed the same as controls but were less happy with fair offers.



More activity is nucleus accumbens, dorsal caudate nucleus, and vmPFC when fairness was increasing for controls





More activity is medial occipital lobe when fairness was decreasing for controls

# Conclusions




Findings suggest that nucleus accumbens and dorsal caudate nucleus may be linked to impairments in experiencing positive social interaction in depression – thus impacting decision-making in these situations.

## Study 6

6068 • The Journal of Neuroscience, April 15, 2015 • 35(15):6068–6078

Behavioral/Cognitive

# Altered Resting-State Functional Connectivity in Cortical Networks in Psychopathy

 Carissa L. Philippi,<sup>1</sup>  Maia S. Pujara,<sup>1</sup> Julian C. Motzkin,<sup>1</sup> Joseph Newman,<sup>2</sup> Kent A. Kiehl,<sup>3,4,5,6</sup> and  Michael Koenigs<sup>1</sup>

Departments of <sup>1</sup>Psychiatry and <sup>2</sup>Psychology, University of Wisconsin–Madison, Madison, Wisconsin 53706, <sup>3</sup>Mind Research Network, An Affiliate of Lovelace Biomedical and Environmental Research Institute, Albuquerque, New Mexico 87131, and Departments of <sup>4</sup>Psychology, <sup>5</sup>Neuroscience, and <sup>6</sup>Law, University of New Mexico, Albuquerque, New Mexico 87131

# The Idea

People with psychopathy make different decisions than the rest of us.

Why? Again, differences in neural circuitry.

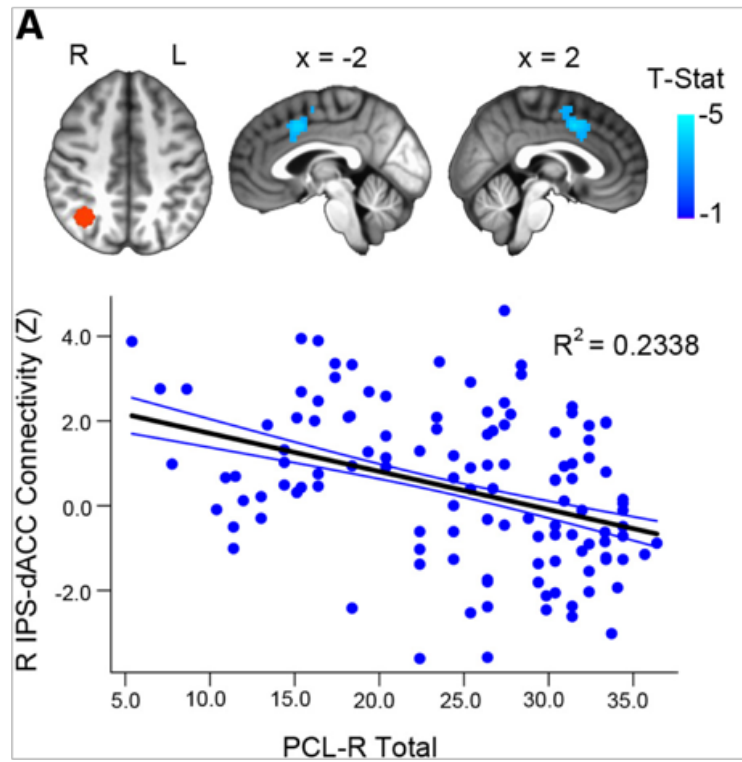
Participants

n = 46 depressed patients

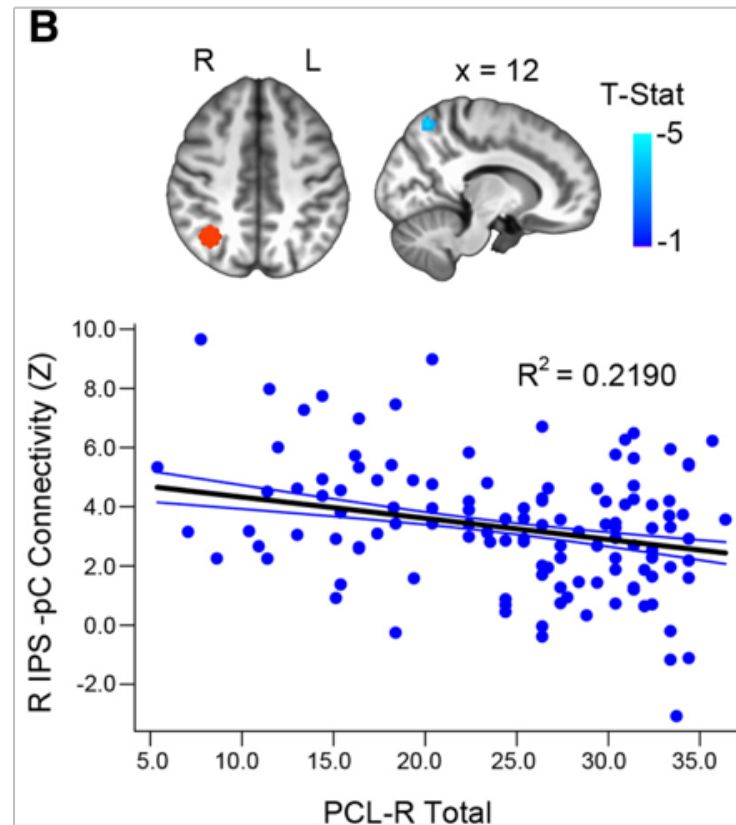
n = 49 healthy control volunteers

**Table 1. Participant characteristics**

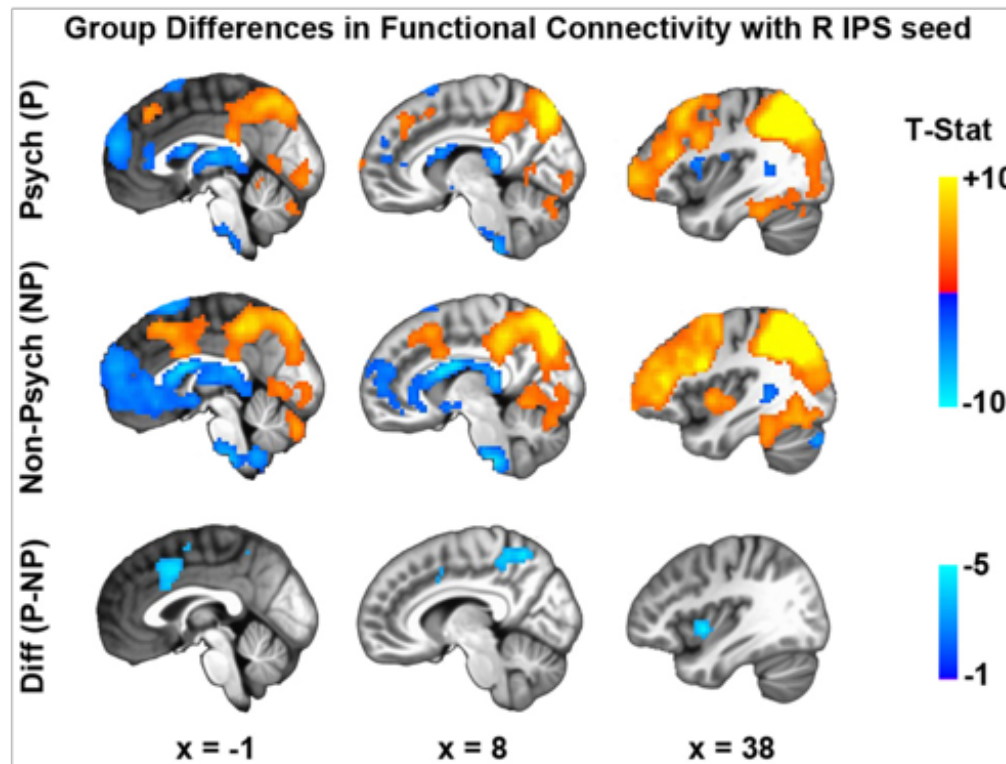
Variable	All participants (n = 142)				Nonpsychopathic (n = 49)				Psychopathic (n = 46)				<i>p</i> <sup>a</sup>
	Mean	SD	%	<i>n</i>	Mean	SD	%	<i>n</i>	Mean	SD	%	<i>n</i>	
Age	30.2	6.8			30.4	6.7			29.6	6.9			0.58
IQ <sup>b</sup>	98.0	11.1			98.6	11.7			99.1	10.0			0.84
Total PCL-R score	23.9	7.7			14.8	3.6			32.1	1.6			<0.001
Factor 1 score	8.8	3.5			5.1	2.2			12.1	1.8			<0.001
Factor 2 score	13.2	4.3			8.2	2.8			17.2	1.3			<0.001
Facet 1 score	3.2	2.0			1.3	1.1			4.9	1.6			<0.001
Facet 2 score	5.6	1.9			3.9	1.7			7.1	0.8			<0.001
Facet 3 score	6.8	2.1			4.8	1.9			8.4	1.2			<0.001
Facet 4 score	6.2	2.8			3.2	2.0			8.7	1.0			<0.001
SUD <sup>c</sup>			67.2	90 of 134			40.9	18 of 44			76.7	33 of 43	0.001
Race													
Caucasian			56.3	80 of 142			73.5	36 of 49			58.7	27 of 46	0.14
African American			41.5	59 of 142			26.5	13 of 49			41.3	19 of 46	0.14
Native American			0.7	1 of 142			0.0	0 of 49			0.0	0 of 46	N/A
Hispanic			1.4	2 of 142			0.0	0 of 49			0.0	0 of 46	N/A



The higher the psychopathy score, the less connectivity between Intraparietal sulcus and the ACC.



The higher the psychopathy score, the less connectivity between Intraparietal sulcus and the PC.



Differences in ACC (conflict), Precuneus (self-awareness), and Insular Cortex (emotion).



# Conclusions

People with psychopathy make different decisions because of reduced functional connectivity between parts of the brain involved in decision-making.

## Study 7

### Reduced engagement of the anterior cingulate cortex in the dishonest decision-making of incarcerated psychopaths

Nobuhito Abe,<sup>1</sup> Joshua D. Greene,<sup>2</sup> and Kent A. Kiehl<sup>3,4,5</sup>

<sup>1</sup>Kokoro Research Center, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan, <sup>2</sup>Department of Psychology and Center for Brain Science, Harvard University, Cambridge, MA 02138, USA, <sup>3</sup>The Nonprofit Mind Research Network (MRN) and Lovelace Biomedical and Environmental Research Institute (LBERI), Albuquerque, NM, USA, <sup>4</sup>Department of Psychology, University of New Mexico, Albuquerque, NM, USA, and <sup>5</sup>Department of Neurosciences, University of New Mexico, Albuquerque, NM, USA

Correspondence should be addressed to Nobuhito Abe, Kokoro Research Center, Kyoto University, 46 Shimoadachi-cho, Yoshida Sakyo-ku, Kyoto 606-8501, Japan. E-mail: [abe.nobuhito.7s@kyoto-u.ac.jp](mailto:abe.nobuhito.7s@kyoto-u.ac.jp)

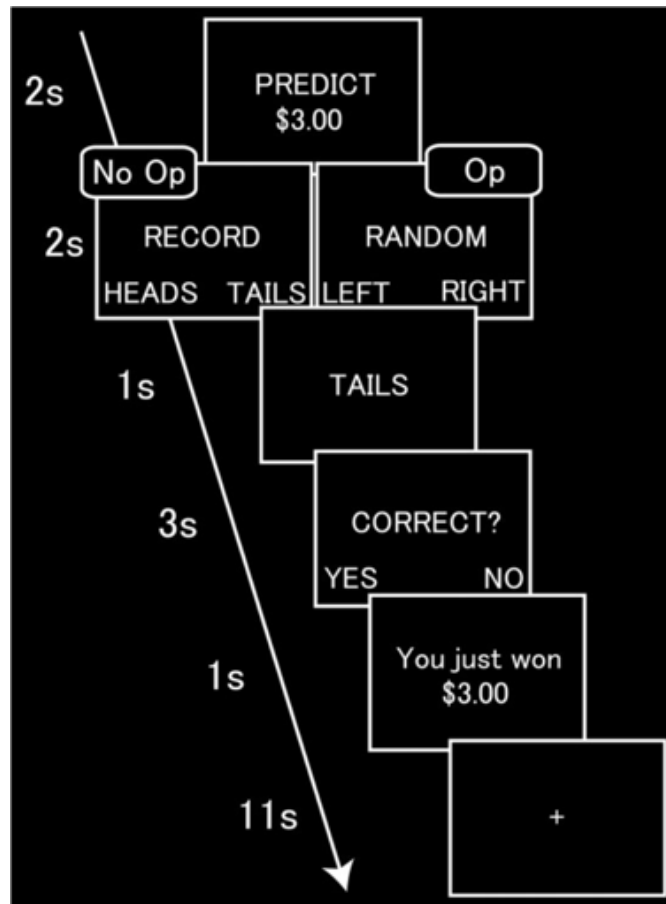
# The Idea

People with psychopathy make different decisions than the rest of us.  
In this case, they tend to be more dishonest.

Why? Inhibition of reward circuitry in the ACC.

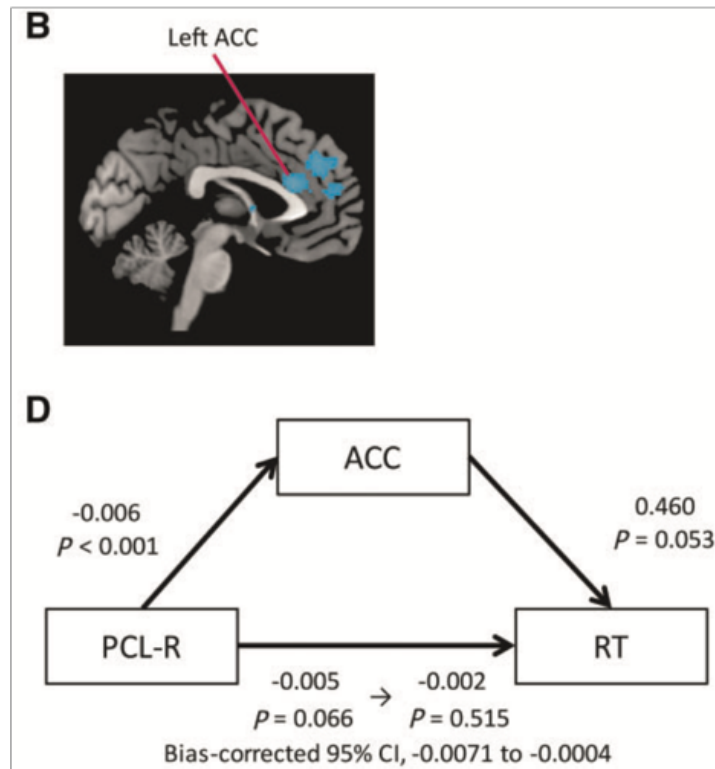
Participants

n = 67 incarcerated individuals with psychopathy

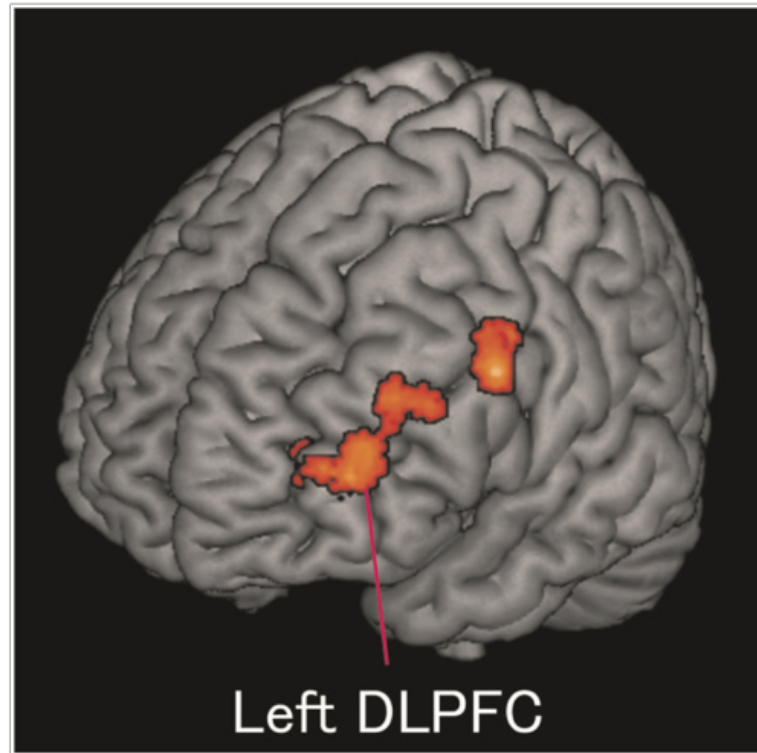


Participants were told this was a study of psychic ability.

There was a "hidden" opportunity to be dishonest – in the "Op: Opportunity" condition participants did make a prediction about outcome to themselves. Thus, they could claim they were accurate after the fact (dishonesty).



Relationship between psychopathy, response, and activity in ACC.



Interestingly, a connectivity relationship was also revealed with DLPFC that scaled inversely with psychopathy.

# Conclusions

People with psychopathy had reduced activity in a reward processing part of the brain that was related to dishonesty. This was also related to connectivity with a part of the brain associated with cognitive control.

## Study 8

# Neural mechanisms of social decision-making in the primate amygdala

Steve W. C. Chang<sup>a,b,1</sup>, Nicholas A. Fagan<sup>a</sup>, Koji Toda<sup>c,d</sup>, Amanda V. Utevsky<sup>e</sup>, John M. Pearson<sup>e</sup>,  
and Michael L. Platt<sup>c,e,f,g,h</sup>

<sup>a</sup>Department of Psychology, Yale University, New Haven, CT 06520; <sup>b</sup>Department of Neuroscience, Yale University School of Medicine, New Haven, CT 06510; <sup>c</sup>Duke Institute for Brain Sciences, Duke University School of Medicine, Durham, NC 27710; <sup>d</sup>Japan Society for the Promotion of Science, Tokyo 102-0083, Japan; <sup>e</sup>Department of Neurobiology, Duke University School of Medicine, Durham, NC 27710; <sup>f</sup>Department of Neuroscience, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA 19104; <sup>g</sup>Department of Psychology, University of Pennsylvania, Philadelphia, PA 19104; and <sup>h</sup>Marketing Department, The Wharton School, University of Pennsylvania, Philadelphia, PA 19104



# The Idea

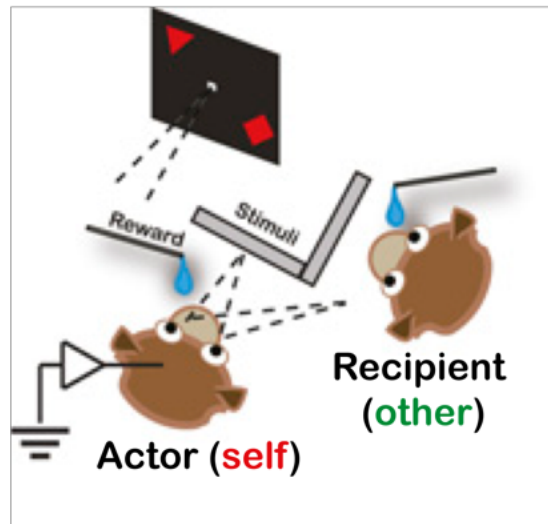
Social context clearly impacts decision-making, but how?

Why? Evidence would suggest emotional parts of the brain (the amygdala) would play a role in this process.

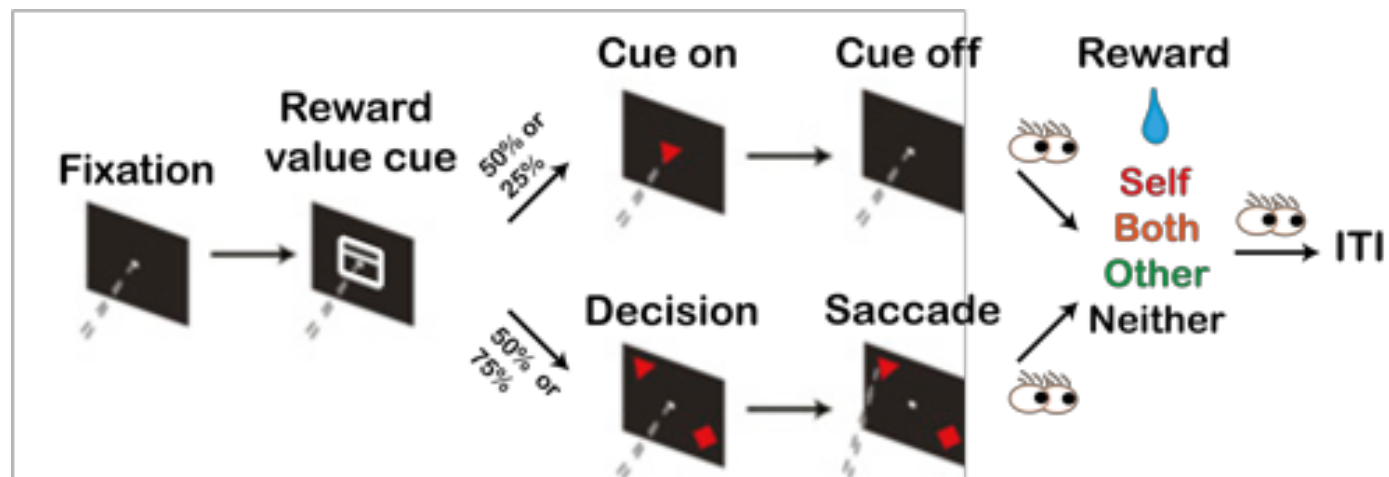
Participants

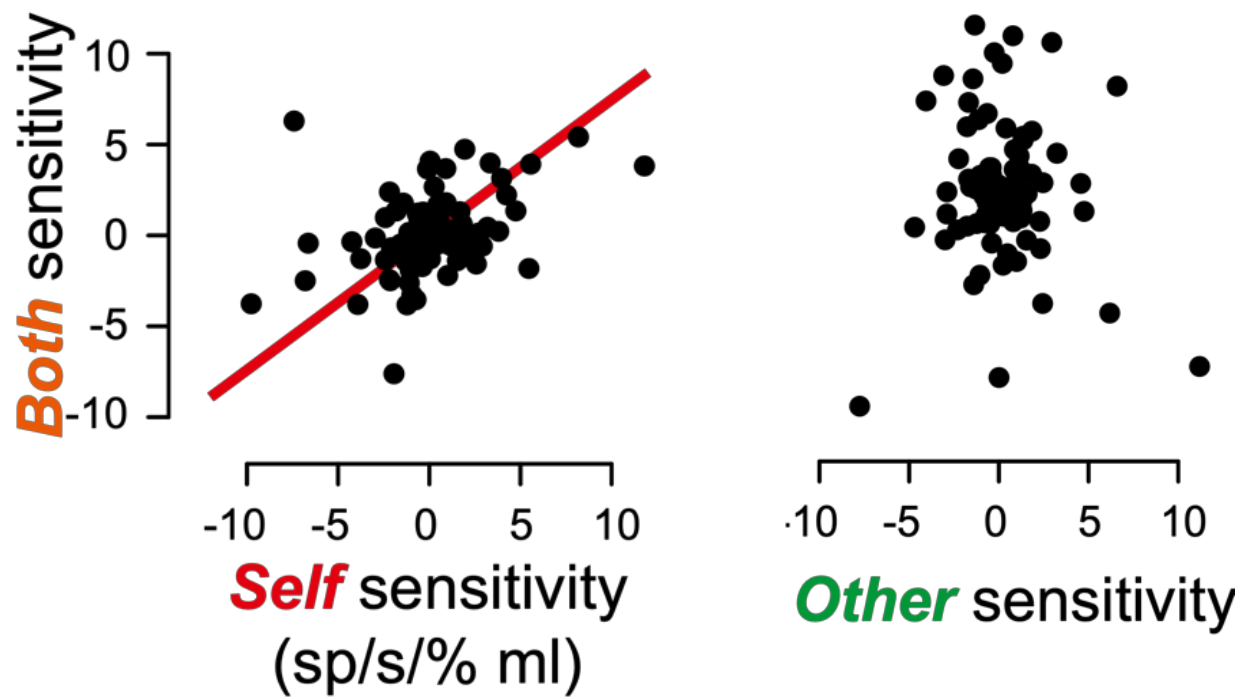
n = 4 monkeys

A



Monkey can choose to give or withhold reward (Dictator Game)





Firing in the amygdala encoded self relative to other

# Conclusions

The amygdala also seems to contribute to social decisions by encoding relative emotion values.

## Study 9

# Lateralized Readiness Potentials Reveal Properties of a Neural Mechanism for Implementing a Decision Threshold

**Marieke K. van Vugt<sup>1\*</sup>, Patrick Simen<sup>2</sup>, Leigh Nystrom<sup>3</sup>, Philip Holmes<sup>3,4</sup>, Jonathan D. Cohen<sup>3</sup>**

<sup>1</sup> Department of Artificial Intelligence, University of Groningen, Groningen, The Netherlands, <sup>2</sup> Department of Neuroscience, Oberlin College, Oberlin, Ohio, United States of America, <sup>3</sup> Princeton Neuroscience Institute, Princeton University, Princeton, New Jersey, United States of America, <sup>4</sup> Department of Mechanical & Aerospace Engineering, Princeton University, Princeton, New Jersey, United States of America

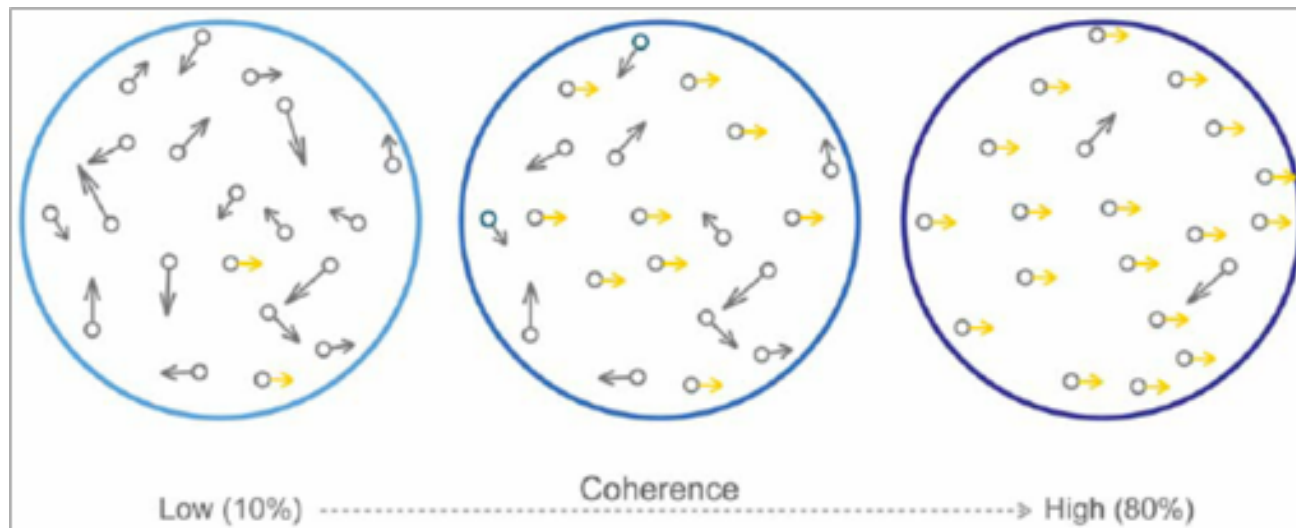
# The Idea

We posit that a decision-threshold has to be reached before action.

Why? As evidence accumulates our values change but at some point a decision is made – thus a threshold has been reached.

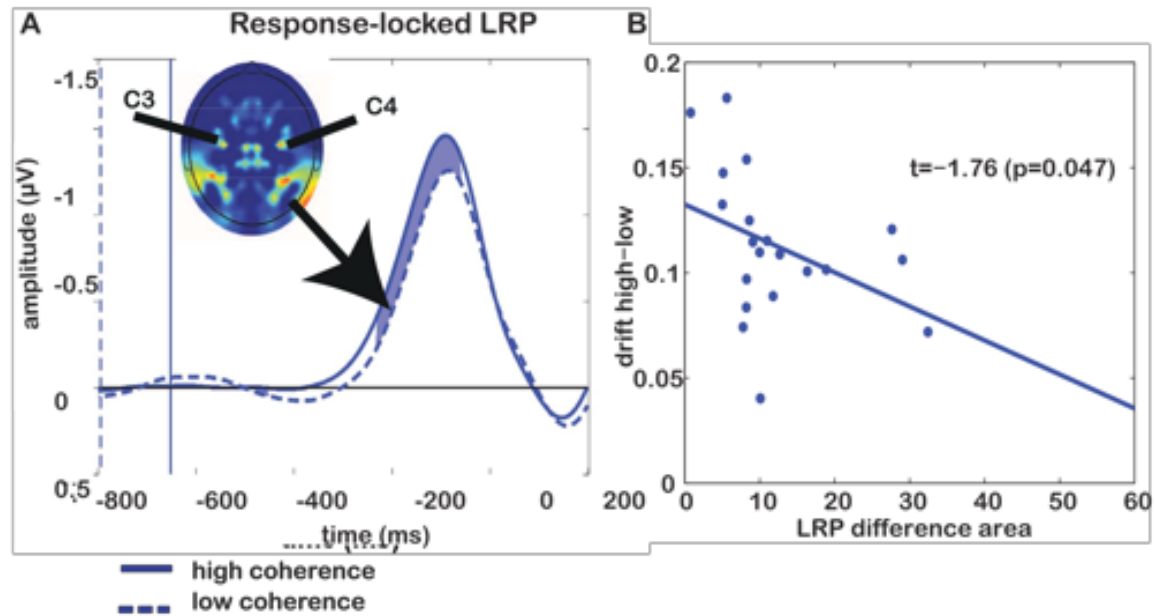
Participants

n = 20 healthy participants



Key Manipulation: Changing threshold of detection depending on coherence – participant has to make a decision on dot direction.





Amplitude of the brain wave component negativity scales to level of coherence prior to the response suggesting a threshold has been reached.

# Conclusions

Brain waves appear to scale to needed threshold levels of detection prior to a response – this at least partially validates evidence accumulation decision-making models.

## Study 10



Contents lists available at [ScienceDirect](#)

# Behavioural Brain Research

journal homepage: [www.elsevier.com/locate/bbr](http://www.elsevier.com/locate/bbr)



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Research report

## An fMRI study of behavioral response inhibition in adolescents with and without histories of heavy prenatal alcohol exposure

Ashley L. Ware<sup>a</sup>, M. Alejandra Infante<sup>a</sup>, Jessica W. O'Brien<sup>a</sup>, Susan F. Tapert<sup>b,c</sup>, Kenneth Lyons Jones<sup>d</sup>, Edward P. Riley<sup>a</sup>, Sarah N. Mattson<sup>a,\*</sup>

<sup>a</sup> Center for Behavioral Teratology, Department of Psychology, San Diego State University, San Diego, CA 92120, USA  
<sup>b</sup> Department of Psychiatry, University of California, San Diego, San Diego, CA 92037, USA  
<sup>c</sup> VA San Diego Healthcare System, San Diego, CA 92161, USA  
<sup>d</sup> University of California, San Diego, School of Medicine, Department of Pediatrics, San Diego, CA 92093, USA



# The Idea

People with Fetal Alcohol Syndrome Disorder (FASD) have impaired cognitive function.

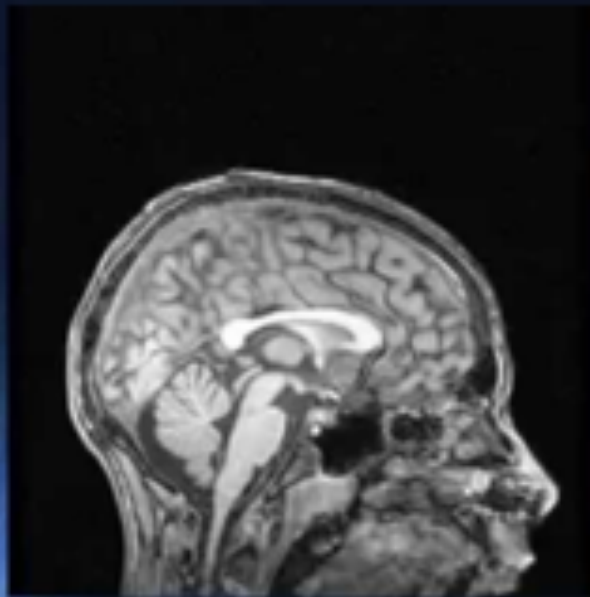
Why? In utero exposure to alcohol via the mother damages the developing brain.

Participants

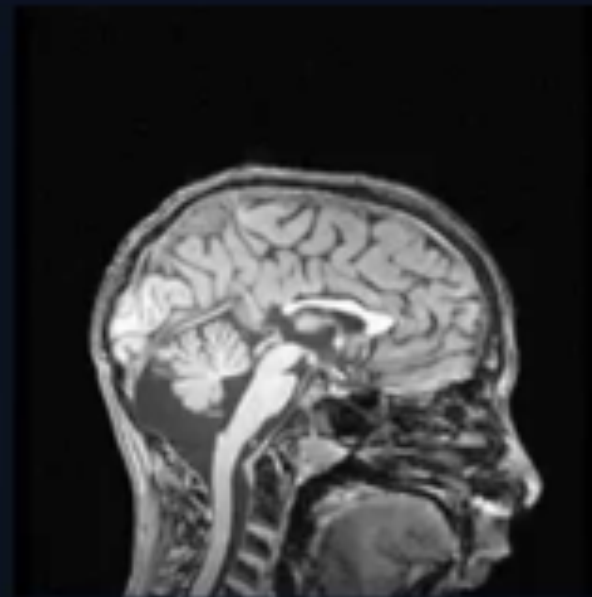
n = 21 participants with FASD

n = 21 healthy participants

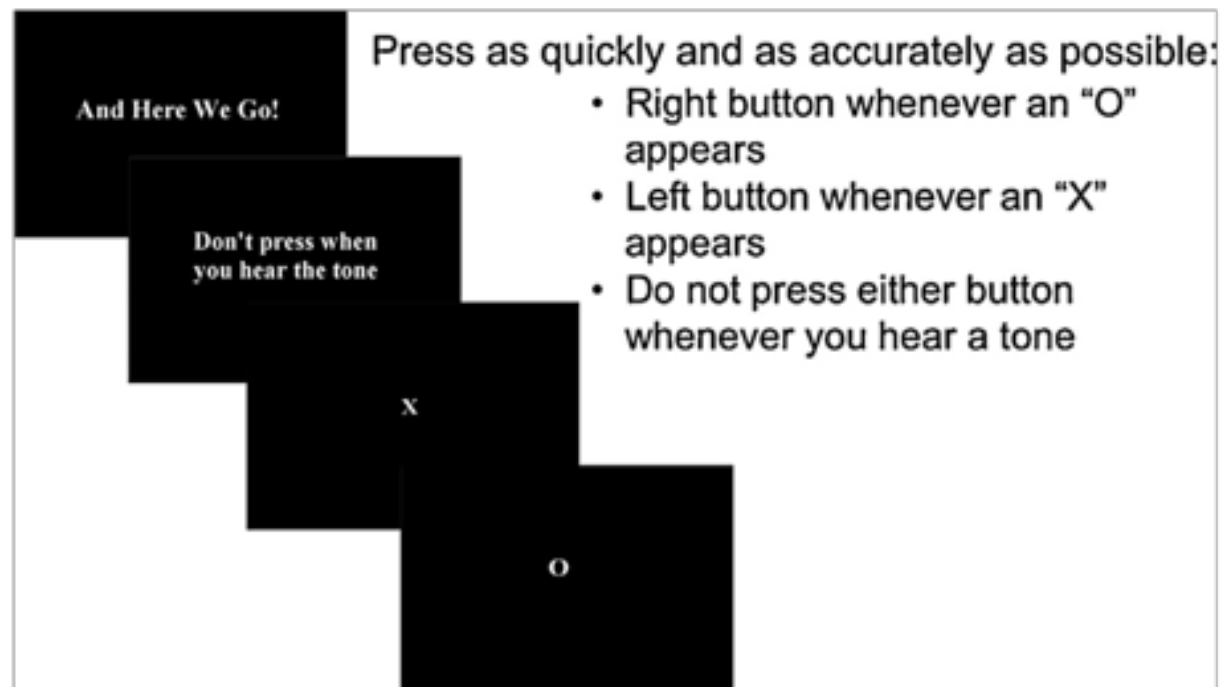
Extreme structural abnormalities in FAS  
(12 year old male subjects)



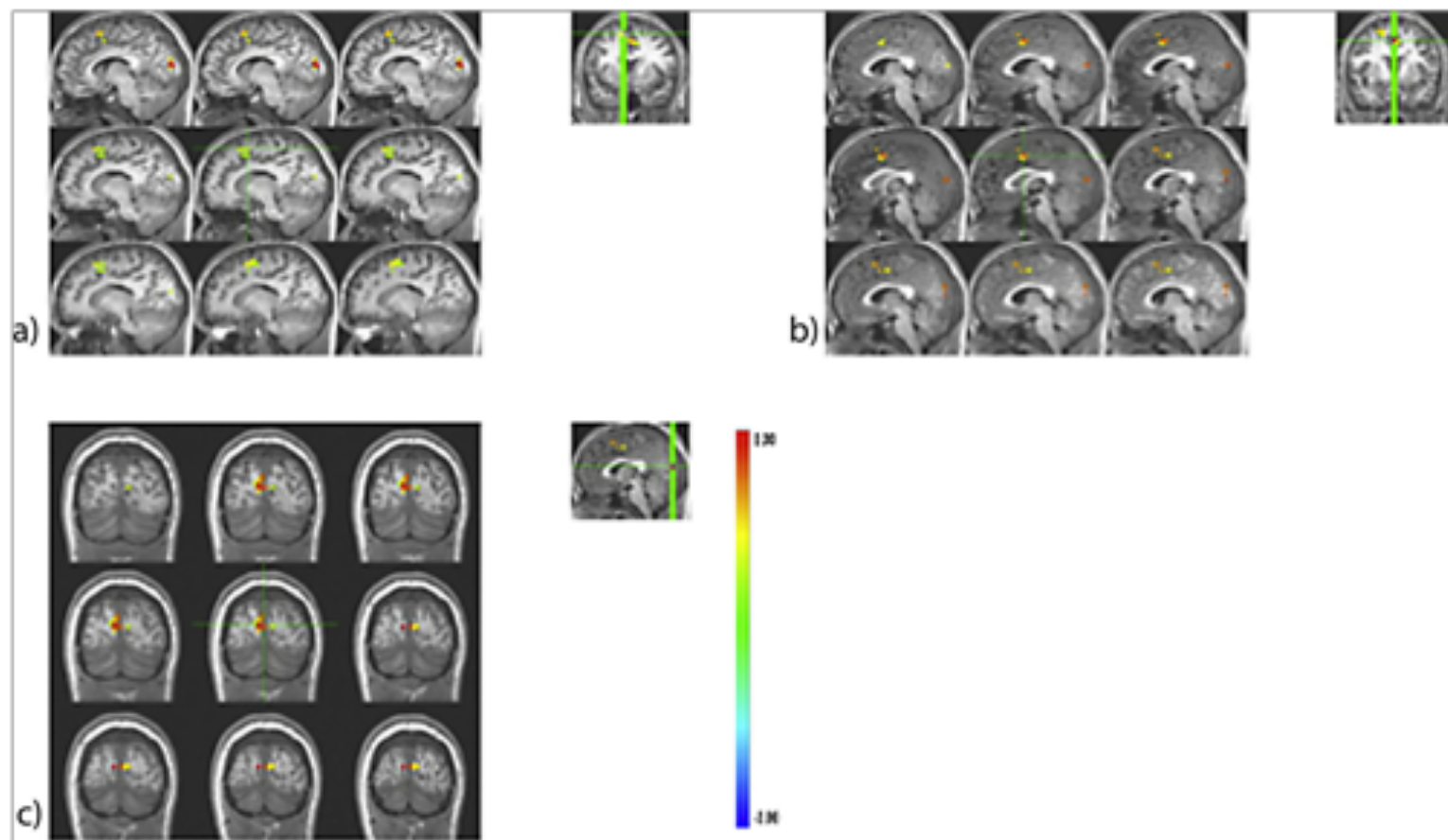
Normal Development



Fetal Alcohol Syndrome

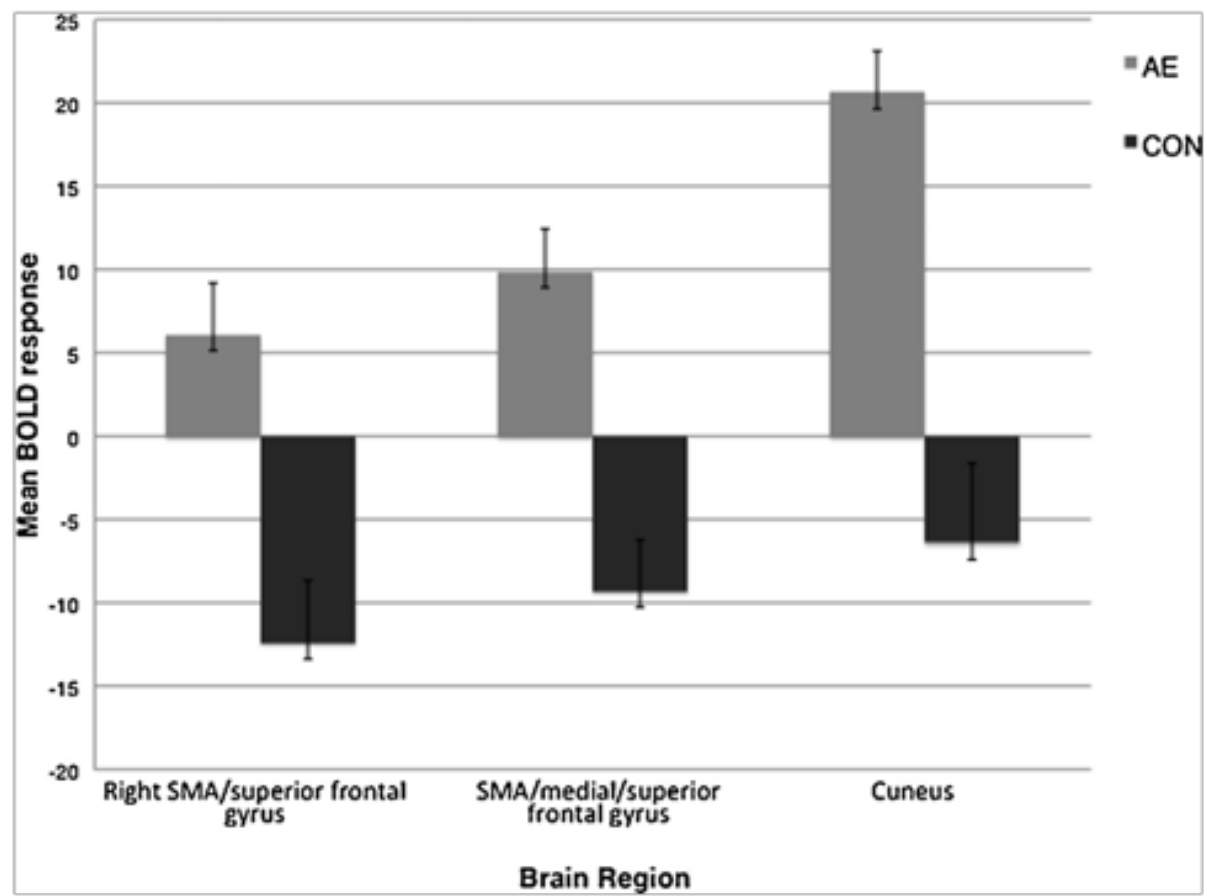


**Fig. 1.** Stop-signal fMRI paradigm instructions. Task based on paradigm described by Matthews et al. [\[35,36\]](#).



Stop-signal contrast	Anatomical region	$t(1, 41)$	Effect size $\eta_p^2$	Brodmann area	Volume ( $\mu\text{l}$ )	Talairach coordinates (reported in LPI)		
						X	Y	Z
Baseline (motor responding)	R precentral gyrus	4.65	.351	6	1408	-48.9	-2.8	31.8
	L pre- and postcentral gyrus	4.75	.361	6, 4	1408	-45.1	-11.0	32.0
All-stop	L postcentral gyrus	4.63	.349	4	2304	-47.0	-13.0	34.8
	R precentral gyrus	4.51	.337	6	1344	-48.7	-6.9	35.0
	L putamen/lentiform nucleus	4.31	.317	-	1088	-27.9	-7.1	-9
	L SMA/middle cingulate	3.62	.232	6, 24	1088	-7.2	-5	49.2
	R middle cingulate	4.26	.312	24	896	12.0	-13.9	38.6
Medium	L insula/superior temporal gyrus	5.11	.395	38	1024	-35.5	-2.0	-8.5
	R middle/medial temporal gyrus	5.35	.417	21, 20	960	50.0	2.7	-22.9
Hard	L postcentral gyrus	4.85	.371	3, 4	5312	-41.9	-19.3	43.6
	R pre- and postcentral/supramarginal gyrus	5.13	.397	6, 40	3712	53.0	-15.8	29.9
	L middle cingulate/SMA	4.063	.292	24, 6	2688	-8.3	-2.0	45.0
	L precentral gyrus	4.40	.326	6	1024	-25.5	-4.5	29.8
	L thalamus/caudate	3.84	.269	-	960	-13.7	-9.0	14.7
	L middle/anterior cingulate	4.51	.337	24	960	.4	-2.1	32.3
Hard-easy	R SMA/superior frontal gyrus	4.18	.304	6	1344	10.0	19.0	56.0
	SMA/medial/superior frontal gyrus	4.17	.303	6, 24, 32	1088	-2.0	7.0	44.0
	Cuneus	3.62	.247	18	1024	6.0	-81.0	12.0





# Conclusions

FASD results in differences in brain function during performance of a simple decision-making task – these differences result in differences in behavior.

# Study 11



## Mindfulness training increases cooperative decision making in economic exchanges: Evidence from fMRI



Ulrich Kirk<sup>a</sup>, Xiaosi Gu<sup>b</sup>, Carla Sharp<sup>c</sup>, Andreas Hula<sup>d</sup>, Peter Fonagy<sup>e,f</sup>, P. Read Montague<sup>d,g,\*</sup>

<sup>a</sup> Department of Psychology, University of Southern Denmark, 5230 Odense, Denmark

<sup>b</sup> Center for Brain Health, School of Behavioral and Brain Sciences, The University of Texas at Dallas, Dallas, TX 75235, USA

<sup>c</sup> Department of Psychology, University of Houston, Houston, TX 77004, USA

<sup>d</sup> Wellcome Trust Centre for Neuroimaging, University College London, London WC1N 3BG, UK

<sup>e</sup> Research Department of Clinical, Educational, and Health Psychology, University College London, London WC1E 6BT, UK

<sup>f</sup> Anna Freud Centre, London NW3 5SD, UK

<sup>g</sup> Human Neuroimaging Laboratory, Virginia Tech Carilion Research Institute, Roanoke, VA 24016, UK

# The Idea

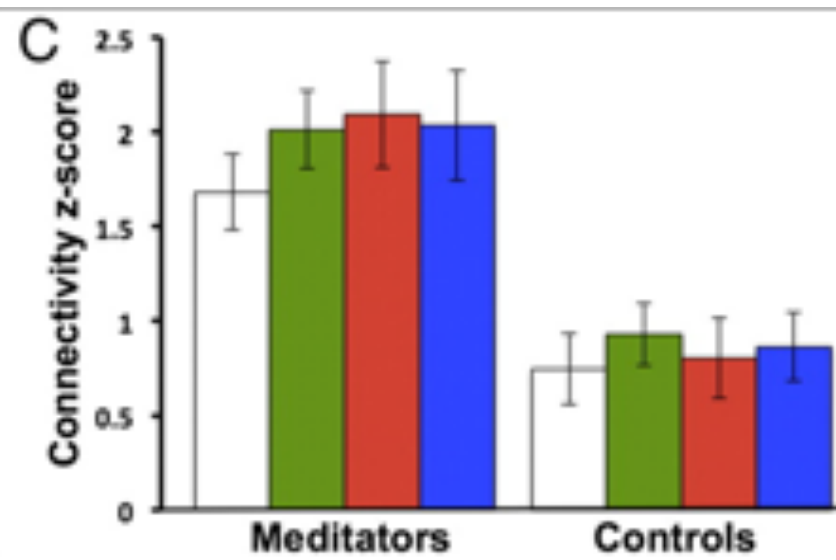
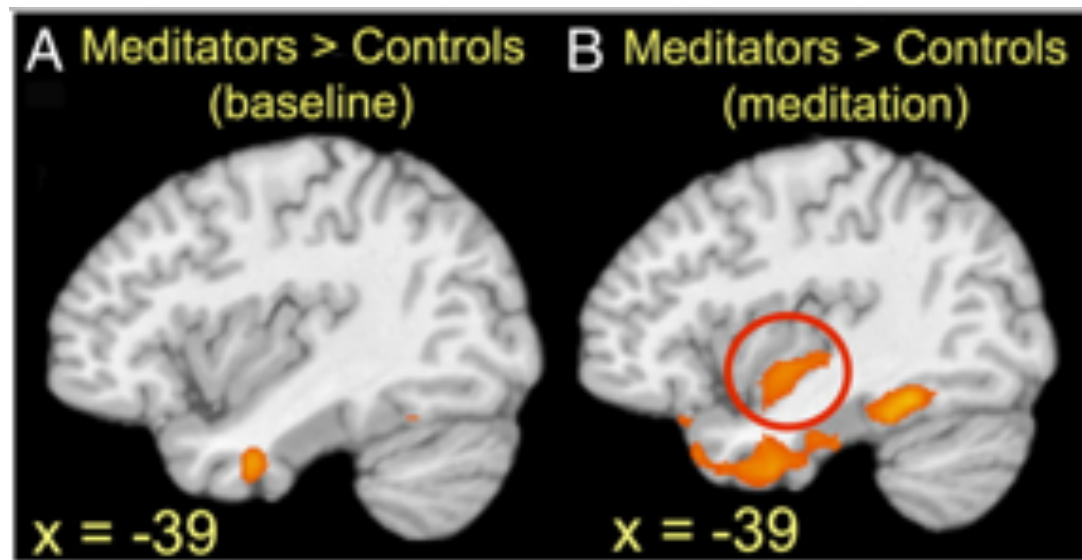
Mindfulness training may improve human decision-making.

Why? It is well established now that mindfulness practitioners have different patterns of brain activity than controls.

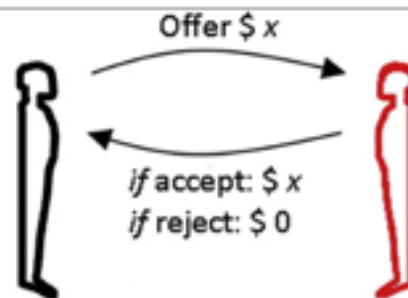
## Participants

n = 17 participants with FASD

n = 10 healthy participants

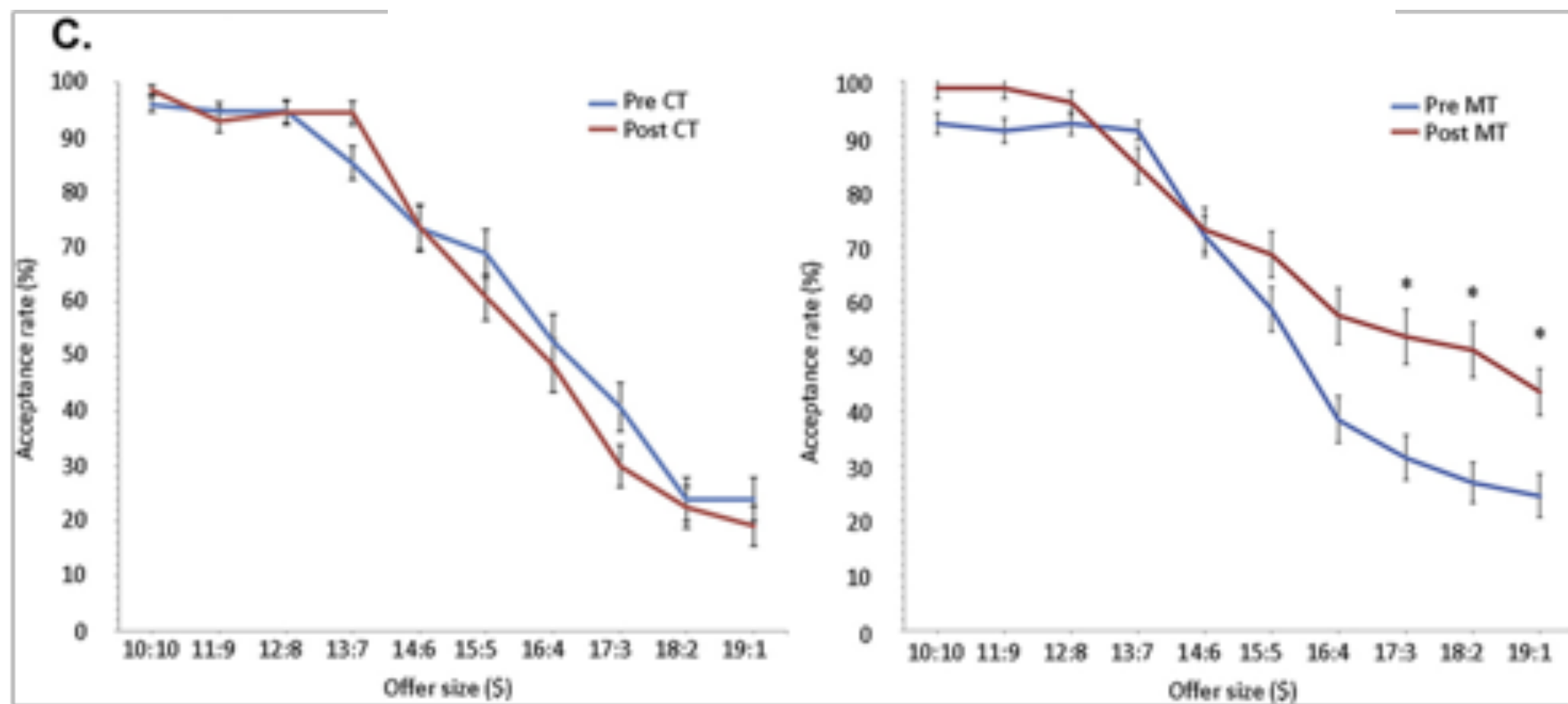


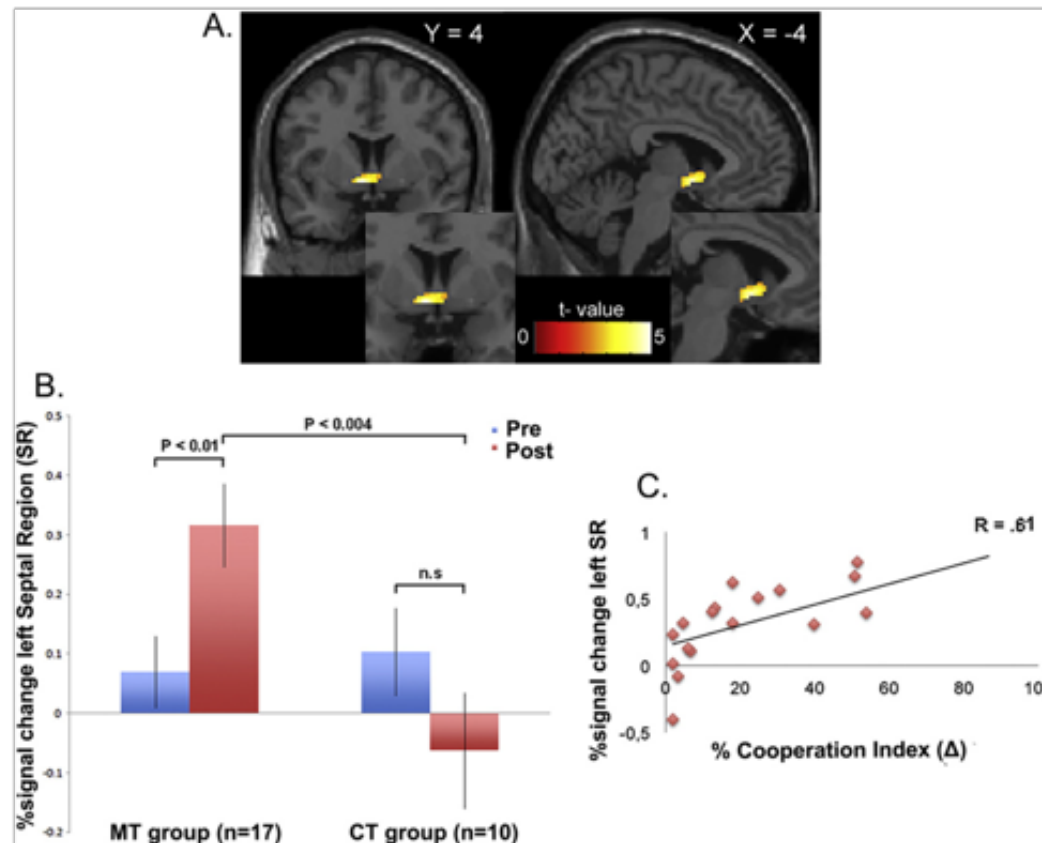
A.



B.

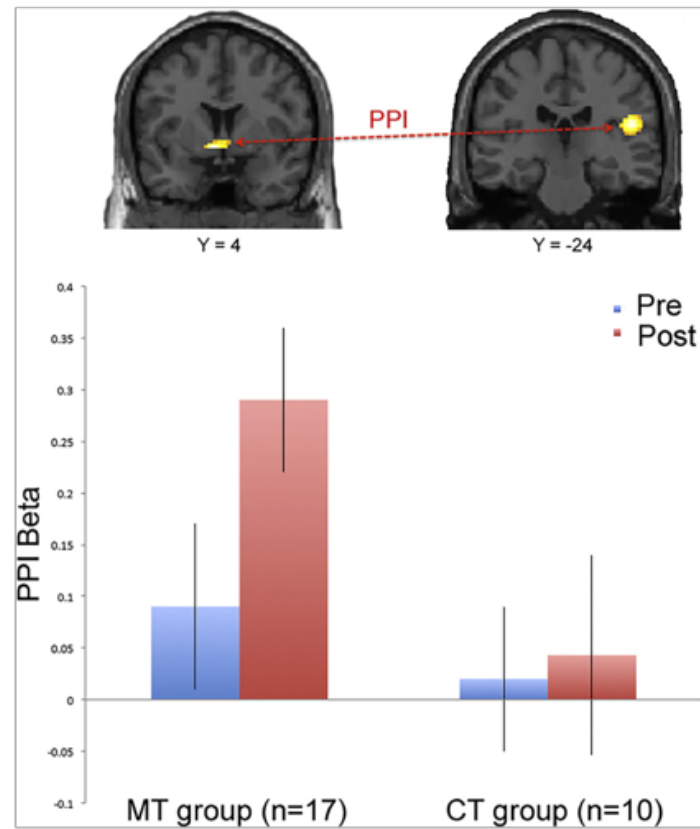






Increase in activity in the septal region (plays a role in human reward processing)





Also observed was increased connectivity with posterior insular (emotion)

# Conclusions

Mindfulness training changed brain activity in reward processing areas of the brain and connectivity with emotional areas of the brain.

## **The scarcity heuristic impacts reward processing within the medial-frontal cortex**

Chad C. Williams<sup>a</sup>, Boaz Y. Saffer<sup>b</sup>, Robert B. McCulloch<sup>a</sup> and  
Olave E. Krigolson<sup>a</sup>

# The Idea

We know that higher level information – heuristics – can bias our actions.

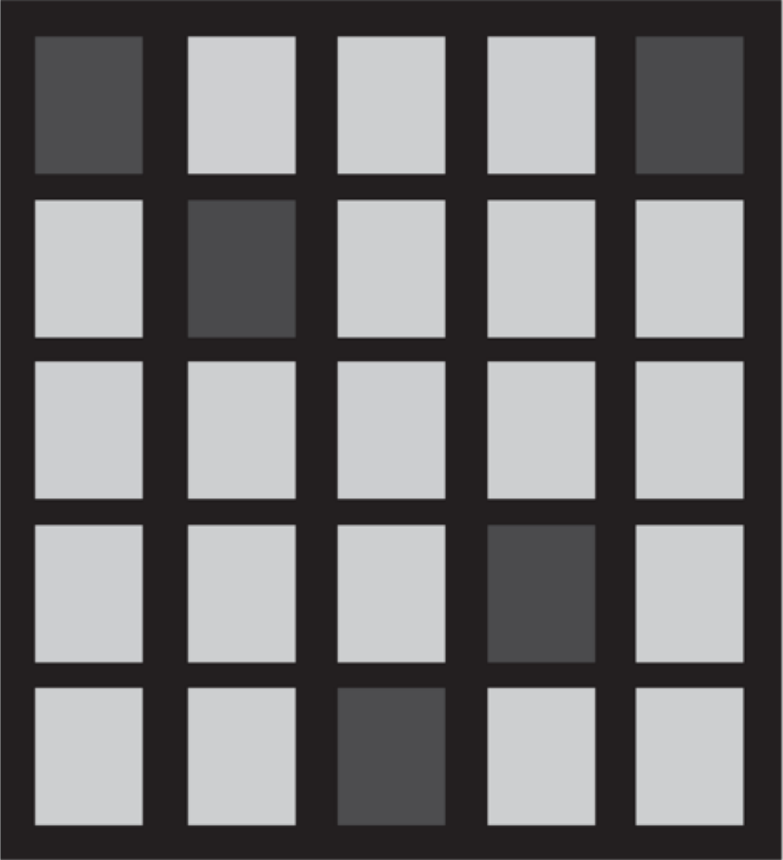
Why? Potentially differences in neural processing of outcomes.

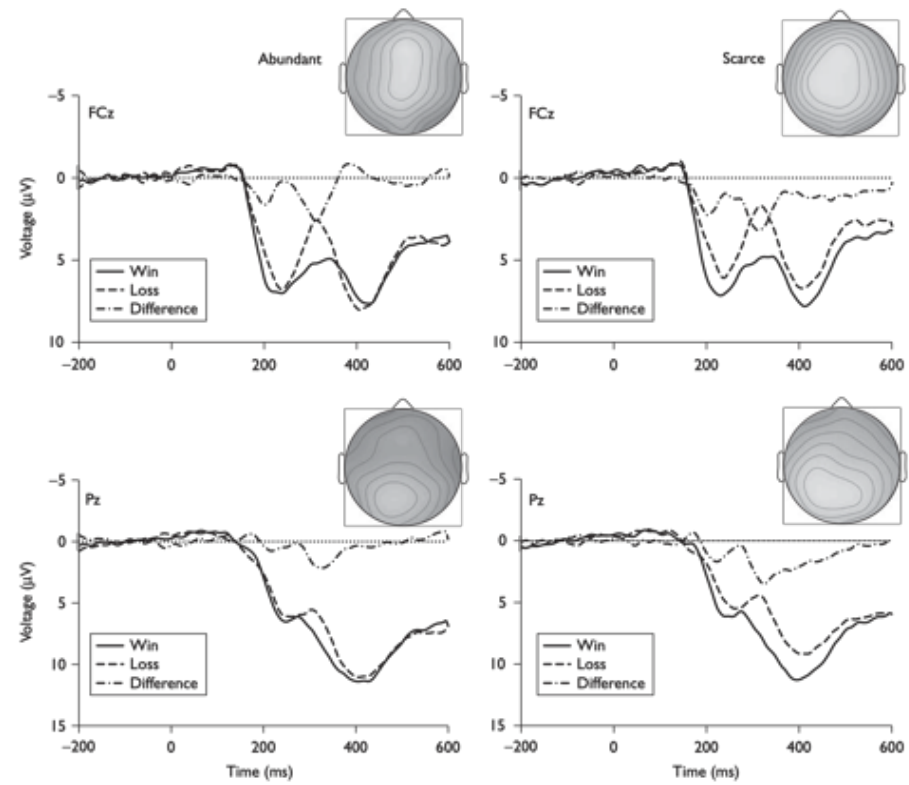
Participants

n = 30 healthy younger adults

friday 19:25 at the supermarket








# Conclusions

Heuristics can exert a top-down bias on low-level reward systems.





## Older adults display diminished error processing and response in a continuous tracking task

Francisco L. Colino<sup>1</sup>  | Harvey Howse<sup>1</sup> | Angela Norton<sup>1</sup> | Robert Trska<sup>1</sup> |  
Anthony Pluta<sup>1</sup> | Stephen J. C. Luehr<sup>1</sup> | Todd C. Handy<sup>2</sup> | Olave E. Krigolson<sup>1</sup>

# The Idea

Age impacts decision-making. In this case, we know older adults can be prone to making more motor errors than younger adults.

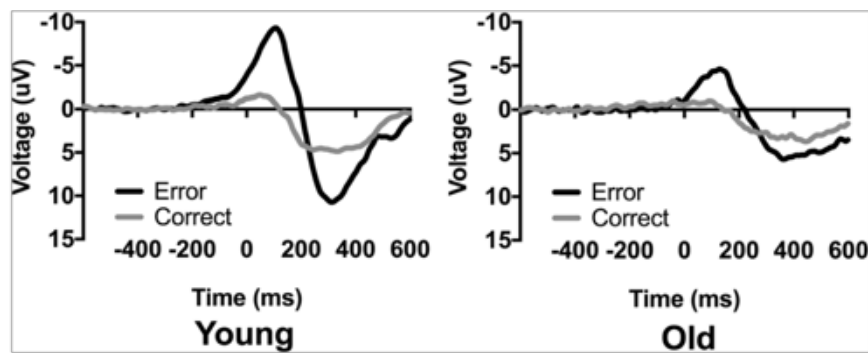
Why? Potentially differences in ability to process errors.

## Participants

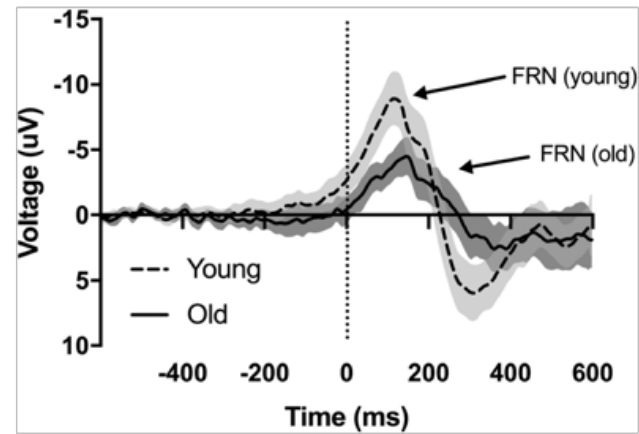
n = 20 healthy younger adults

n = 20 healthy older adults

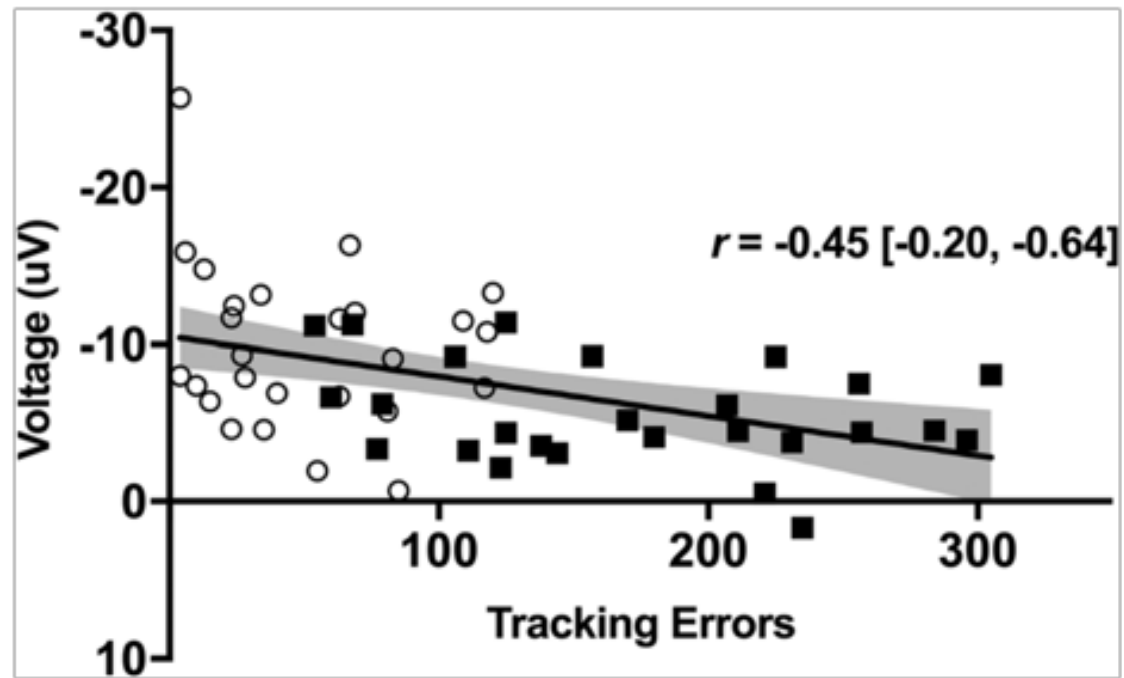




**FIGURE 1** Within-group conditional waveforms at channel FCz on correct and incorrect trials. Negative values are plotted upward reflecting convention



**FIGURE 2** Between-group difference waveforms at channel FCz on incorrect trials. The solid line represents older adult difference wave and the dashed line represents younger adult difference wave. Shaded regions surrounding each difference wave depict 95% confidence intervals. Negative values are plotted upwards reflecting convention



# Conclusions

Reduced ability to evaluate movement errors may underlie performance deficits observed as we age.

# Study 14

NeuroImage 130 (2016) 13–23



Contents lists available at ScienceDirect

NeuroImage

journal homepage: [www.elsevier.com/locate/ynimg](http://www.elsevier.com/locate/ynimg)



## Neural correlates of state-based decision-making in younger and older adults



Darrell A. Worthy<sup>a,\*</sup>, Tyler Davis<sup>b</sup>, Marissa A. Gorlick<sup>c</sup>, Jessica A. Cooper<sup>c</sup>, Akram Bakkour<sup>d</sup>, Jeanette A. Mumford<sup>e</sup>, Russell A. Poldrack<sup>f</sup>, W. Todd Maddox<sup>c</sup>

<sup>a</sup> Texas A&M University, USA

<sup>b</sup> Texas Tech University, USA

<sup>c</sup> University of Texas at Austin, USA

<sup>d</sup> Columbia University, USA

<sup>e</sup> University of Wisconsin Madison, USA

<sup>f</sup> Stanford University, USA

# The Idea

Age impacts decision-making.

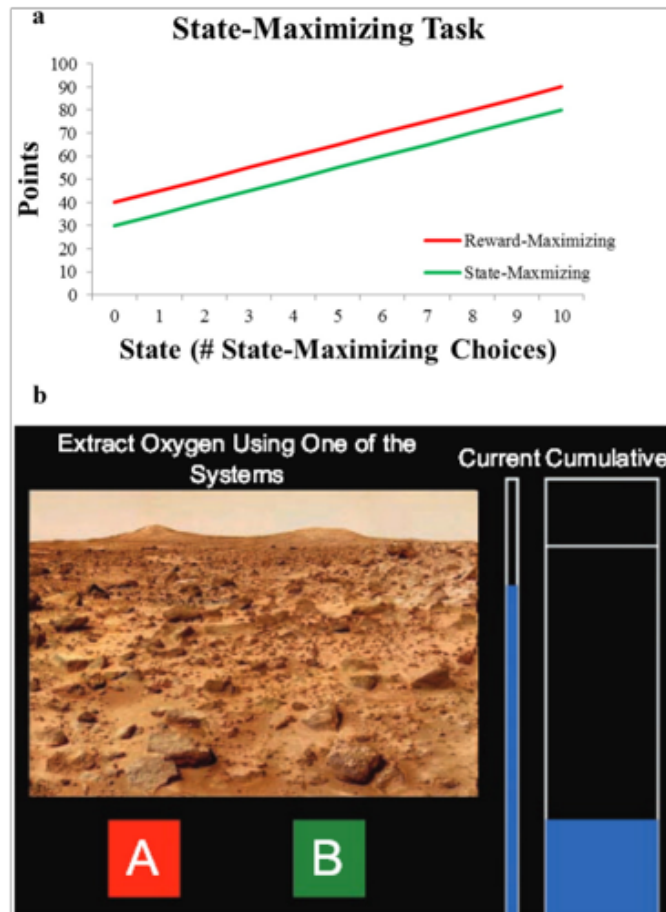
Why? Potentially differences in neural activity in different regions of the brain.

Participants

n = 18 healthy younger adults

n = 18 healthy older adults



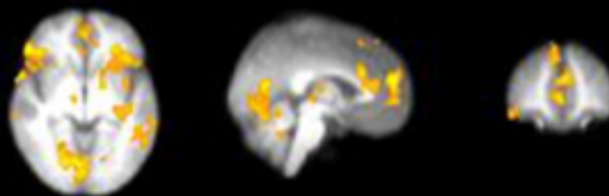


A complex task.

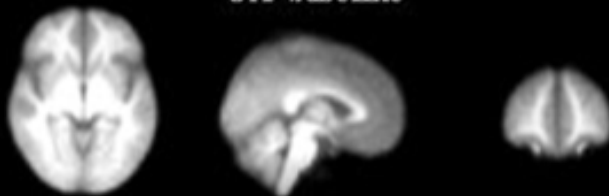
One option maximizes rewards, the other improves the state of the participant. In other words, one pays out more (left blue bar), the other increases progress toward the goal (right blue bar).

# Difference in Expected Value Weighted Activation

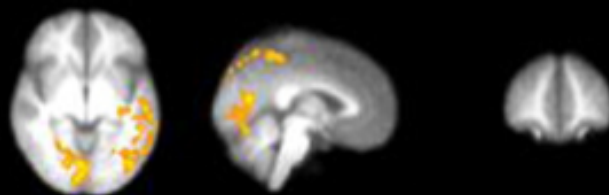
YA>baseline

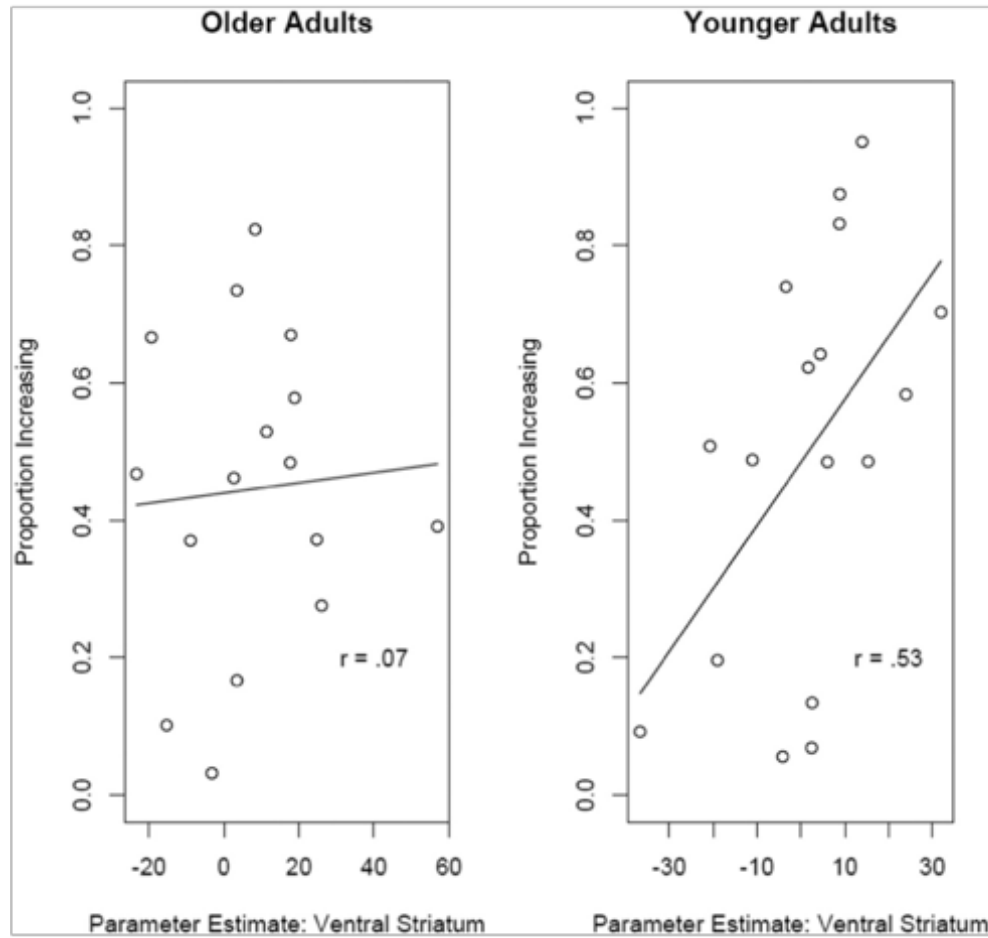


OA>baseline



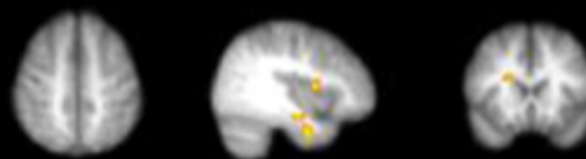
YA > OA



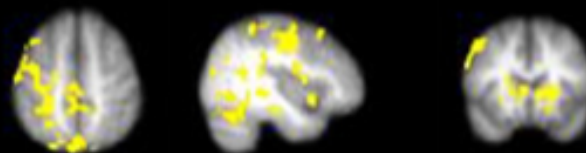


## State-Change Uncertainty Weighted Activation

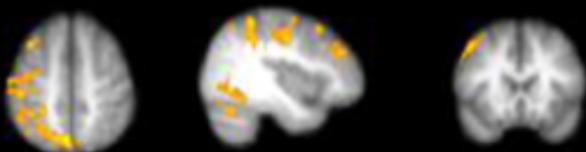
YA>baseline

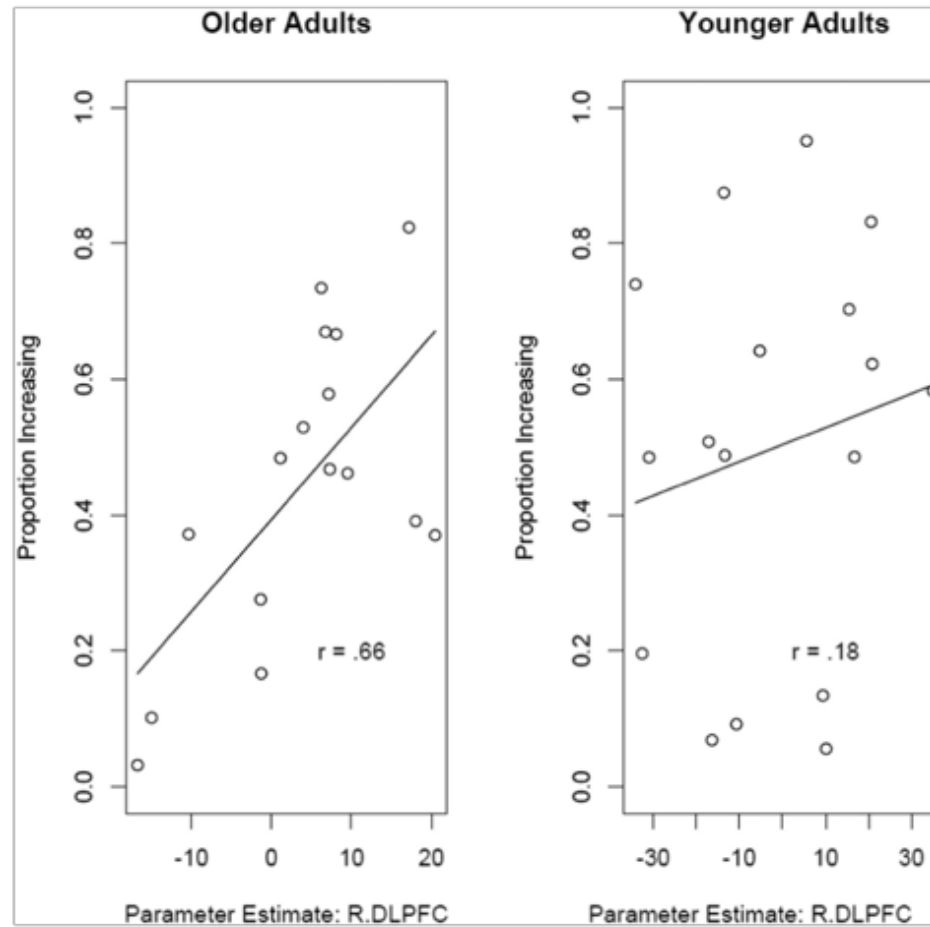


OA>baseline



OA > YA





# Conclusions

Younger adults had more activity in ventral striatum (reward focus), older adults had more activity in DLPFC (goal focus).

# Review

1. Expected Value
2. Exploitation or Exploration
3. Threshold Decision Making
4. Neural Evidence of Expected Value / Exploration / Exploitation
5. System I versus System II
6. Emotional Decision-Making
7. Individual Differences