Varieties of “Voodoo”

Ed Vul

MIT
Reception

“such interchanges, in my experience, lead to more heat than light”

“What is the most we can learn about the mind by studying the brain?”

“grossly over-strong pronouncements”

“I haven't had so much fun since Watergate!”

“an unrepentant Vul”

“They look like idiots because they're out of their statistical depth”

“there are people who would otherwise be dead if we adopted Vul’s opinions”
Reception

“such interchanges, in my experience, lead to more heat than light”

From SEED magazine
Varieties of “voodoo”

Historical perspective

What captured our attention?

The “voodoo correlation” method and generalizations

Objections

Solutions
B-Projective Psychokinesis Test

Edward Cureton (1950)

Can we use the same data to make an item analysis and to validate the test?

1) Noise data:
   - 29 students & grades
   - 85 random flips/student
2) Find tags predicting GPA
3) Evaluate validity on same data

Result: validity = 0.82

This analysis produces high validity from pure noise.

Thanks to: Dirk Vorberg!
The moral of this story, I think, is clear. When a validity coefficient is computed from the same data used in making an item analysis, this coefficient cannot be interpreted uncritically. And, contrary to many statements in the literature, it cannot be interpreted "with caution" either. There is one clear interpretation for all such validity coefficients. This interpretation is—

"Baloney!"
A new name in each field

• Auctioneering: “the winner’s curse”
• Machine learning: “testing on training data”
  “data snooping”
• Modeling: “overfitting”
• Survey sampling: “selection bias”
• Logic: “circularity”
• Meta-analysis: “publication bias”
• fMRI: “double-dipping”
  “non-independence”
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Interoceptive accuracy, an outcome associated with neuroticism, was better accounted for by dACC reactivity ($r^2 = .74$) than by self-reported neuroticism ($r^2 = .16$), suggesting that neural reactivities may provide a more direct measure of personality than self-reports do.

Figure 4: (A) Scatterplot showing self-reported neuroticism scores plotted against interoceptive accuracy (controlling for arousal levels) across participants. (B) Scatterplot showing dorsal anterior cingulate cortex activations to oddball trials relative to nonoddball trials, plotted against interoceptive accuracy (controlling for arousal levels) across participants.
Large Correlations

Neural Correlates of Human Virtue Judgment


Figure 3. Regression lines of correlations between (A) praiseworthiness (B) blameworthiness and degree of brain activation. (A) There were correlations ($r = 0.82$, degrees of freedom $[df] = 13$, $P < 0.001$) between self-rating of praiseworthiness and degree of activation in OFC. (B) There were positive linear correlations ($r = -0.83$, $df = 13$, $P < 0.001$) between self-rating of blameworthiness and degree of activation in pSTS.

$r = 0.82$
Large Correlations

The influence of personality on neural mechanisms of observational fear and reward learning

Christine I. Hooker\textsuperscript{a,*}, Sara C. Verosky\textsuperscript{b}, Asako Miyakawa\textsuperscript{c}, Robert T. Knight\textsuperscript{c,d}, Mark D’Esposito\textsuperscript{c,d}

$r = 0.88$

Hooker, Verosky, Miyakawa, Knight, & D’Esposito (2008)
Large Correlations

Does Rejection Hurt? An fMRI Study of Social Exclusion

Naomi I. Eisenberger, Matthew D. Lieberman, Kipling D. Williams

Fig. 2. Scatterplots showing the relation during exclusion, relative to inclusion, between (A) ACC activity and self-reported distress, (B) RVPFC and self-reported distress, and (C) ACC and RVPFC activity. Each point represents the data from a single participant.

Eisenberger, Lieberman, & Williams (2003)
How common are these correlations?

Phil Nguyen surveyed soc/aff/person fMRI, in search of these correlations.

Vul, Harris, Winkielman, & Pashler (2009)
What’s wrong with big correlations?

- (Expected) observed correlations are limited by reliability:

$$r(\hat{A}, \hat{B}) = r(A, B) \sqrt{r(\hat{A}_1, \hat{A}_2) r(\hat{B}_1, \hat{B}_2)}$$

Expected observed correlation \hspace{1cm} True underlying \hspace{1cm} Geometric mean of
correlation \hspace{1cm} correlation \hspace{1cm} measure reliabilities

- **Maximum** expected observed correlation should be the geo. mean. of reliabilities...
Reliability of personality measures

• Viswesvaran and Ones (2000) reliability of the Big Five: .73 to .78.

• Hobbs and Fowler (1974) MMPI: .66 - .94 (mean=.84)

We say:

0.8 optimistic guess for ad hoc scales
Reliability of fMRI measures

- (a lot of variability depending on measure)
- Choose estimates most relevant for across-subject correlations
  - 0-0.76  Kong et al. (2006)
  - 0.23 – 0.93 (mean=0.60)  Manoach et al (2001)
  - ~0.8  Aron, Gluck, and Poldrack (2006)
  - 0.59-0.64  Grinband (2008)

- We say:
  not often over 0.7
Maximum expected correlation

Expected observed correlation | True underlying correlation | Geometric mean of measure reliabilities

\[ r(\hat{A}, \hat{B}) = r(A, B) \sqrt{r(\hat{A}_1, \hat{A}_2) r(\hat{B}_1, \hat{B}_2)} \]

\[ 0.74 = \left[ 1.0 \right] \sqrt{0.7} \left[ 0.8 \right] \]
“Upper bound”?

Many exceeding the maximum possible expected correlation.

(variability is possible, but this struck us as exceedingly unlikely)

Vul, Harris, Winkielman, & Pashler (2009)
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How are these correlations produced?

Response? Would you please be so kind as to answer a few very quick questions about the analysis that produced, i.e., the correlations on page XX?...

“No response”

1 What is the brain measure: One peak voxel, or average of several voxels?

Go to question 2

1.1 How was this set of voxels selected?

“Independent”

If 1: The voxels whose data were plotted (i.e., the “region of interest”) were selected based on...

1a …only anatomical constraints
1b …only functional constraints
1c … anatomical and functional constraints

The data plotted reflect the percent signal change or difference in parameter estimates (according to some contrast) of...
1 …the average of a number of voxels
2 …one peak voxel that was most significant according to some functional measure
How are these correlations produced?

2. What sort of functional selection?
   - The functional measure used to select the voxel(s) plotted in the figure was...
     - A ...a contrast within individual subjects
     - B ...the result of running a regression, across subjects, of the behavioral measure of interest against brain activation (or a contrast) at each voxel
     - C ...something else?

3. Same or different data?
   - Finally: the fMRI data (runs/blocks/trials) displayed in the figure were...
     - A ...the same data as those employed in the analysis used to select voxels
     - B ...different data from those employed in the analysis used to select voxels.

54% said correlations were computed in voxels that were selected for containing high correlations.
54% did what?

<table>
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<th>Subject</th>
<th>Behavioral measure</th>
<th>Voxel 1</th>
<th>Voxel 2</th>
<th>Voxel 3</th>
<th>...</th>
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<td>V2(k)</td>
<td>V3(k)</td>
<td></td>
<td>Vn(k)</td>
</tr>
</tbody>
</table>

Vul, Harris, Winkielman, & Pashler (2009)
What would this do on noise?

Simulate 10 subjects, 10,000 voxels each.

This analysis produces high correlations from pure noise.

Vul, Harris, Winkielman, & Pashler (2009)
False Alarms vs. Inflation

Multiple comparisons correction:

1) Minimizes false alarms
2) Exacerbates effect-size inflation

Vul, Harris, Winkielman, & Pashler (2009)
Source of high correlations

Biased method produced the majority of the “surprisingly high” correlations

Vul, Harris, Winkielman, & Pashler (2009)
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Solutions
This analysis produces high selectivity from pure noise.
This analysis produces high classification accuracy from pure noise.

Kriegeskorte, Simons, Bellgowan & Baker (2009)
And if there is some signal?

Signal or not, non-independent selection produces biased results.

Adapted from Kriegeskorte, Simons, Bellgowan & Baker (2009)
Same problem in different guises

• Null-hypothesis tests on non-independent data.

• Computing meaningless effect sizes (e.g., correlations).

• Showing uninformative/misleading graphs... (with error bars?)
Testing null-hypothesis

p < 0.005 uncorrected

peak voxel: $F_{(2,14)} = 22.1$; $p < .0004$

Significant results, potentially out of nothing!

Summerfield et al, 2006
Computing effect sizes

“$r^2 = 0.74$”

A “voodoo” correlation

Eisenberger, Lieberman, & Satpute (2005)
Modulating motion perception

Non-independent selection produces bizarre spurious patterns

Rees, Frith, & Lavie (1997)
Data Analysis

Reporting peak voxel, cluster mean, etc. amounts to two analysis steps!

\[ M_1(data_1) > \alpha \]

\[ M_2(data_2) \]
Data Analysis

\[ M_1(data_1) > \alpha \]

Non-Independent:

\[ M_1 = M_2 \]

&

\[ data_1 = data_2 \]

Independent:

\[ M_1 \neq M_2 \]

or

\[ data_1 \neq data_2 \]
Data Analysis

Non-Independent: 
Conclusions can only be based on selection step 
$M_2$ is biased

Independent: 
Conclusions can be based on both measures 
$M_2$ provides unbiased estimates of effect size

$M_1(data_1) > \alpha$

$M_2(data_2)$
Some fields are more susceptible

- fMRI, genetics, finance, immunology, etc.
- A whole lot of data are available
- Only some contains relevant signal
- Goals:
  - Find the relevant bits of data (brain, genes, etc.)
  - Estimate their signal
  - Without extra costs of data
- Data are reused, non-independence is common.
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Inflation isn’t so bad

• Cannot estimate inflation in general – must reanalyze data.

• We know of one comparison (in real data) of independent – non-independent correlations

  ~0.8 down to ~0.5

  (non-indep. \( r^2 \) would be inflated by more than a factor of 2)

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Poldrack and Mumford (submitted)
Location, not magnitude, matters

• Do we want to study the brain for its own sake?
  • Only location matters, but...
    
    Localization seems to be overestimated by underpowered studies: Studies with adequate power yield small widespread correlations
    (Yarkoni and Braver)

• Do we want to use measures/manipulations of the brain to predict/alter behavior?
  • Effect size really matters!
Correlations not used for inference?

In the present study, the first neuroimaging study to include an outcome measure against which both self-reported and neurologically assessed neuroticism could be compared, it was found that dACC reactivity was a substantially better predictor of interoceptive accuracy than self-reported neuroticism was, accounting for nearly five times the variance in interoceptive accuracy (74% vs. 16%). With the utilization of these types of methods, future personality research may have the potential to account for a substantially larger portion of the variation in human experience and behavior than has been possible with self-report measures alone.

Eisenberger, Lieberman, & Satpute (2005)
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Solutions
Positive suggestions

1: Independent localizers

*Use different data or orthogonal measure to select voxels.*
Positive suggestions

1: Independent localizers
2: Cross-validation methods

*Use one portion of data to select, another to obtain a validation measure, repeat.*
Positive suggestions

1: Independent localizers
2: Cross-validation methods
3: Be careful with graphs

From Kriegeskorte, Simons, Bellgowan and Baker (2009)
Positive suggestions

1: Independent localizers
2: Cross-validation methods
3: Be careful with graphs
4: Random/Permutation simulations to evaluate independence

If orthogonality of measures or independence of data are not obvious, try the analysis on random data (Generates empirical null-hypothesis distributions.)
Reusing the same data and measure to (a) select data and (b) estimate effect sizes leads to overestimation: “Baloney” – Cureton (1950)

Most high correlations in individual differences research in fMRI are obtained in this manner: “Voodoo”

Many fMRI papers contain variants of this error 42% in 2008 (Kriegeskorte et al, 2009)

Simple solutions exist to avoid these problems!
Thanks to:
Nancy Kanwisher, Hal Pashler, Chris Baker, Niko Kriegeskorte and many others for very engaging discussions.


Vul, Kanwisher (in press) Begging the question: The non-independence error in fMRI Data Analysis, *Foundational issues for human brain mapping*.


Poldrack, Mumford (submitted) Independence in ROI analyses: Where’s the voodoo?


Vul, Harris, Winkielman, Pashler (2009) Reply to comments on “Puzzlingly high correlations...”, *Perspectives on Psychological Science*.

Yarkoni (2009) Big correlations in little studies..., *Perspectives on Psychological Science*.

Yarkoni, Braver (in press) Cognitive neuroscience approaches to individual differences in working memory... *Handbook of individual differences in cognition*.