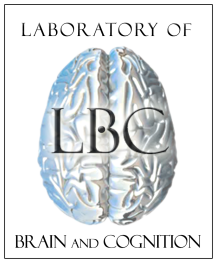
Voodoo correlations and double dipping: a cautionary tale

Chris Baker

Section on Learning and Plasticity

Laboratory of Brain and Cognition



nature neuroscience

PERSPECTIVE

Circular analysis in systems neuroscience: the dangers of double dipping

Nikolaus Kriegeskorte, W Kyle Simmons, Patrick S F Bellgowan & Chris I Baker

PERSPECTIVES ON PSYCHOLOGICAL SCIENCE

Voodoo

Correlations in fMRI Studies of Emotion, Personality, and Social Cognition[1]

Edward Vul,[1] Christine Harris,[2] Piotr Winkielman,[2] & Harold Pashler[2]

[1]*Massachussetts Institute of Technology and* [2]*University of California, San Diego*

HISTORICAL NEWS & VIEWS: REPRODUCIBILITY

Double-dipping revisited

Robust conclusions require rigorous statistics. In 2009 a seminal paper described the dangers and prevalence of double-dipping in neuroscience. Ten years on, I consider progress toward statistical rigor in neuroimaging.

Katherine S. Button

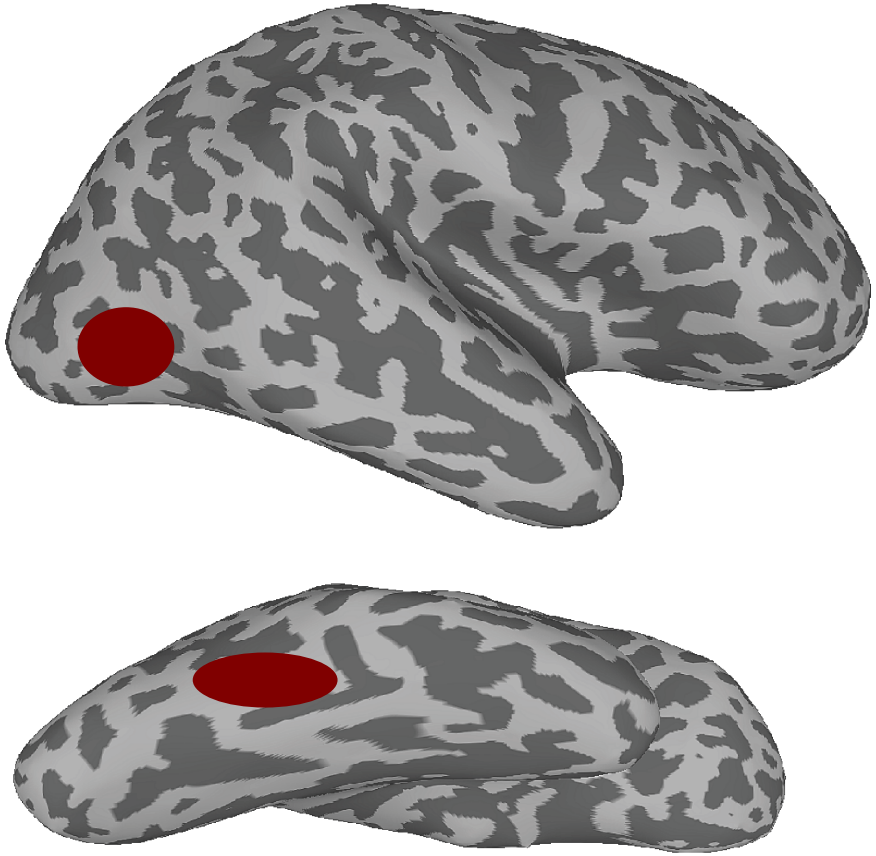
Take Home Message

Data selection should be independent from any other data testing

Faces

Occipital face area

Fusiform face area

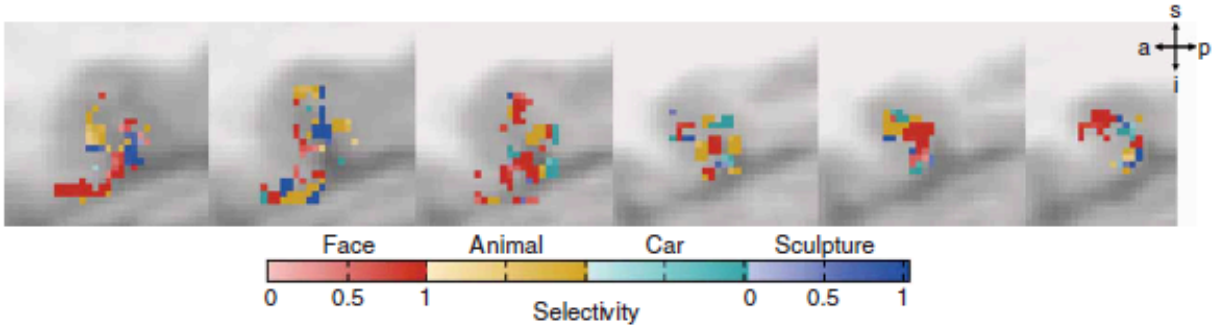


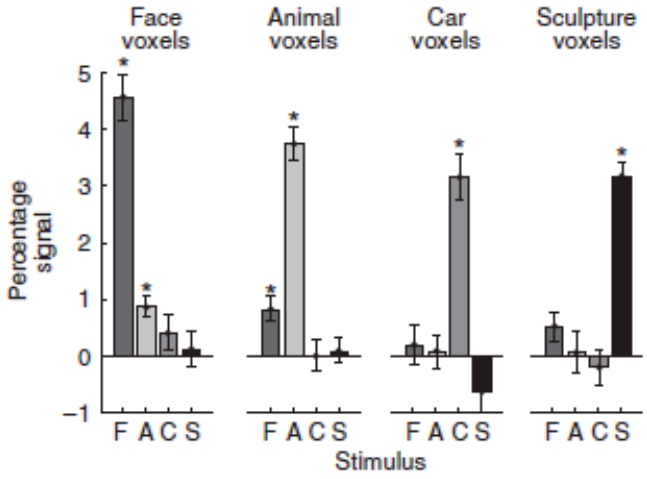
Regions specialized for face processing?

nature neuroscience

High-resolution imaging reveals highly selective nonface clusters in the fusiform face area

Kalanit Grill-Spector[1,2], Rory Sayres[2] & David Ress[3]

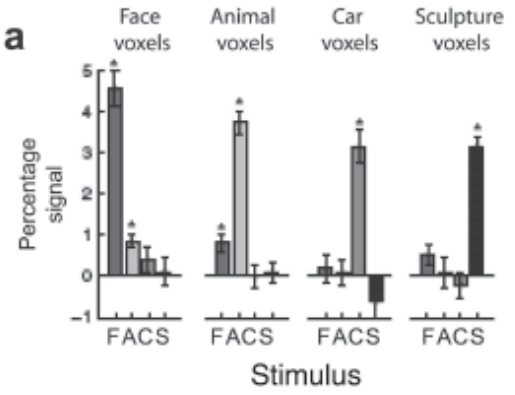




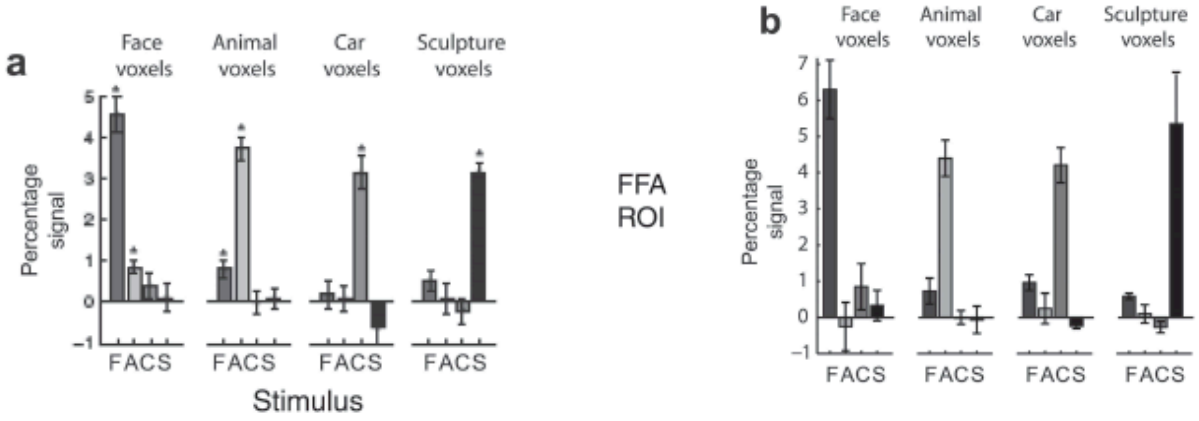
Example 1

Univariate activation

Baker et al, 2007, *Nature Neuroscience*



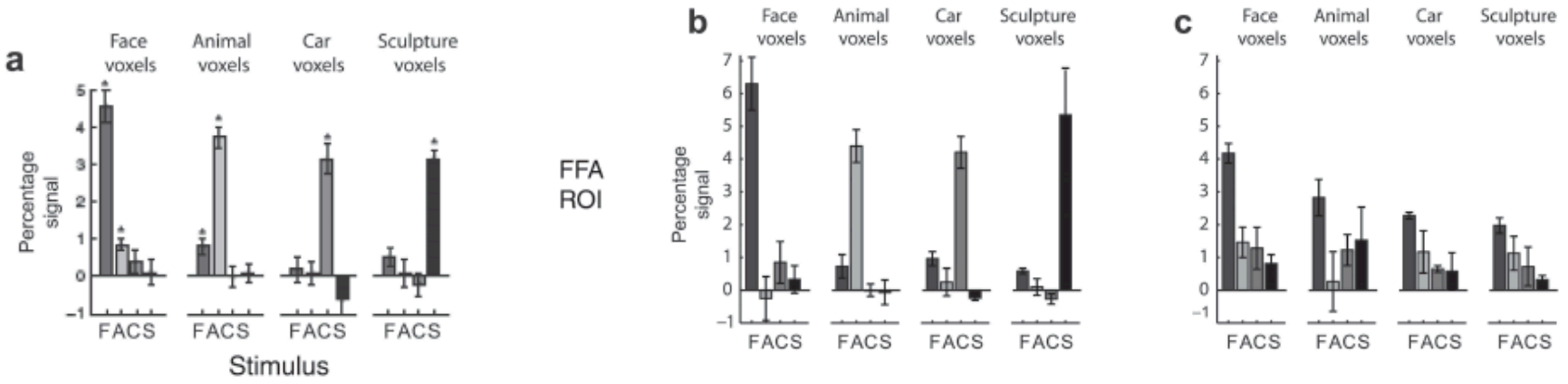
Baker et al, 2007, *Nature Neuroscience*



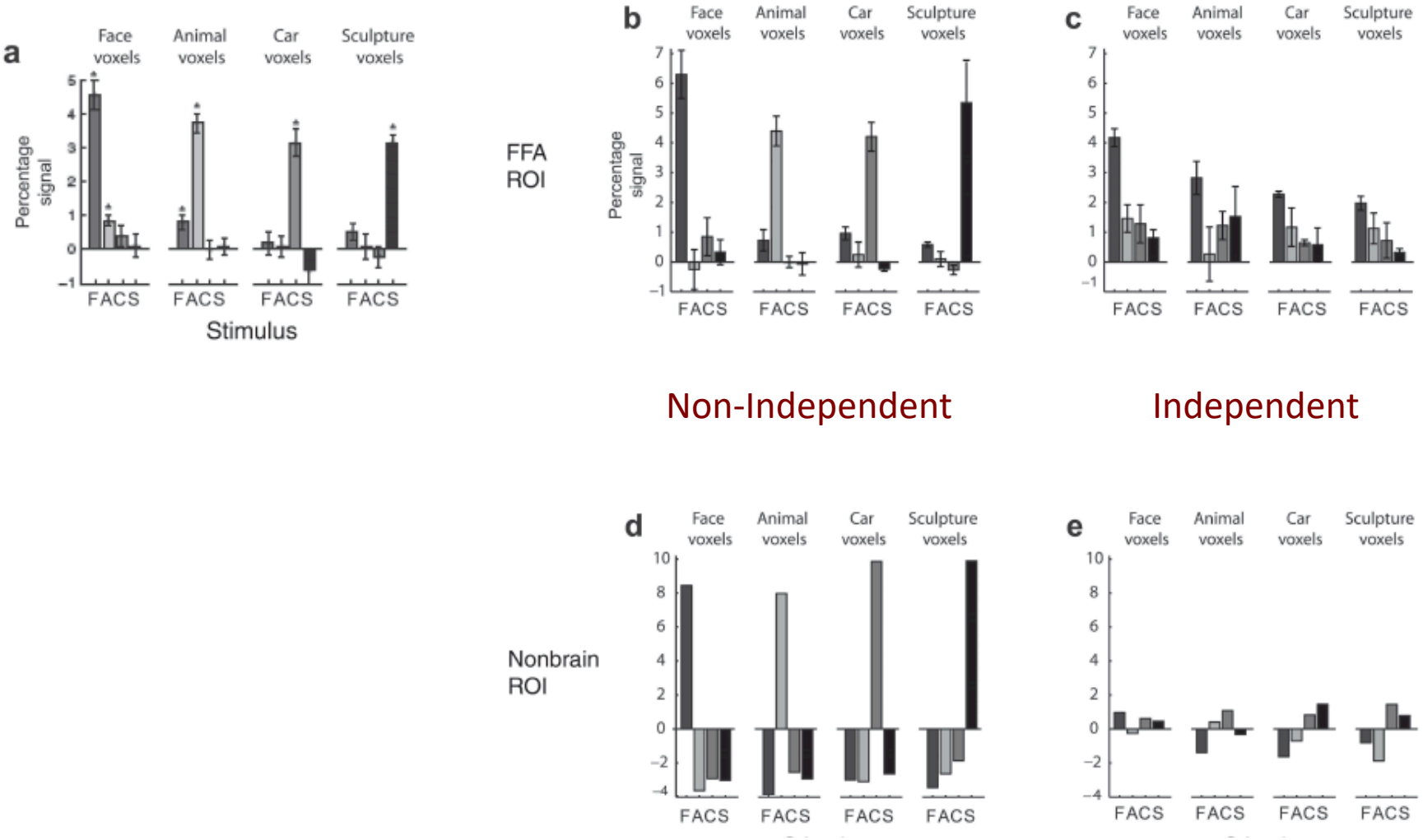
Non-Independent

Independent

Baker et al, 2007, *Nature Neuroscience*



Baker et al, 2007, *Nature Neuroscience*

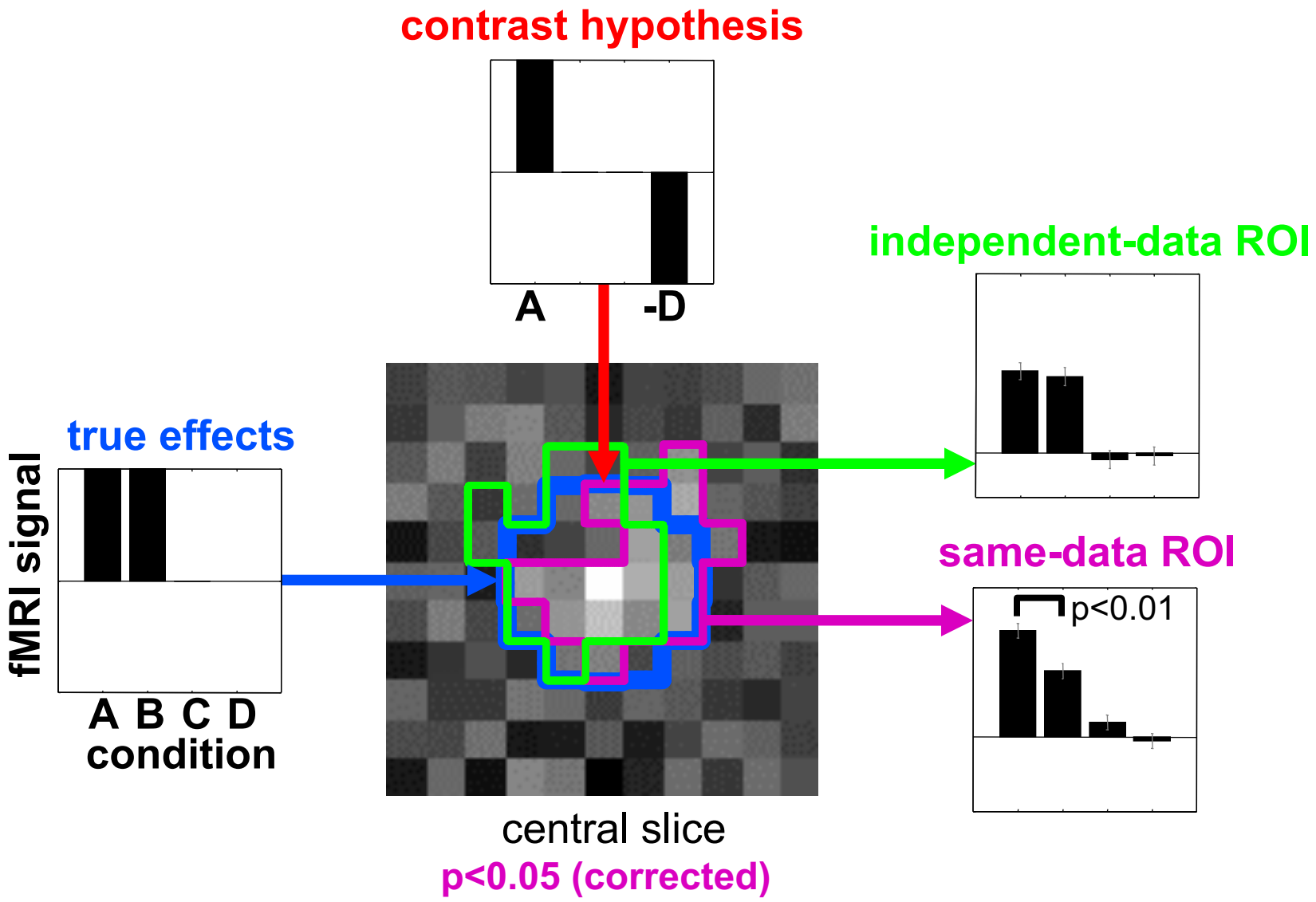


Double dipping can produce an effect where there is none

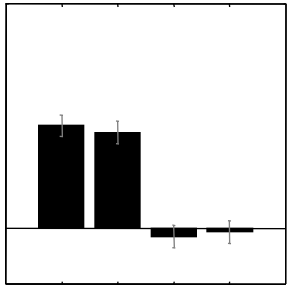
Can also distort a true underlying effect

Simulation:
Regional activation analysis

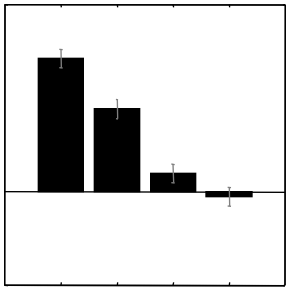
- 3D voxel volume (30 x 30 x 20 voxels)
- Block-design experiment
- 4 conditions (A, B, C, D)
- Spatiotemporal noise:
  Gaussian, slightly spatially smoothed


contrast hypothesis
A
-D
independent-data ROI
true effects
fMRI signal
A B C D
condition
same-data ROI
p<0.01
central slice
p<0.05 (corrected)

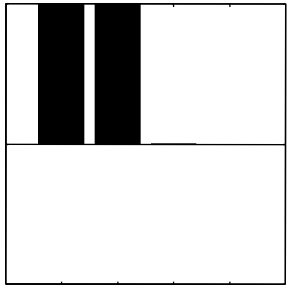
independent-data ROI



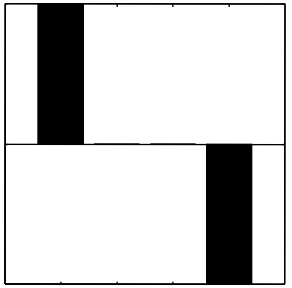
same-data ROI



blending continuum



truth



hypothesis

Simulation:
Regional activation analysis

- Double dipping can produce distortions of the data even when there is a true underlying effect

Example 2

Multivariate Pattern Analysis (MVPA)

Example 2:
MVPA

Simmons, Martin et al. 2006

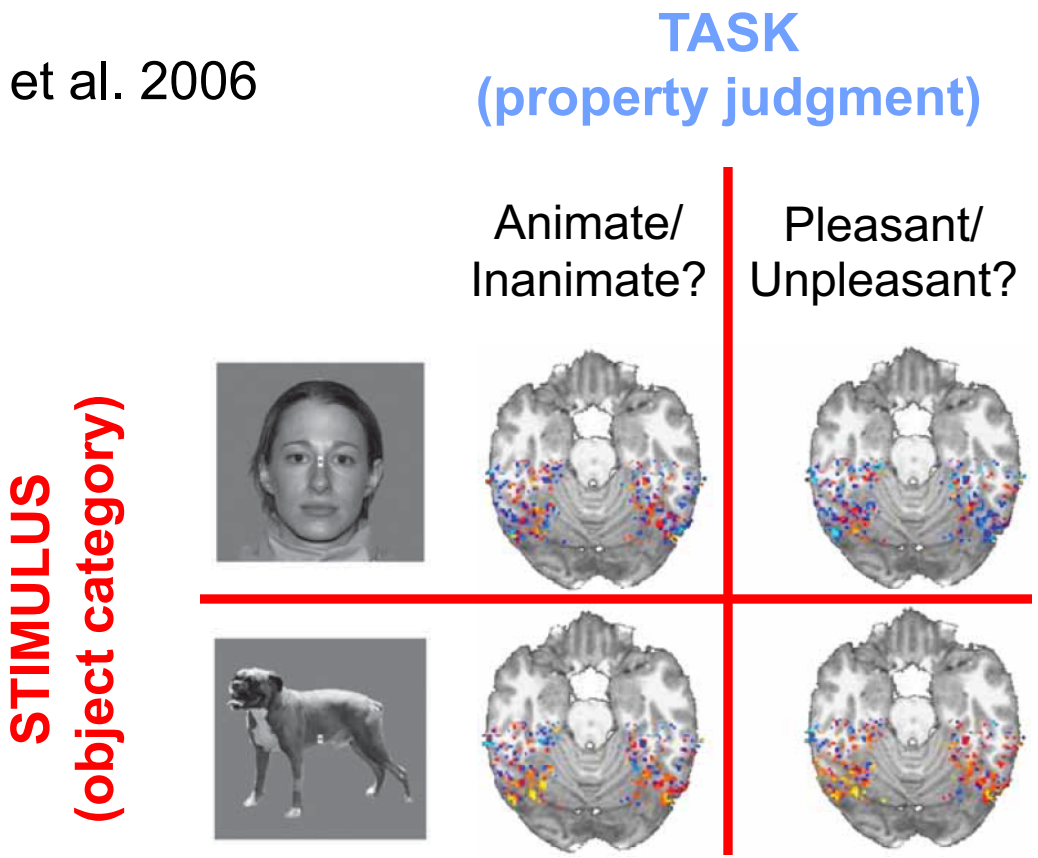
TASK
(property judgment)

Animate/ Inanimate?	Pleasant/ Unpleasant?

STIMULUS
(object category)

Example 2:
MVPA

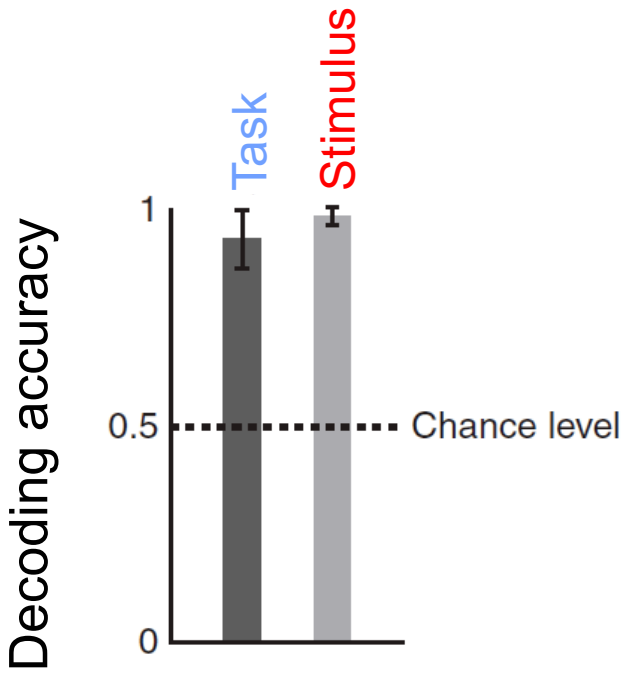
Simmons, Martin et al. 2006



Split-half analysis (Haxby et al., 2001)

- Define ROI
  - Select voxels for which any pairwise condition contrast is significant
- Correlation analysis
  - Split data in half (training and test)
  - Compare activity patterns for same versus different conditions

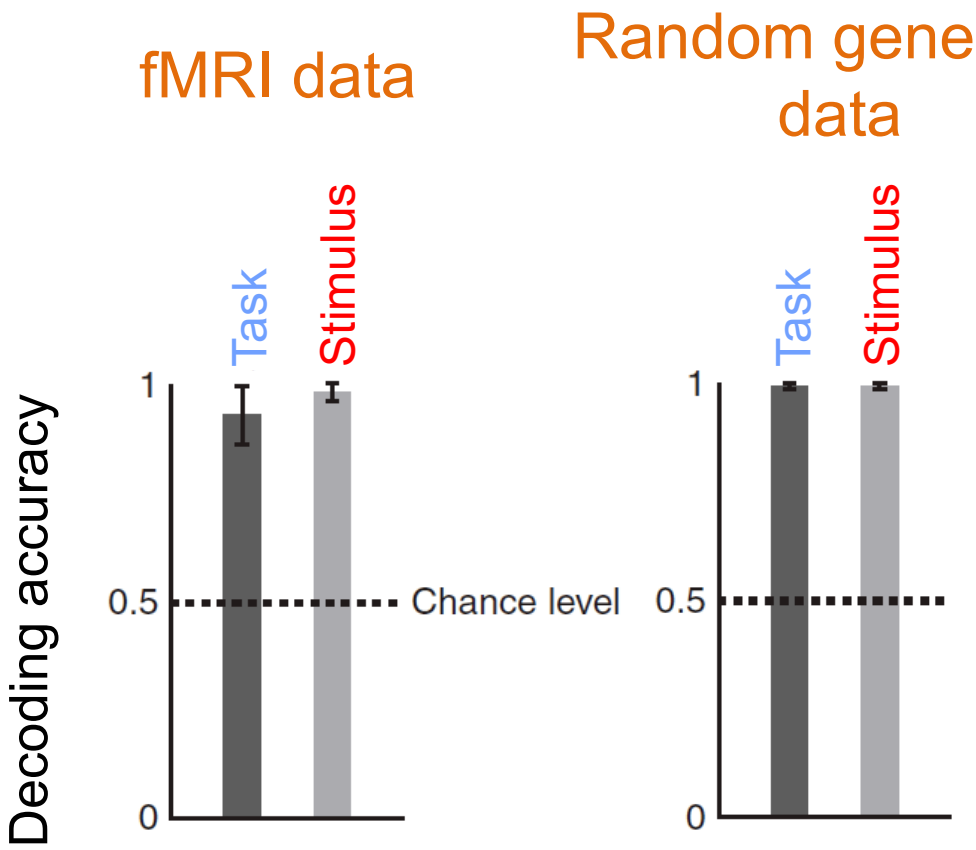
fMRI data



But training and test were independent….

All data used to select voxels

Half data used to select voxels



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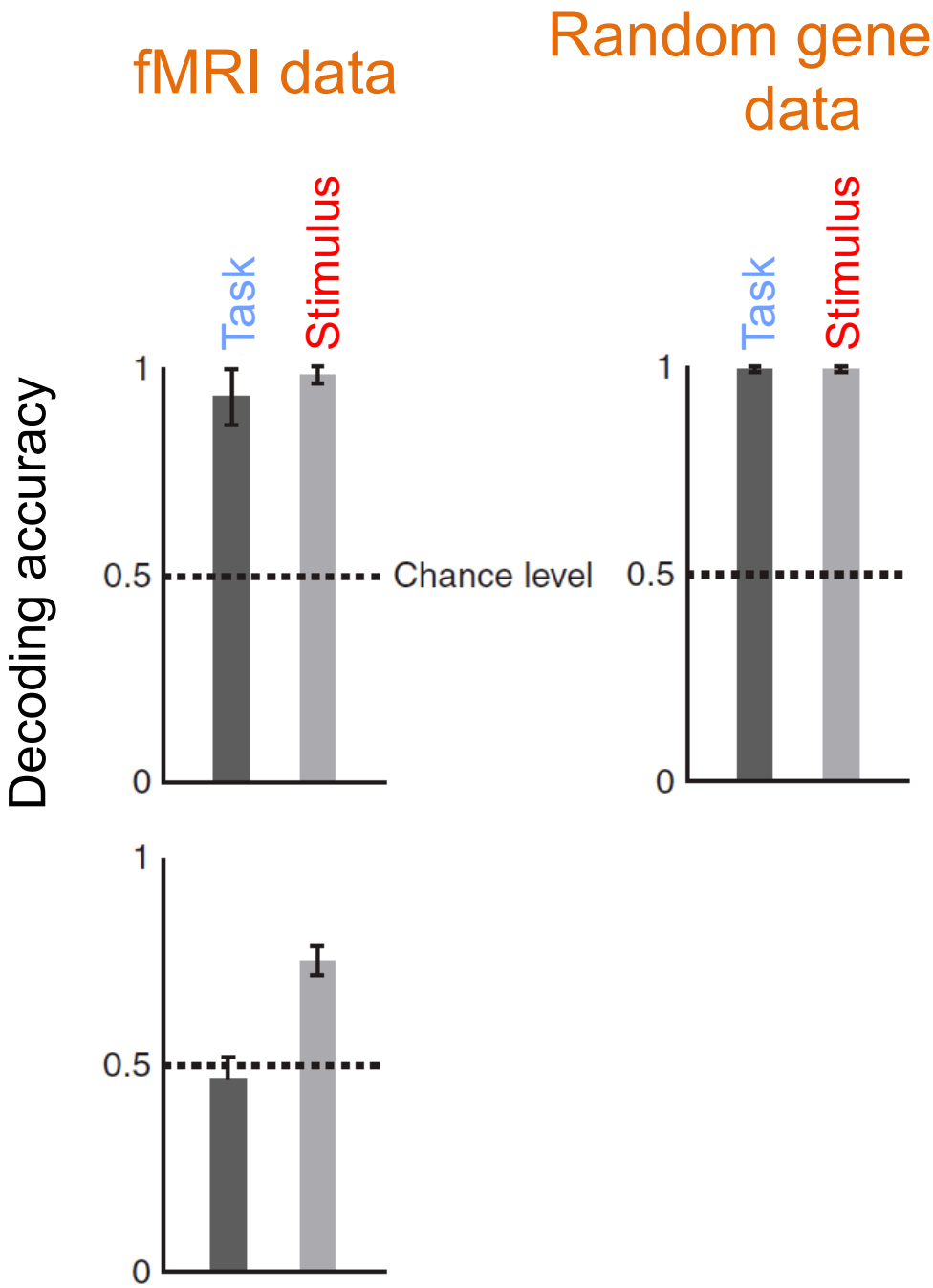

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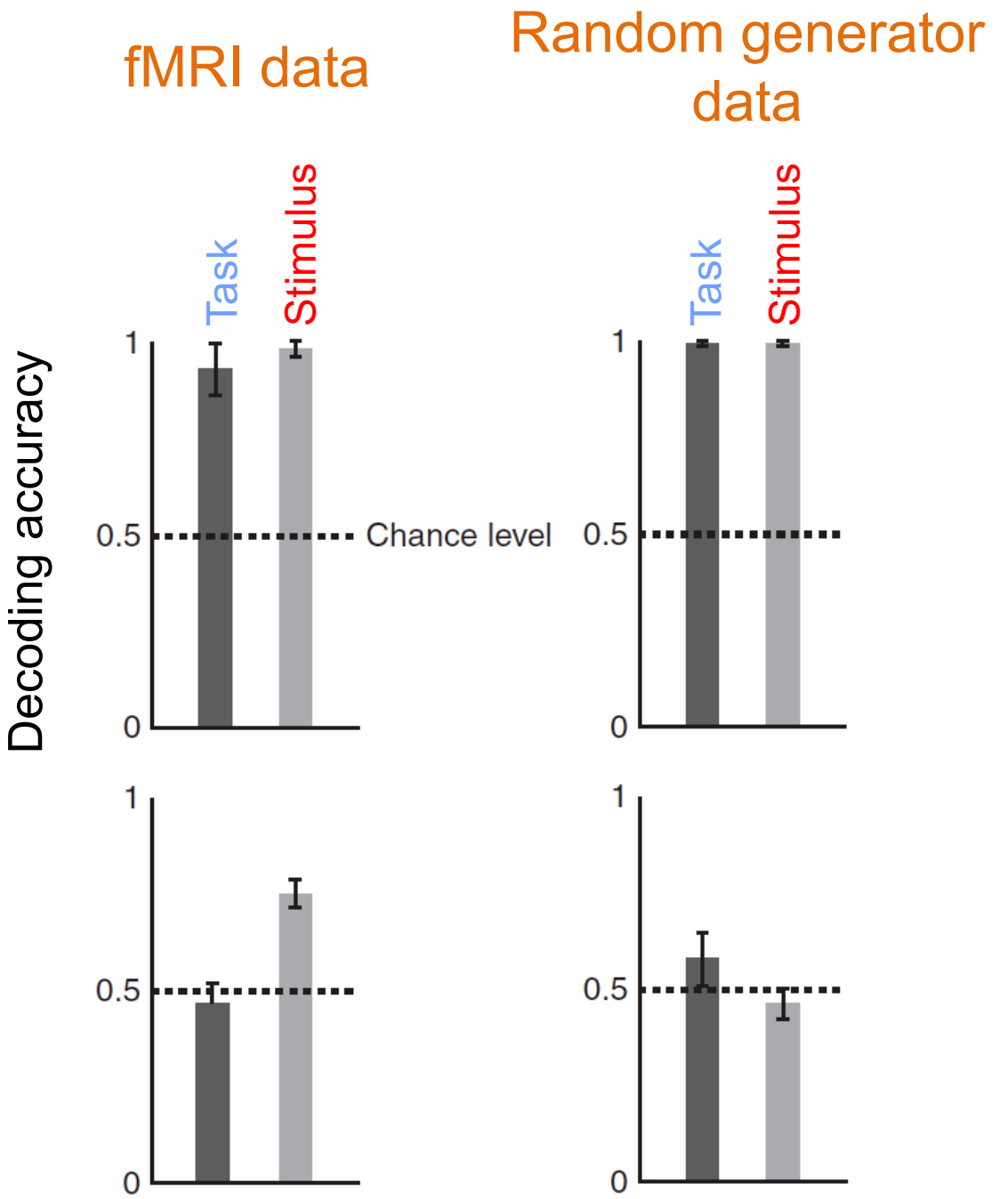


Example 2:
Multivariate Pattern Analysis (MVPA)

- Test data must not be used in
  - Training the classifier
  - Defining the ROI

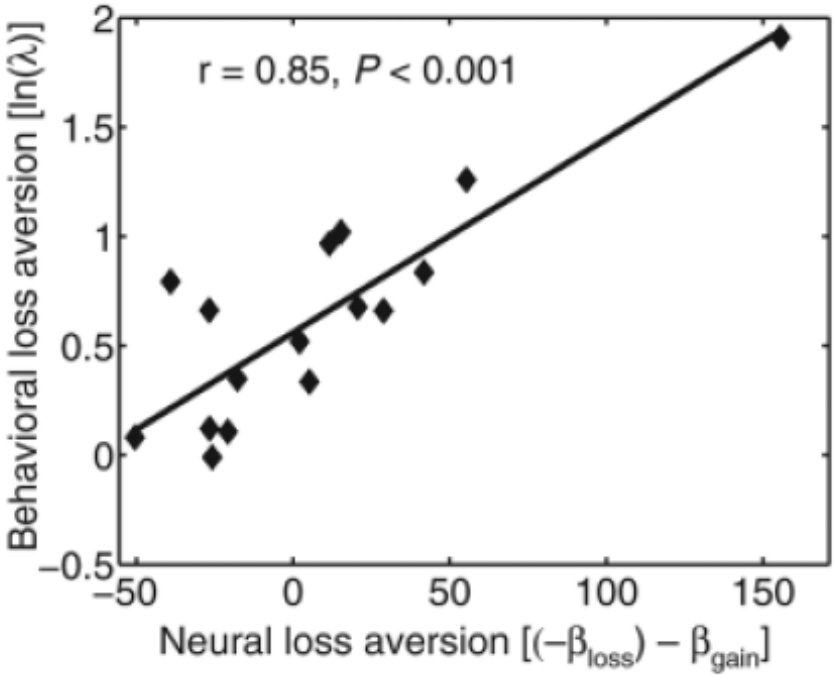
Example 3

Brain-behavior correlations

(voodoo)

The Neural Basis of Loss Aversion in Decision-Making Under Risk

Sabrina M. Tom,[1] Craig R. Fox,[1,2] Christopher Trepel,[2] Russell A. Poldrack[1,3,4]*



Correlation	Number of voxels	Anatomical location
0.9	284	L inferior/middle frontal
0.88	175	R inferior/middle frontal
0.87	104	L inferior frontal (opercular)/anterior insula
0.86	122	R inferior frontal (opercular)
0.85	332	B ventral striatum
0.83	358	R inferior parietal
0.81	110	B pre-supplementary motor area
0.46	963	L lateral occipital/cerebellum

Non-Independent

doi:10.1093/scan/nsp011 SCAN (2009) 4, 208–213

Tools of the Trade

Independence in ROI analysis: where is the voodoo?

Russell A. Poldrack,[1,2] and Jeanette A. Mumford[1]
[1]Department of Psychology and [2]Department of Psychiatry & Biobehavioral Sciences, University of California, Los Angeles, CA 90095, USA

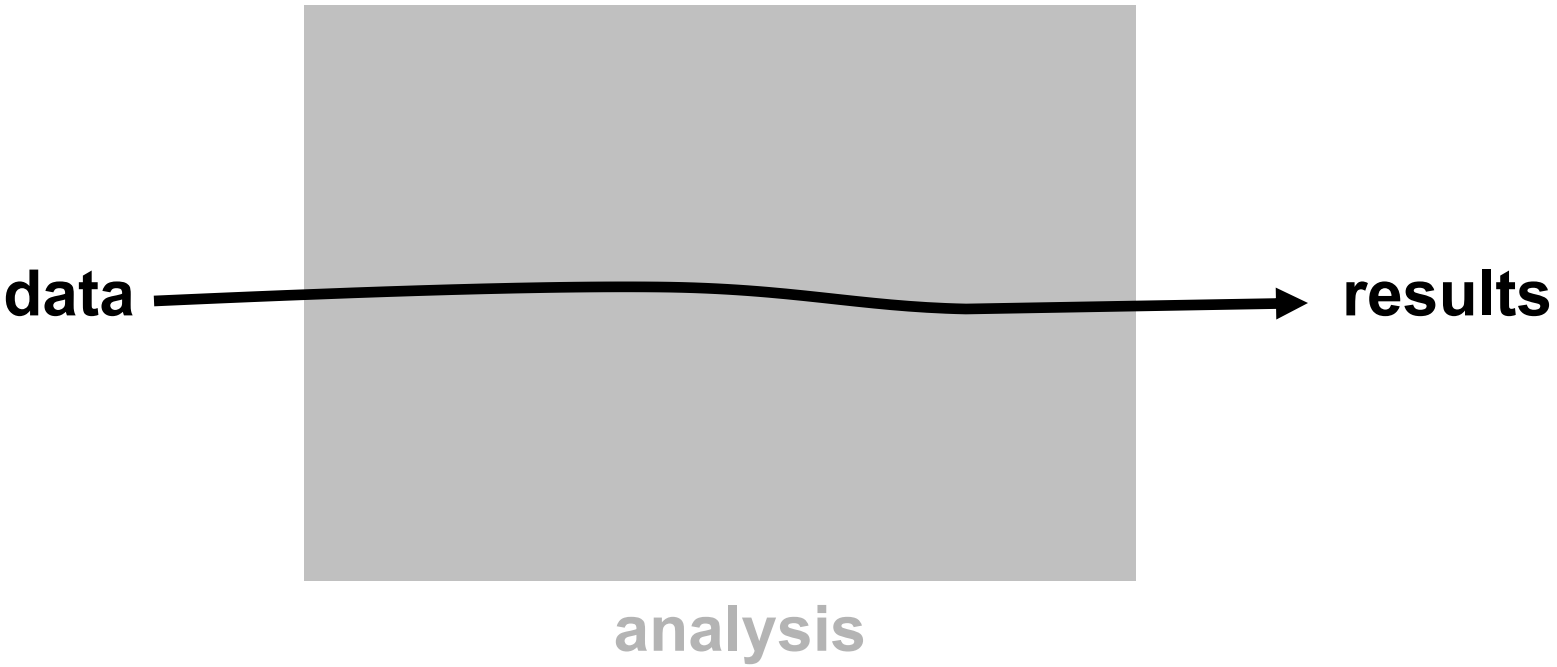
Double dipping can inflate brain-behavior correlations

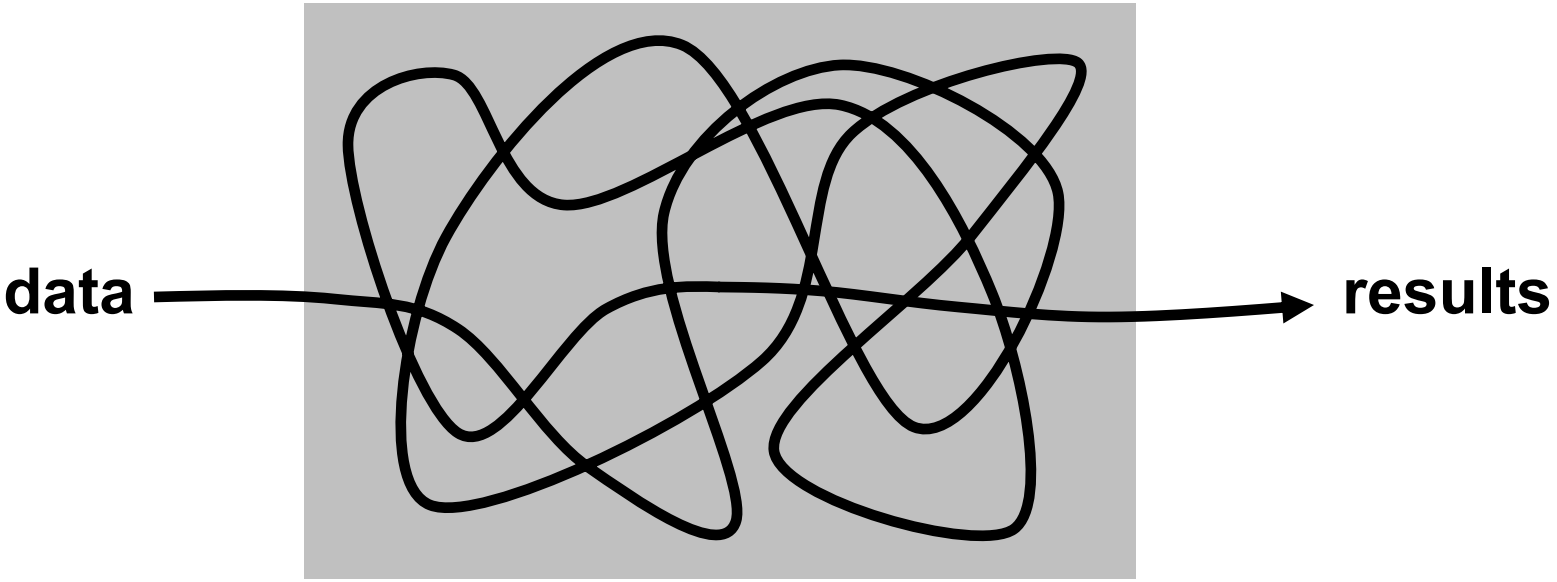
Independent

Non-Independent

Run 1		
Voxels	**Test r**	**Train r**
257	0.563	0.761
276	0.228	0.783
311	0.486	0.760
331	0.473	0.875
346	0.614	0.827
492	0.329	0.861
498	0.470	0.793
634	0.551	0.825
711	0.666	0.787
1135	0.552	0.806
Bias	**0.315**	

data
results


data
results
analysis


data
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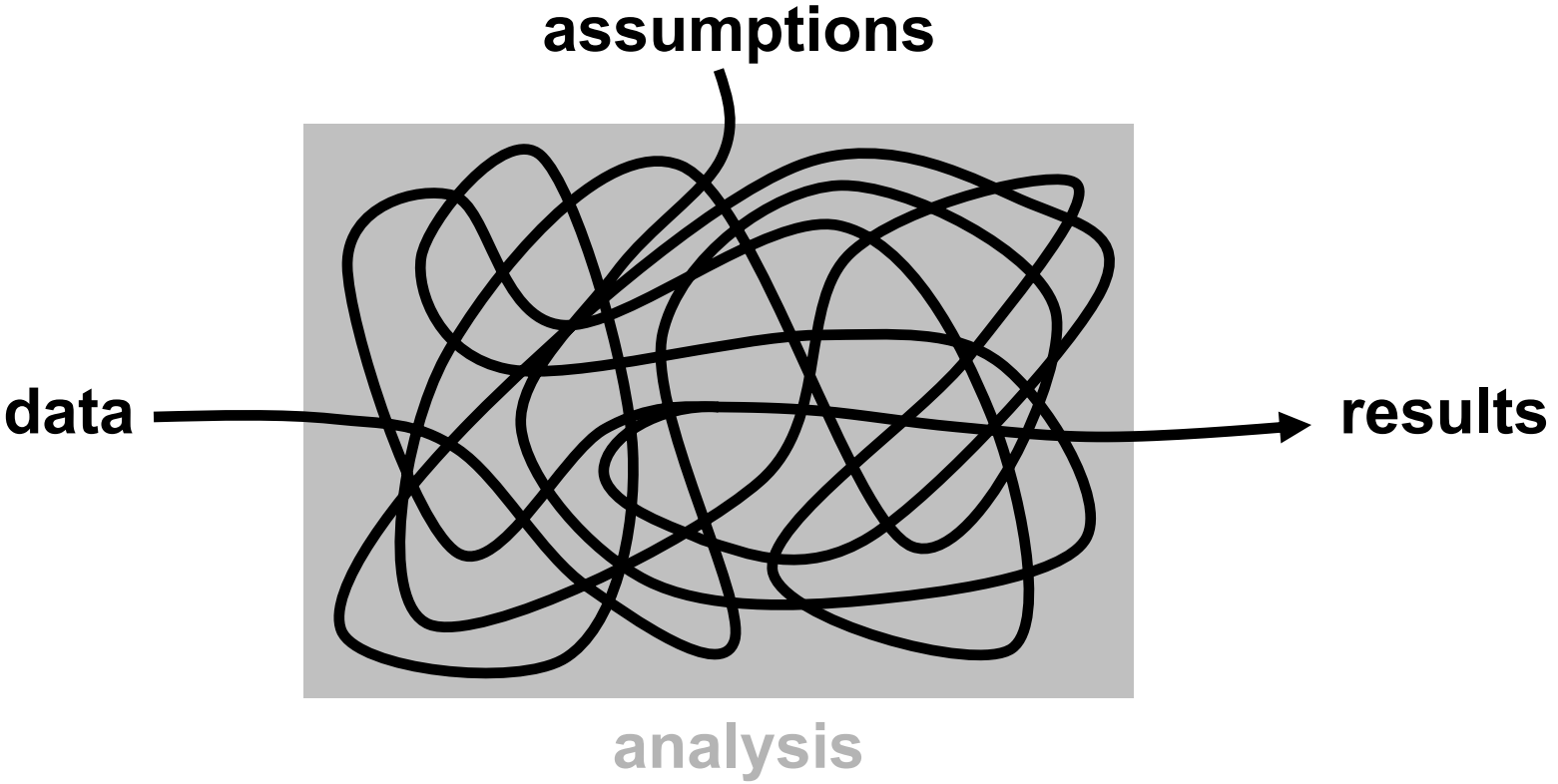
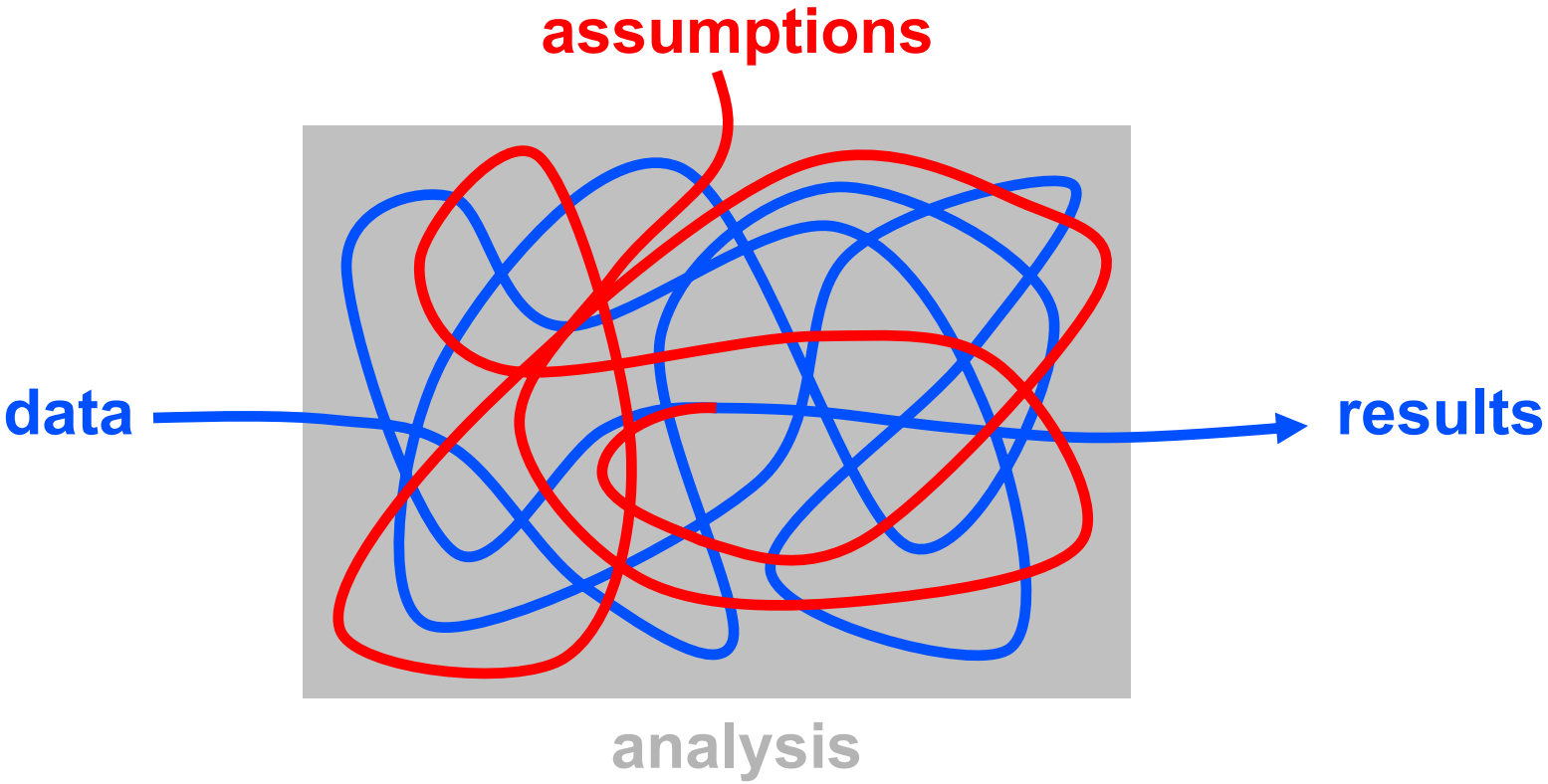
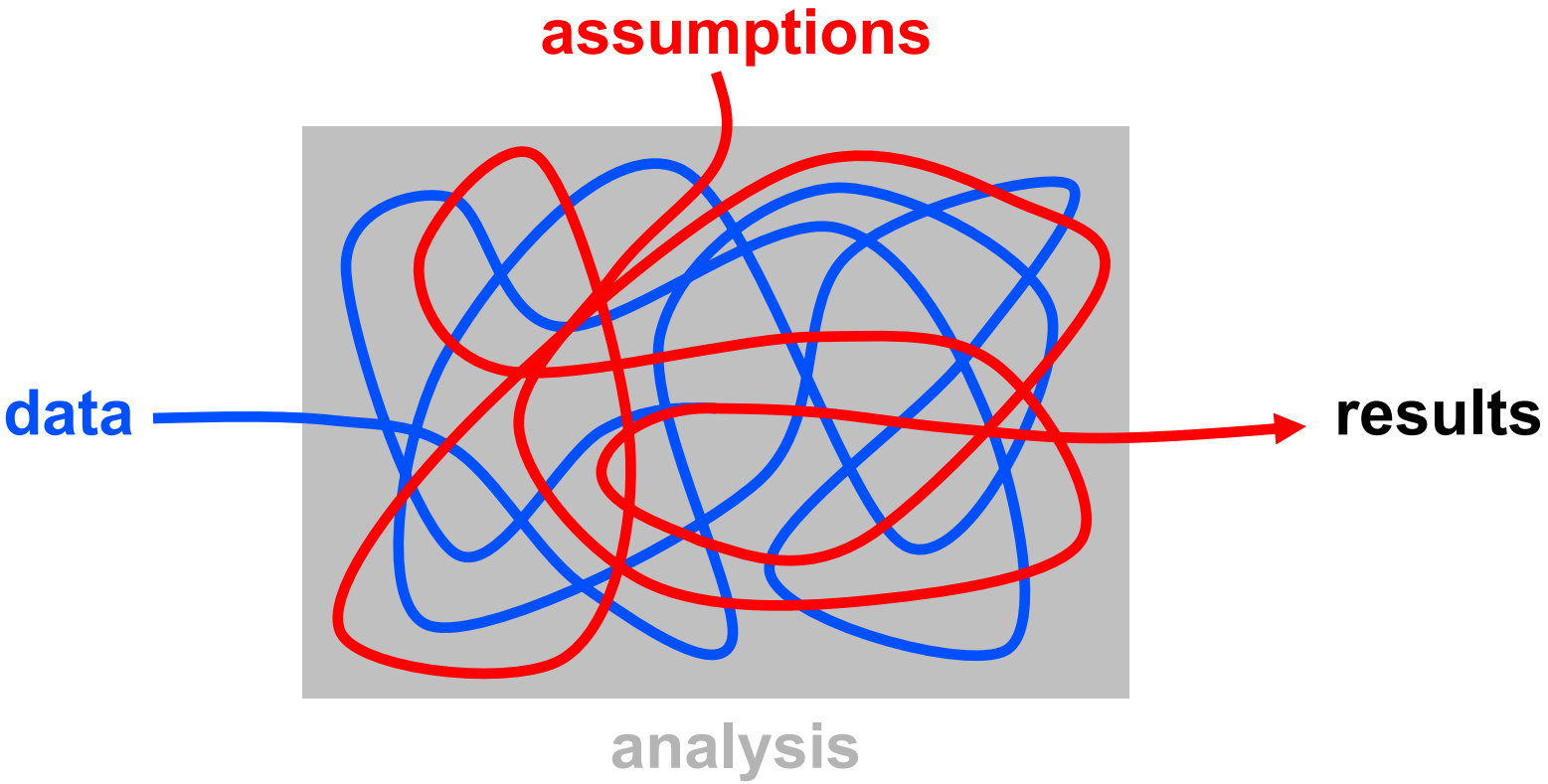
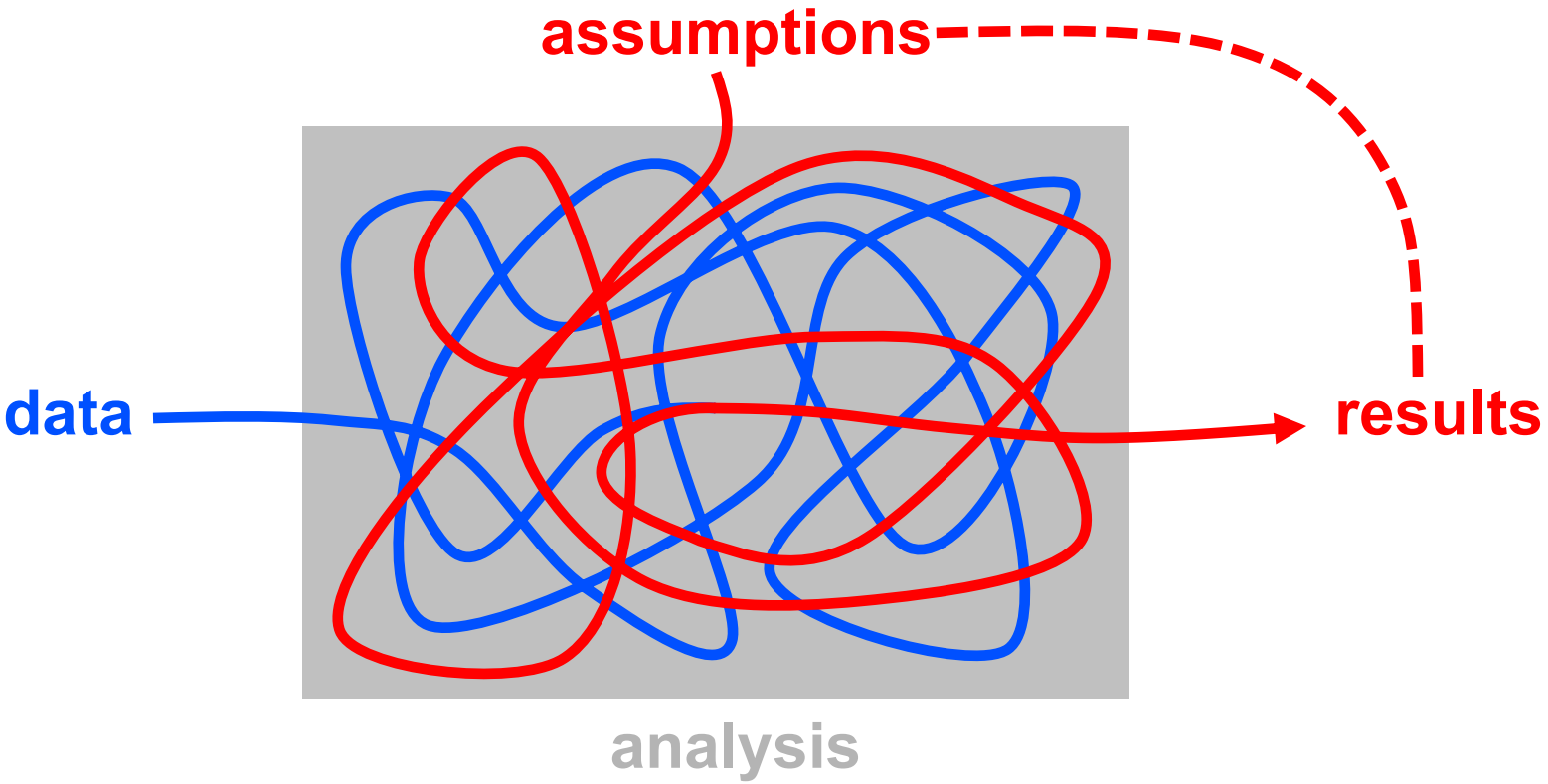
analysis


assumptions
data
results
analysis

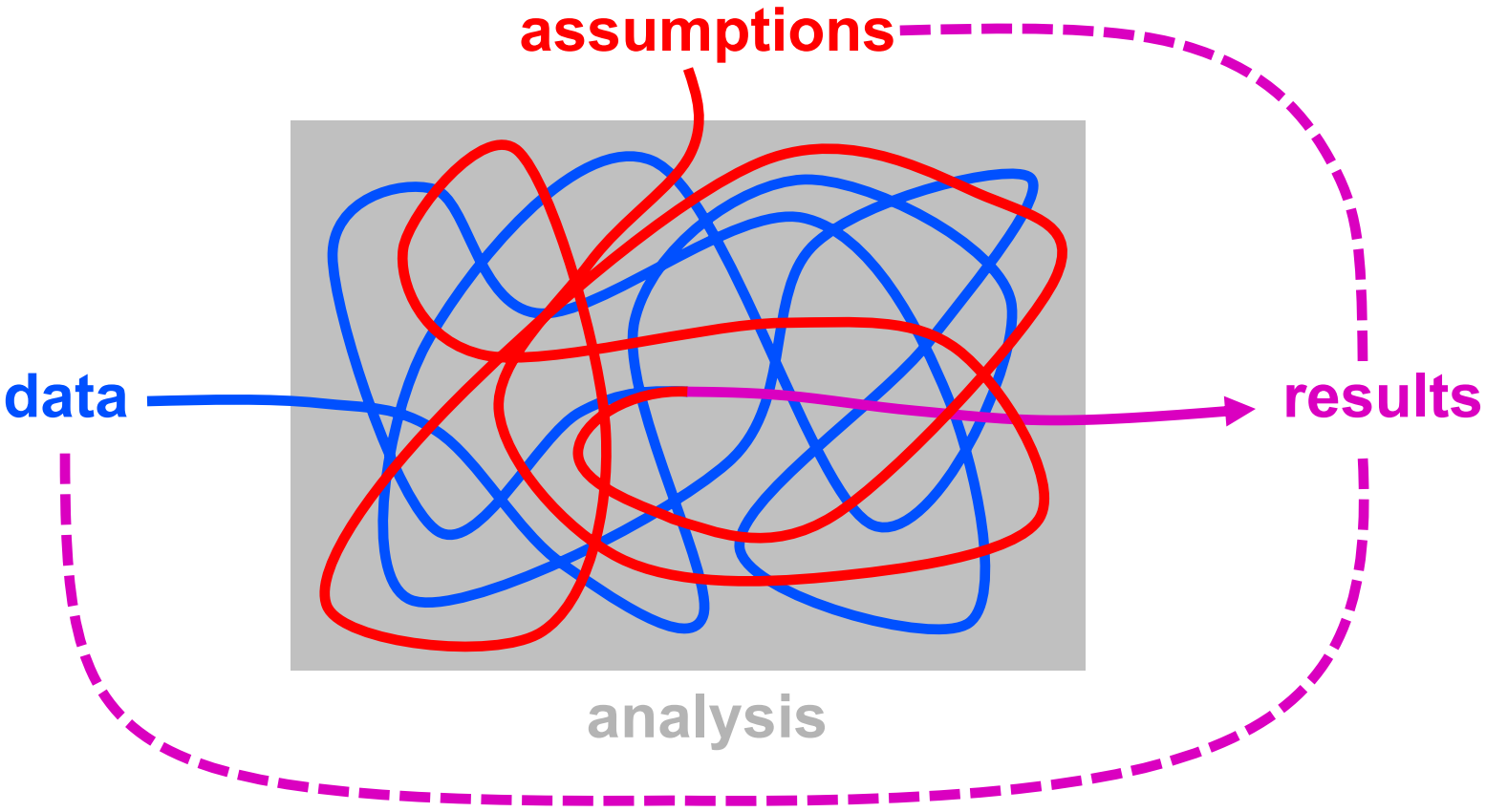

assumptions
data
results
analysis


assumptions
data
results
analysis

Circular inference



Circular inference



How do assumptions in fMRI produce circularity?

- Selection

Selective Analysis

- Powerful and essential tool
  - Increasingly large datasets
- Common throughout neuroscience

How do assumptions in fMRI produce circularity?

- Selection
  - When the results statistics are not independent of the criteria used for selection
- Why?
  - Selection is based on true effects + noise

Types of selection

- Binary selection
- Continuous selection (weighting)
- Sorting

Examples of selection

- fMRI
  - ROI or voxels of interest

Double dipping is not just a problem for fMRI

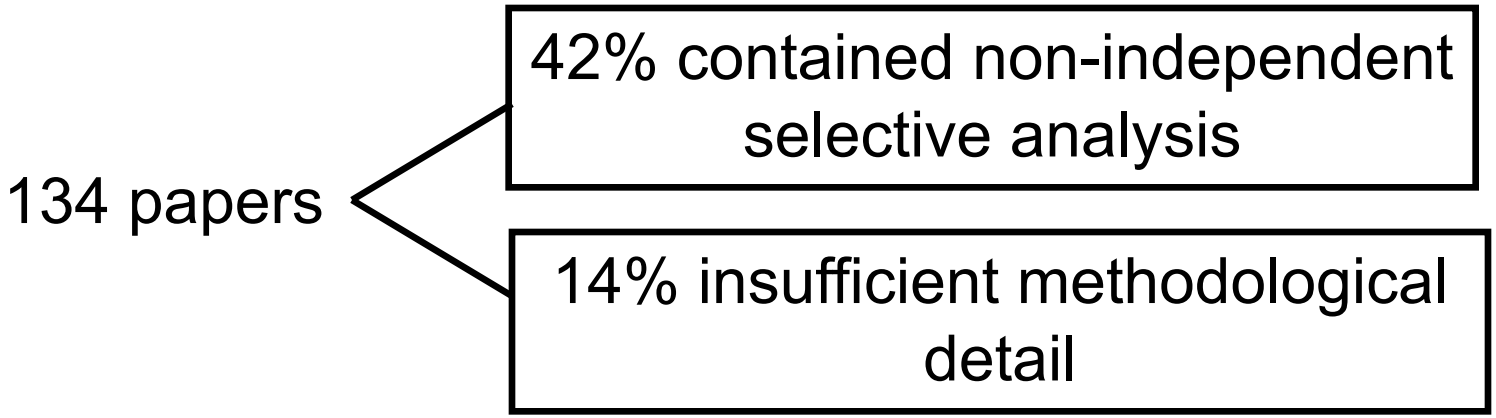
Examples of selection

- fMRI
  - ROI or voxels of interest
- Single-unit recording
  - “typical” neuron
  - pre-specified selectivity e.g. visually responsive
- EEG/MEG
  - Sensors or waveforms of interest
- Behavior
  - Sorting participants by performance e.g. fast learners versus slow learners
- Gene microarrays
  - Subsets of genes

How common is double dipping?

- All fMRI articles published in 2008 in
  - Nature
  - Science
  - Nature Neuroscience
  - Neuron
  - Journal of Neuroscience

How common is double dipping?



These papers may not be wrong in their main claims, but it's very difficult to know how much of a bias has been introduced

How common is double dipping?

Today?

Take Home Message

Data selection should be independent from any other data testing