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Psychological Questions and Inference

What can neuroimaging tell us…and what can't it tell us?

OP-ED CONTRIBUTOR

You Love Your iPhone. Literally.

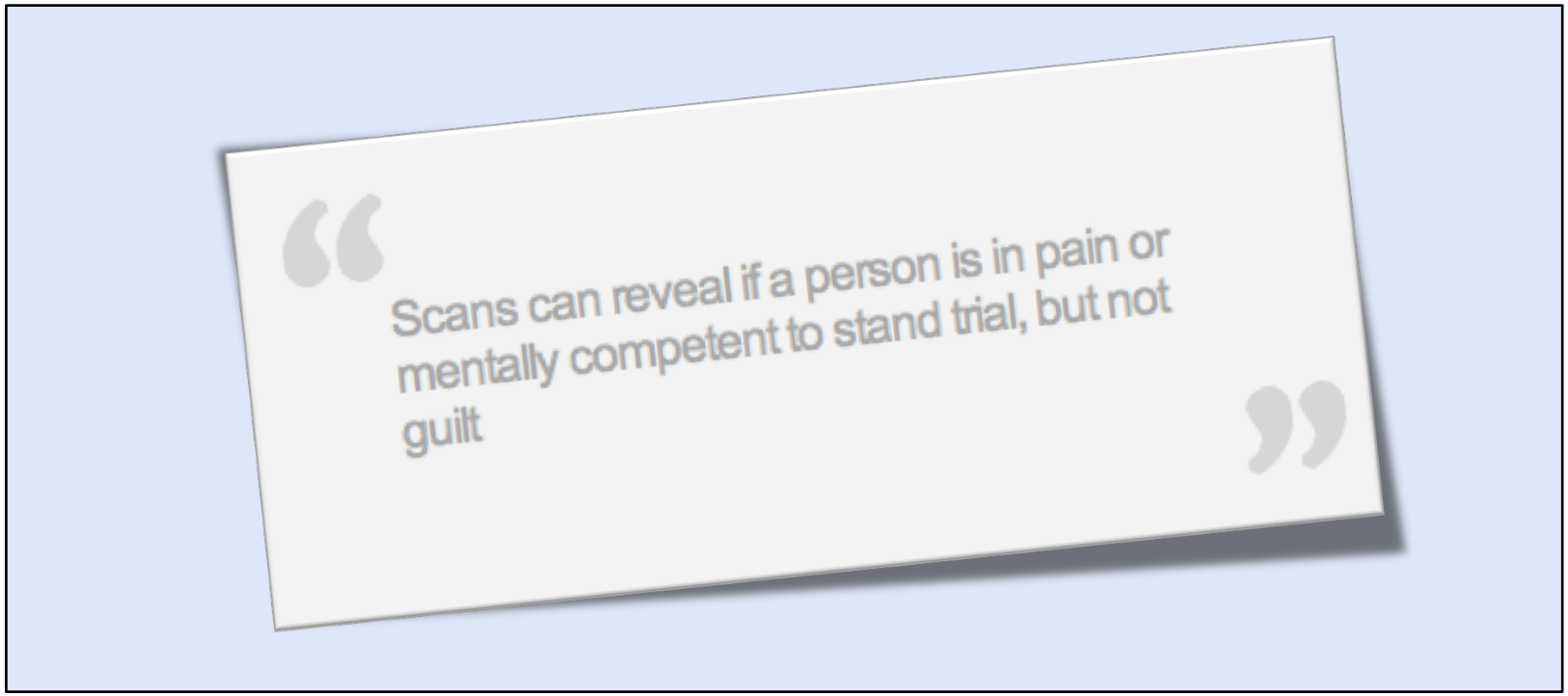
By MARTIN LINDSTROM
Published: September 30, 2011

WITH Apple widely expected to release its iPhone 5 on Tuesday, Apple addicts across the world are getting ready for their latest fix.

But most striking of all was the flurry of activation in the insular cortex of the brain, which is associated with feelings of love and compassion. The subjects' brains responded to the sound of their phones as they would respond to the presence or proximity of a girlfriend, boyfriend or family member.

In short, the subjects didn't demonstrate the classic brain-based signs of addiction. Instead, they *loved* their iPhones.

Many new potential applications in different fields

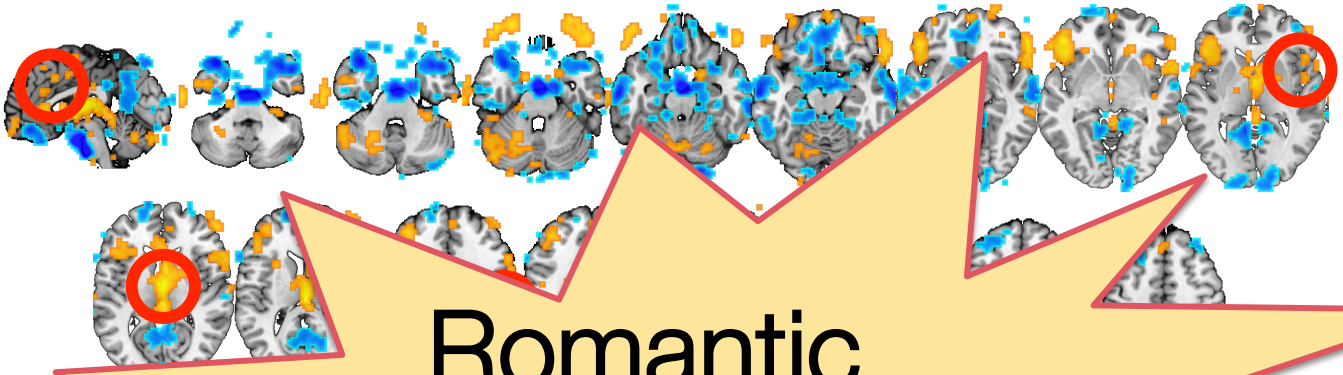


Judge John Kennedy, New Jersey Judiciary, Nov 2008

New Scientist, “Judges junk bogus neuroscience,” Dec. 2008

Psychological inference requires understanding the psychological implications of our brain maps

What does this map *mean*?

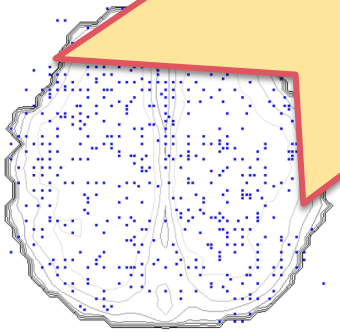


Romantic rejection

Kross et al. 2011, PNAS

Neurosy

from



this pattern:

kious, heat, somatosensory, painful, sensation, stimulation, muscle, temperature

THE ROYAL SOCIETY

If neuroimaging is the answer, what is the question?

S. M. Kosslyn

832 William James Hall, Harvard University, 33 Kirkland Street, Cambridge, MA 02138, USA (smk@wjh.harvard.edu)

It is unclear that we will come to a better understanding of mental processes simply by observing which neural loci are activated while subjects perform a task. Rather, I suggest here that it is better to come

- Neuroimaging analyses should be designed to test theories.
- But what kinds of theories can neuroimaging analyses test?

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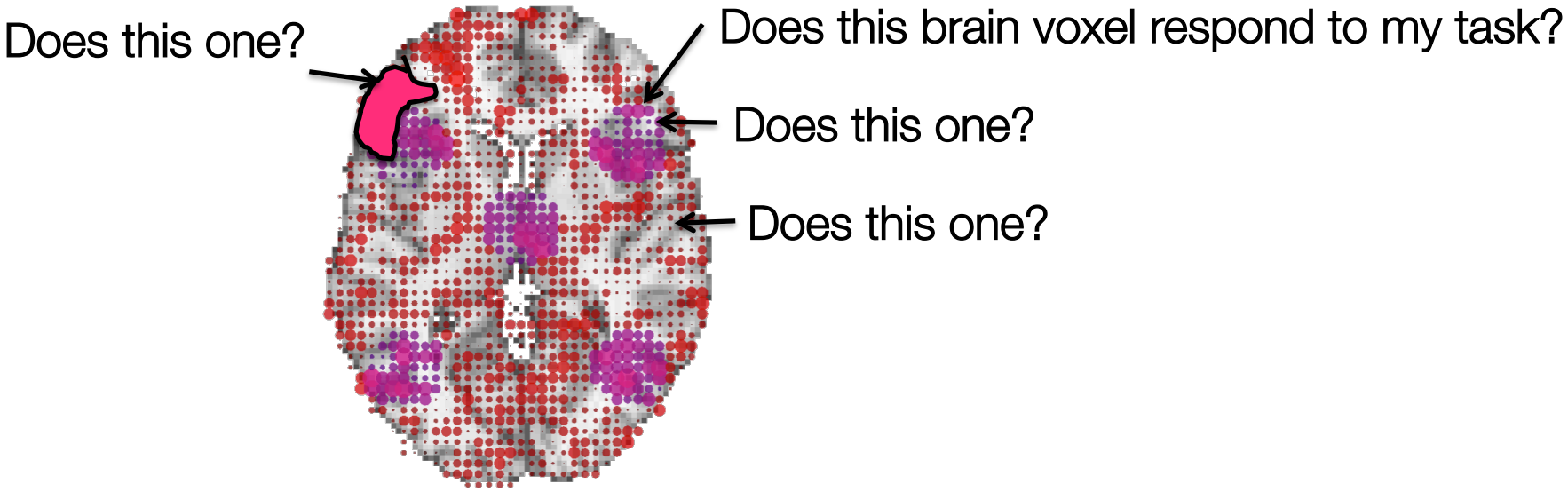
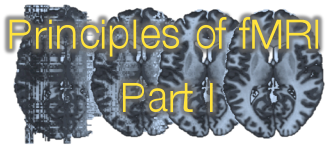
What is the answer?

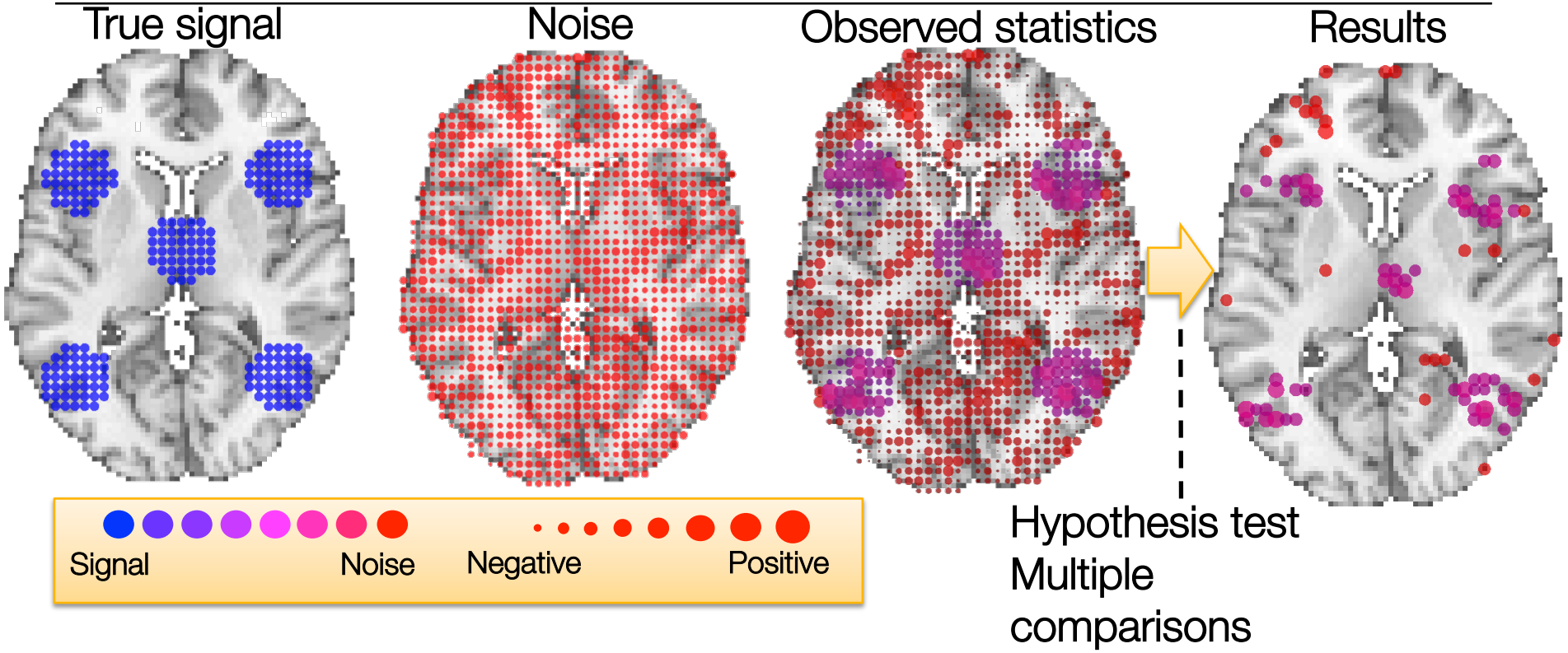
- Typical results: A statistical map
- Colored areas indicate reliable non-zero effects

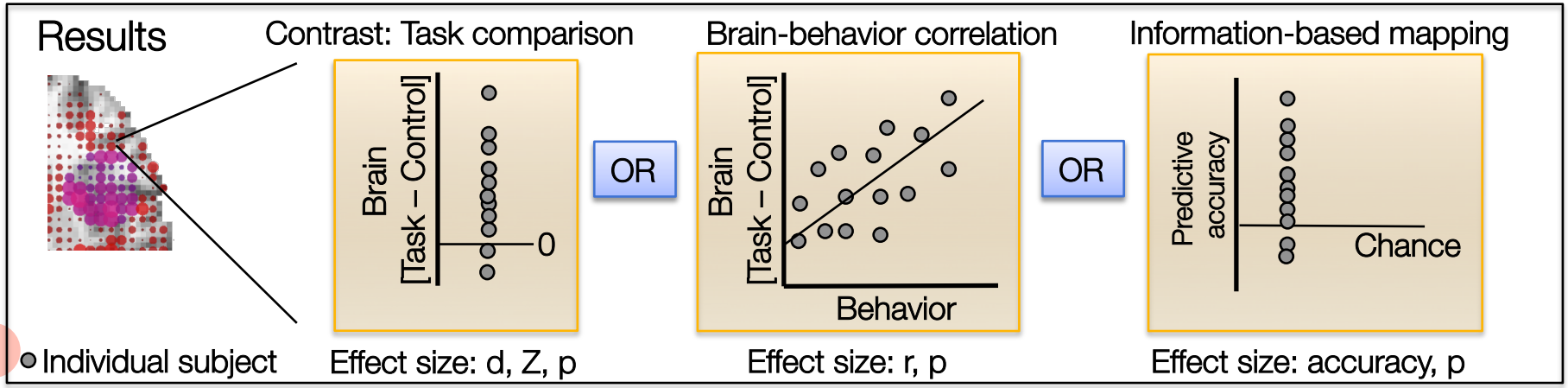


- This is the “brain mapping” approach
- The answer it provides is a hypothesis test on whether a task-brain or brain-outcome relationship is non-zero.

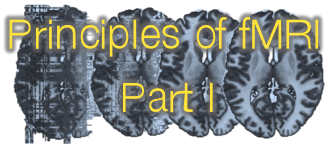
The brain mapping approach

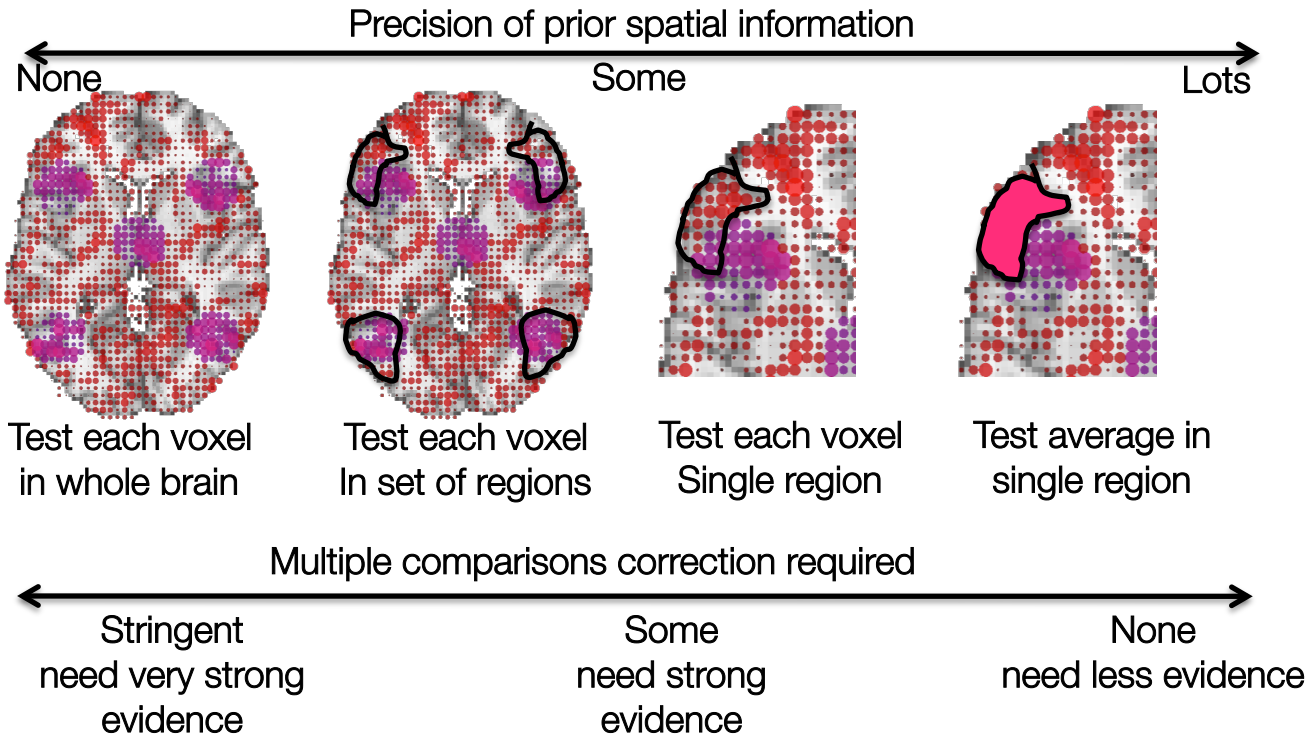






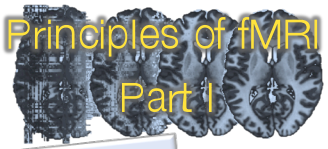
Many choices about how to test





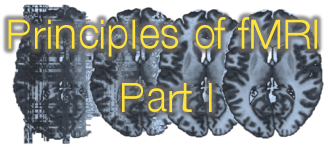
- Can test activation, correlations, local predictive accuracy, connectivity, or other kinds of ‘maps’
- Fundamental hypothesis testing framework is the same.

What is the answer?



- "The demonstration that a particular pattern of brain activity accompanies the performance of particular kinds of tasks is not, in and of itself, of great interest. Such data are only interpretable in the context of theories...Simply finding that certain areas of the brain are active when someone performs a task is not enough" - Kosslyn, 1999

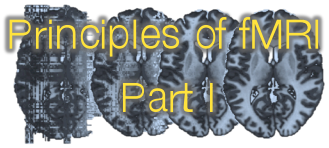
What is the question?



- The key: Whether a target brain region is active or not must constrain your theory teach you something new).

- If you want to learn something about the *mind*, the brain region must be characterized sufficiently to infer something about the mind from its activation.

Forward and reverse inference



- To learn something about the mind, you need *reverse inference.*
- Brain mapping approaches provide *forward inference*

Forward inference	Given an induced psychological state	*P(Brain | Psy)* →	We observe brain activity
Reverse inference	Can we infer psychological state?	*P(Psy | Brain)* ←	Given brain activity

- 'Forward' and 'reverse' inference are *not* the same!

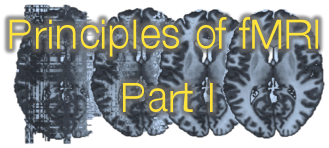
Fallacious reverse inference: Affirming the consequent

Dogs like ice cream. Mary likes ice cream.
Therefore, Mary is a dog.

If P -> Q
Q
Therefore P

e.g., Poldrack et al. 2006

Forward and reverse inference



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Forward inference

Given an induced psychological state

P(Brain | Psy)

We observe brain activity

Reverse inference

Can we infer psychological state?

P(Psy | Brain)

Given brain activity

Bayes' Rule: Relates forward and reverse inference

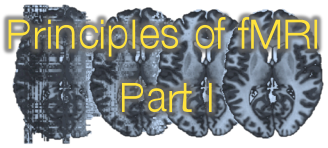
$$\frac{\mathrm{P}(\mathrm{Brain} \mid Psy) = \mathrm{P}(\mathrm{Brain}) * \mathrm{P}(Psy \mid \mathrm{Brain})}{P(Psy)}$$

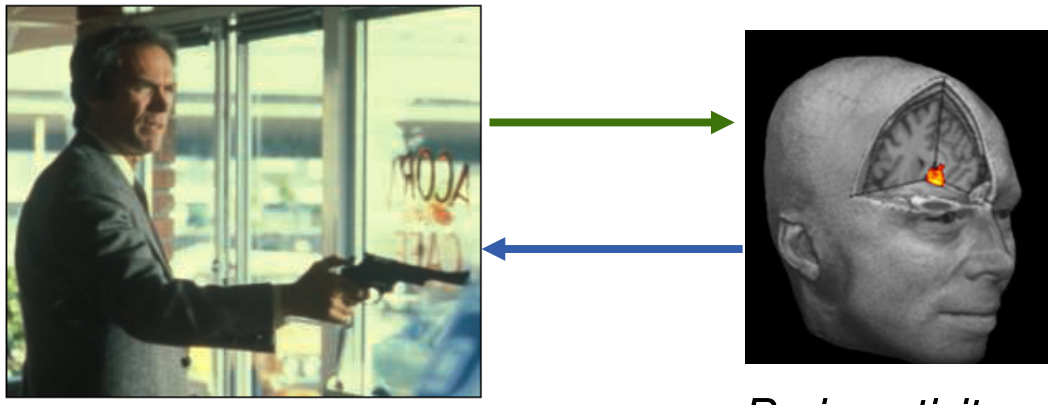
Example: Does punishing wrongdoers feel good?

- "Punishing wrongdoers feels good because it activates pleasure centers in the brain…"

De Quervain et al., Science 305, 1254

Inference, sensitivity, and specificity





Punishing wrongdoers

Brain activity

1. If I'm enjoying something, then my caudate is activated.
   - This can be quantified in terms of *sensitivity: P(caudate | enjoyment)*

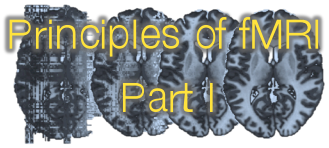
2. My caudate is activated…

3. Therefore I'm enjoying?

   - Only if enjoyment is the ONLY thing that activates the caudate!

   - Quantified in terms of *specificity: 1 - P(caudate | NOT enjoyment)*

Applying Bayes Rule



For reverse inference, we are interested in the *positive predictive value* of caudate activation for enjoyment:
P(enjoyment | caudate)

No-enjoyment

P(Brain | No enjoyment) = 0.4
1-Specificity

P(enjoyment) = 0.1
Prior

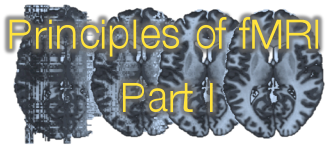
Enjoyment → Ventral caudate

P(Brain | enjoyment) = 0.9
Forward inference; Sensitivity

Calculate *positive predictive value* using Bayes' rule:

P(enjoyment | caudate) = 0.2

Reverse inference take-home

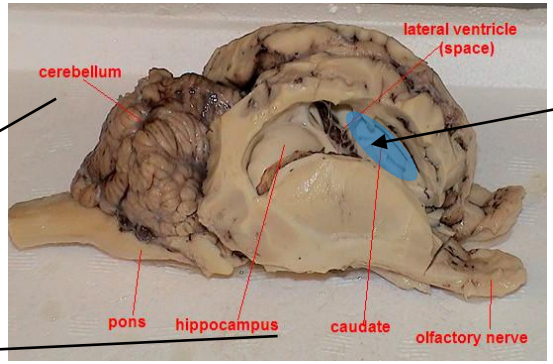


- Reverse inference is the practice of treating the brain as a marker for something
- When people make reverse inferences, they assume high positive predictive value (PPV)
- PPV can be calculated, but requires assessment of multiple potentially confusable tasks/states
- For regional brain activation to have high PPV:
  - It must respond consistently to the task/state (high sensitivity)
  - It must respond only to the task/state (high specificity)

Jose Delgado and aggression

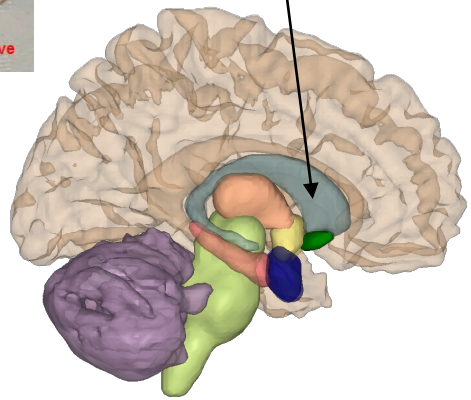
- Reproduced from Elliot Valenstein, *Brain Control,* 1986

Misleading interpretations of 'reward' stimulation



Caudate nucleus:

Initiation of movement



- Caudate stimulation: the bull stopped attacking because it was *forced to turn continuously to the right*.

- For many more examples, see
  Elliot Valenstein, Brain Control

Reverse inference is hard

- Even when you can directly manipulate the brain!

- Is it impossible?

PERHAPS FUNCTIONAL NEUROIMAGING HAS NOT TOLD US ANYTHING ABOUT THE MIND (SO FAR)

Max Coltheart

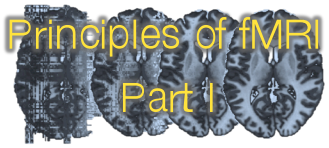
(Macquarie Centre for Cognitive Science, Macquarie University, Sydney, Australia)

"Provide an example of a neuroimaging result that has distinguished between two competing psychological theories"

– Coltheart, Cortex, 2006

2010 Redux – Cacioppo, …sarter/caciopo paper

Reverse inference can be done

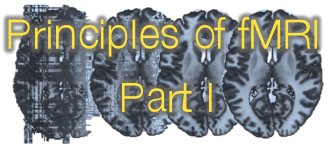


- Strategy 1: Leverage neuroscience
  - Strong prior knowledge about psycholgocial processes that do (and don't) activate a brain area
  - Assume that activation implies psychological process

- Strategy 2: Quantitative reverse inference
  - Assess activation of a region (or other brain measure) across candidate set of tasks
  - Quantify its sensitivity, specificity, and positive and negative predictive values
  - May require testing many tasks, contexts, and study populations

- Both can (and should) be used together!

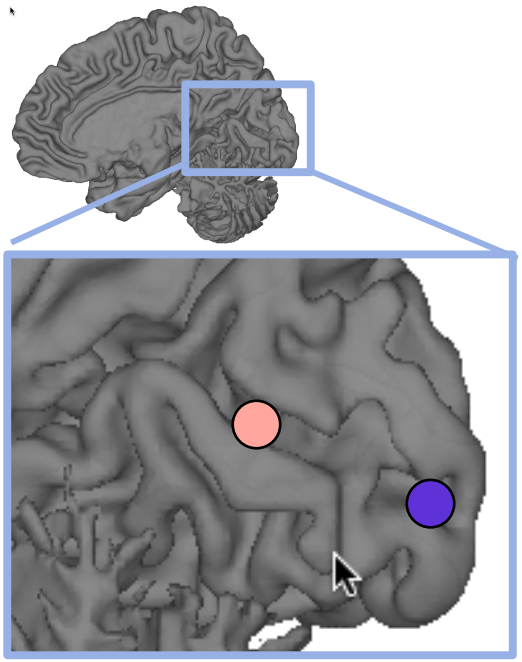
Strategy 1 Example: Mental imagery



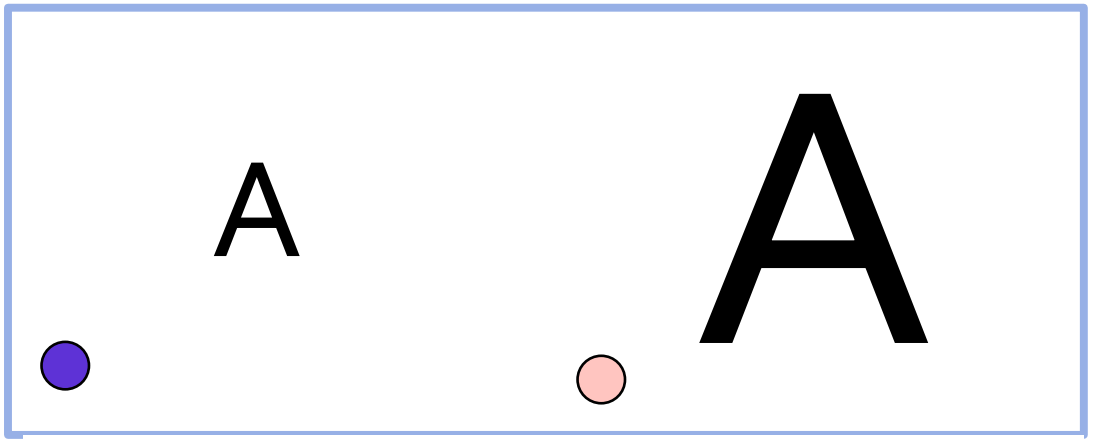
Is mental imagery like seeing?

Pylyshyn (1973 and on): Imagery is "propositional" -- a set of logical rules. The feeling of "seeing" mental images is epiphenomenal.

Kosslyn: Imagery is depictive and analogue, uses perceptual machinery



Area 17: Primary visual cortex

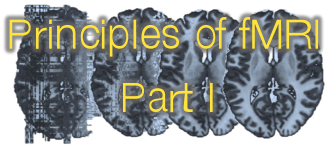


Imagine small “A”: foveal activation.
Imagine big “A”, peripheral (anterior) activation.

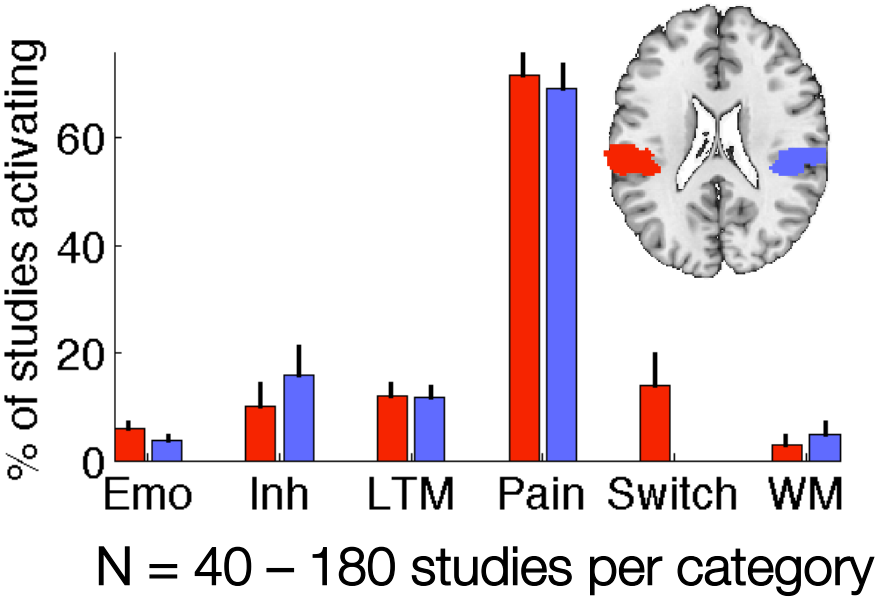
- Mental imagery engages primary visual cortex

Kosslyn et al. 1993; Kosslyn 1996. Image and brain: The resolution of the imagery debate

Strategy 2 Example: Meta-analysis



- Meta-analysis is analysis of results across many different studies.
- In neuroimaging, meta-analysis across types of studies can help quantify our ability to make reverse inferences.



N = 40 – 180 studies per category

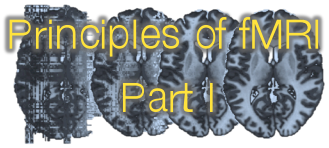
Positive predictive value of SII activation

P(Pain | SII) = 0.87

Task categories: Emotion, Inhibition, Long Term Memory, Pain, Task Switching, Working Memory

Kross et al. 2011, PNAS

What brain mapping is good for

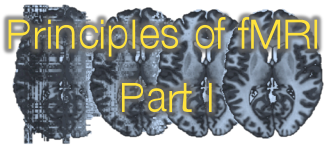


- Making inferences on the presence of activity, to either a) test a theory, or b) characterize the pattern of brain responses to a task.

- Limiting the false positive rate to a specified level.

- Leverage hypothesis testing to provide evidence on a variety of theories: Is Area *r* involved in Task *x*?

What brain mapping is not good for



- Reverse inference:
  - Does not provide direct inferences about psychological states
  - Need clever experimental designs, specialized analyses, meta-analyses
- Establishing meaningful effects:
  - Terrible for estimating effect sizes and predictive accuracy
- Testing assumptions
  - Inference depends on many assumptions
  - You must check these yourself (more on this later)
- Comparing evidence for different theories
  - Just because a model shows some effect it does not mean it's the best model (or even close).
  - Cannot confirm theories, only falsify them.

End of Module

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