Four Lesson in Statistics, and Some Statistics Along the Way

STATISTICALLY SPEAKING ...
October 2016

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Associate Professor
Department of Preventive Medicine, Division of Biostatistics
Department of Psychiatry and Behavioral Sciences
BCC: Biostatistics Collaboration Center

What We Do

Our mission is to support FSM investigators in the conduct of high-quality, innovative health-related research by providing expertise in biostatistics, statistical programming, and data management.
BCC: Biostatistics Collaboration Center
How We Do It

Are you writing a grant?

YES

We provide:
Study Design
Analysis Plan
Power Sample Size

BCC faculty serve as Co-Investigators; analysts serve as Biostatisticians.

NO

Short or long term collaboration?

Short

Recharge Model
(hourly rate)

Long

Subscription Model
(salary support)

The BCC recommends requesting grant support at least 6-8 weeks before submission deadline.

Statistical support for Cancer-related projects or Lurie Children’s should be triaged through their available resources.

Every investigator is provided a FREE initial consultation of up to 2 hours with BCC faculty of staff.
BCC: Biostatistics Collaboration Center
How can you contact us?

• Request an Appointment
  - http://www.feinberg.northwestern.edu/sites/bcc/contact-us/request-form.html

• General Inquiries
  - bcc@northwestern.edu
  - 312.503.2288

• Visit Our Website
  - http://www.feinberg.northwestern.edu/sites/bcc/index.html
Four Lessons in Statistics: Outline

4. A (good) picture is worth 1,000 words.
3. Not all observations are independent.
2. Are 50% of us really above average?
1. What the ** is a p-value?
Lesson #4

“A (good) picture is worth 1,000 words.”
Correlation Defined

Correlation often denoted as $r$

Measures strength of the *linear* association between two continuous variables

$$-1 \leq r \leq 1$$

$r = -1$ \hspace{0.5cm} strong negative linear association

$r = 1$ \hspace{0.5cm} strong positive linear association

$r = 0$ \hspace{0.5cm} no linear association
Good Pictures: An example of why they’re needed

Correlation Example

• The correlation between two variables of interest, A and B, is 0.82.

• Is there a strong positive linear association between A and B?
Good Pictures: An example of why they’re needed

Anscombe’s Quartet
Good Pictures: Excel can lead you far astray
Bad pictures can hurt your brain

- Longitudinal study of juvenile delinquents (*Northwestern Juvenile Project*)
- Are there racial/ethnic differences in
  - Being re-incarcerated
  - Length of time incarcerated

![Bar Chart]

- Extra black ink
- Discretizes (unequally) a continuous scale
- Legend far from information

Colors of unequal visual weight

0 much different than 1

*Northwestern Medicine*
Feinberg School of Medicine
Good Pictures: Side-by-side boxplots
Simple but really useful

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Stata command: `graph box incarceration, over(race)`
Good Pictures: Custom graphics with R
Good pictures tell a story and you can get creative

- Longitudinal study of juvenile delinquents (*Northwestern Juvenile Project*)
- Are there racial/ethnic differences in
  - Being re-incarcerated
  - Length of time incarcerated (*slightly different data*)

Can see exactly how many never re-incarcerated

Color scale indicates increasing severity

Discretizes continuous variable (equally)

35+ lines of custom-written R code
Good Pictures: Graphics “Rules”

Other points to keep in mind

• Maximum information; minimum ink (see work by Edward Tufte)
  - Tower and antenna plots waste a lot of ink
  - Color should be informative, thoughtful, and not gratuitous

• Graphics should have no more dimensions than exist in your data
  - No 3-d histograms
  - Only 3-d if you are plotting a surface

• Labels should be informative but not distracting
  - Graphics should stand on their own
Good Pictures: Worth 1,000 Statistics

Take home messages

• A good picture of your data
  - May help identify appropriate statistical methods
  - May help identify errors or irregularities

• A really good picture of your data
  - Can tell your story for you
  - Doesn’t have to be complicated
Lesson #3

“Not all observations are independent.”
(In)dependence: Two Case-Control Studies

Hodgkins & Tonsillectomy

- Is Tonsillectomy associated with Hodgkin’s?

- Vianna, Greenwald, and Davies (1971)
  - Case-control study (controls unmatched)

- Johnson & Johnson (1972)
  - Case-control study (controls matched)

Adapted from Mathematical Statistics and Data Analysis, John A. Rice, Duxbury (1995)
(In)dependence: Contingency Table Vianna et al.

Vianna et al.

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<tr>
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<td>34</td>
</tr>
<tr>
<td>Control (n = 107)</td>
<td>43</td>
<td>64</td>
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</table>

- Case-control study
  - Recruit people with Hodgkin’s and similar people without
- Look back to see who had exposure (tonsillectomy)
  - In Hodgkin’s group, 67/101 = 66%
  - In Control group, 43/107 = 40%
- Is that a big enough difference to conclude that tonsils are protective?
(In)dependence: Odds and Odds Ratios
Vianna et al.

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- Odds of tonsillectomy in Hodgkin’s group: 67/34
- Odds of tonsillectomy in Control group: 43/64
- Odds ratio comparing tonsillectomy for Hodgkin’s versus Control
  - OR = (67/34)/(43/64) = 2.93
  - “Hodgkin’s had 2.93 times the odds of tonsillectomy compared to Controls.”
- Odds ratios range from 0 to ∞
  - 1 = no difference in groups
- Is 2.93 different enough from 1 to conclude that tonsils are protective?
(In)dependence: Chi-Squared Test

Vianna et al.

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- A chi-squared test can be used to compare whether rows and columns in a 2x2 contingency table are associated
- Computed by comparing “expected” versus observed values
  - E.g. Expect 53.4 people to have Hodgkin’s and a Tonsillectomy, observe 67
    - $101 \times \frac{(67+43)}{208}$
- Chi-squared statistics is 14.46 with 1 degree of freedom
- P-value = 0.0002
- Conclude there is evidence for an association between Hodgkin’s and Tonsillectomy
(In)dependence: A second study, Johnson et al.

Johnson et al.

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<td>33</td>
<td>52</td>
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- Case-control study (**controls matched**)
  - 85 Hodgkin’s who had sibling w/in 5 yrs age and same sex
  - Sibling was *matched* control
(In)dependence: What went wrong?

Johnson et al. NEJM

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- Look back to see who had exposure (tonsillectomy)
  - In Hodgkin’s group, 41/85 = 48%
  - In Control group, 33/85 = 39%
- Odds of tonsillectomy
  - In Hodgkin’s group 41/44
  - In Control group 33/52
  - OR = (41/44)/(33/52) = 1.47
- Chi-squared statistic = 1.53, associated p-value = 0.22
- No evidence that Hodgkin’s is associated with Tonsillectomy
**Independence: Johnson failed to account for pairing**

Johnson et al.

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- This analysis IGNORED pairing (siblings and controls were *matched*)

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<td>26</td>
<td>15</td>
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<td>Hodgkin’s No Tonsillectomy</td>
<td>7</td>
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- Correct contingency table shows pairings (treats the unit of analysis as a pair)
(In)dependence: McNemar’s Test

Johnson et al.

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- Chi-squared test WRONG choice
- Compare discordant pairs (McNemar’s Test):
  - Proportion of pairs in which sibling had tonsillectomy but Hodgkin’s did not
    \[ \frac{7}{85} = 8\% \]
  - Proportion of pairs in which sibling did not have tonsillectomy but Hodgkin’s did
    \[ \frac{15}{85} = 17\% \]
- P-value 0.09
- Less doubt about results of Vianna et al.
(In)dependence: Think about types of variation
Across & Within Person Variation

If assume observations are independent ...

Across person variation

May underestimate variability in population

Overoptimistic p-value

Within person variation

10 people 1 obs each
5 people 2 obs each
2 people 5 obs each
1 person 10 obs
(In)dependence: Recommendations

• Many common statistical methods assume observations are independent

• There are different statistical methods for observations that are not independent

• Examples of paired/not independent data
  - Before and after measurements
  - Case and matched control
  - Longitudinal data
  - Nested samples
  - Spatial data

• Paired data can be powerful and efficient, but you have to do your analysis right
Lesson #2

“Are 50% of us really above average?”
Above Average: Mean vs Median Example
Again examining time incarcerated in the past year

- Longitudinal study of juvenile delinquents (*Northwestern Juvenile Project*)
- Again looking at re-incarceration
- Goal is to summarize time incarcerated in the past year
  - Mean time incarcerated = 84 days
  - Median time incarcerated = 0 days

These are really different estimates - what’s going on?
Above Average: Mean vs Median Example
Look at the data! (Reprise to Lesson #4)

Over 50% of participants have no time in corrections.

Median is “middle” observation. N = 1000, 544 0’s, so Median = 0 days.

Some participants have very large values (365 days).

Mean is ‘balance point’ of distribution 84 days.
Above Average: Mean vs Median Example

What should you report when data are skewed?

• Longitudinal study of juvenile delinquents (Northwestern Juvenile Project)
• Again looking at re-incarceration
• Goal is to summarize time incarcerated in the past year
  - Mean time incarcerated = 84 days
  - Median time incarcerated = 0 days

• What should we report?
  - People expect to see the mean (and the associated standard deviation)
  - I recommend also reporting the median, range, Q1, and Q3

• In this case, it may be better to separately
  - Report the fraction of participants who were never re-incarcerated
  - Report mean/median etc. among the 456 who we re-incarcerated
Above Average: Picture Your Data!

What do you think of when you hear “The mean value was 2.0”? 

What we tend to think
Mean = 2
Median = 2

What might be true
Mean = 2.0
Median = 1.4
Above Average: Standard Deviation vs Standard Error

Averages are less variable than individual observations

- Standard deviation (SD) describes variability in a population
- Standard error (SE) describes variability of an estimate from a sample

- American women are on average 5’4” with standard deviation of about 3”
  - Height is normally distributed, approx 95% of women between +/- 2 SD
  - 95% confidence interval for height of next woman through the door:

  \[(4'10" - 5'10")\]

- Average height in a sample of 35 American women
  - Average is likely to be around 5’4”; estimate standard error of \(3/\sqrt{35} = 0.5\)
  - 95% confidence interval for AVERAGE height of next 35 women through door:

  \[(5'3" - 5'5")\]
Above Average: Reminders and Recommendations

- The mean is not robust to outliers

- For skewed distributions, or distributions with outliers, the mean may be misleading

- In a manuscript, don’t blindly report mean.

- Why use the mean at all?
  - Mathematically convenient
  - Nice statistical properties

- You are above average if you understand the important differences between the median and the mean, standard deviation and standard error
Lesson #1

“What the **** is a p-value?”
P-Values: An Analogy
Cheating at Poker

- Dr. X and I are playing poker
- Dr. X is beating me
- Dr. X’s two most recent hands were a flush and a straight
- Is Dr. X cheating?
P-Values: Poker and Hypothesis Testing
A statistical approach to detect cheating

• Suppose Dr. X is playing fairly (opposite of what I suspect).
  - Called the null hypothesis, or H0

• Observe the data.
  - Dr. X’s next hand is 2 pair.

• What is the probability of Dr. X having a hand that is 2 pair or better if Dr. X is playing fairly?
  - Called the p-value (approximately 0.08 for this example)

• If probability is “small”, conclude that supposition might not be right.
  - Reject the null hypothesis in favor of the alternative hypothesis, or H1
  - Conclude that evidence may support Dr. X cheating.
  - Conclusion may be wrong (what if Dr. X is very lucky/skillful?)

• If the probability is not “small”, conclude do not have evidence to reject the null hypothesis
  - Not the same as ‘accepting’ the null hypothesis, or showing that the null hypothesis is true
  - Dr. X may really be cheating, we just didn’t ‘detect’ it.
P-Values: A more traditional example

Suppose you have a treatment that you suspect may alter performance on a task. You compare the means of your control and experimental groups (say, 20 subjects per group). You use a simple independent means t-test and your result is significant \((t = 2.7, \text{df} = 18, p = 0.01)\).

 Reject \(H_0\) in favor of \(H_1\).

From “The Null Ritual: What you always wanted to know about significance testing but were afraid to ask.” Gigerenzer, G., Krauss, S., Vitouch, O. in The Sage Handbook of Quantitative Methodology of the Social Sciences (2004). David Kaplan, Editor.
P-Values: Definition

• The p-value is the probability of the observed data (or of more extreme data), given that the null hypothesis $H_0$ is true.

\[
p\text{-value} = Pr(\text{data} \mid H_0)
\]

• This doesn’t tell us what we might like to know: $Pr(H_0 \mid \text{data})$ or $Pr(H_1 \mid \text{data})$. 
P-Values: Definition

• If Dr. X is not cheating, we would expect Dr. X to get a hand this good or better less than 8% of the time.

There is no $\text{Pr}(\text{Dr. X Cheating})$. Dr. X is either cheating or not cheating.

• If there were no difference in means between the two groups, we would expect to see a difference in group means this large – or larger – about 1% of the time.

There is no $\text{Pr}(\text{group means different})$. 
Suppose you have a treatment that you suspect may alter performance on a task. You compare the means of your control and experimental groups (say, 20 subjects per group). You use a simple independent means t-test and your result is significant ($t = 2.7$, df = 18, $p = 0.01$).

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2$$

Reject $H_0$ in favor of $H_1$.

P-Values: A Significance Test

Answer each of the following true or false, recall \( p = 0.01 \)

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<td>If the experiment were repeated thousands of times, you would obtain a significant result ( \sim 99% ) of the time.</td>
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**P-Values: A Significance Test**

**Answer key**

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**The p-value is a probability, not proof.**
## P-Values: A Significance Test

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\[ p\text{-value} = p(\text{data} \mid H_0) \text{ NOT } p(H_0 \mid \text{data}) \text{ or } p(H_1 \mid \text{data}) \]
**P-Values: A Significance Test**

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\[
p-value = p(data \mid H0) \text{ NOT } p(H0)\]
P-Values: A Significance Test

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This assumes the null hypothesis is false, or equivalently, the alternative hypothesis is true. (p = 0.01 could be Type I error)
P-Values: Recommendations

• Remember
  - Statistics don’t “prove” anything
  - The p-value is not the probability of a hypothesis
  - Unfortunately, we can reject the hypothesis that most p-values are interpreted correctly.
Review Lessons 1-4

Parting Thoughts
Review: Four Lessons

4. A picture is worth 1,000 words.
   Examine your data before embarking on analysis.

3. Not all observations are independent.
   Recognize dependencies in your data
   Use methods that account for the dependencies

2. Are 50% of us really above average?
   Difference between mean and median
   Don’t look at either in isolation (see #1)
   SD describes population; SE describes estimate from sample

1. What the **** is a p-value?
   Not a probability of the null/alternative hypothesis
Statistically Speaking ...

What’s next?

Tuesday, October 11
Statistical Considerations for Sex Inclusion in Basic Science Research
Denise M. Scholtens, PhD, Associate Professor, Division of Biostatistics
Associate Director, Department of Preventive Medicine

Friday, October 14
The Impact of Other Factors: Confounding, Mediation, and Effect Modification
Amy Yang, MS, Sr. Statistical Analyst,
Division of Biostatistics, Department of Preventive Medicine

Tuesday, October 18
Statistical Power and Sample Size: What You Need and How Much
Mary Kwasny, ScD, Associate Professor, Division of Biostatistics,
Department of Preventive Medicine

Friday, October 21
Clinical Trials: Highlights from Design to Conduct
Masha Kocherginsky, PhD, Associate Professor, Division of Biostatistics,
Department of Preventive Medicine

Tuesday, October 25
Finding Signals in Big Data
Kwang-Youn A. Kim, PhD, Assistant Professor, Division of Biostatistics,
Department of Preventive Medicine

Friday, October 28
Enhancing Rigor and Transparency in Research: Adopting Tools that Support Reproducible Research
Leah J. Welty, PhD, BCC Director,
Associate Professor, Division of Biostatistics, Department of Preventive Medicine

All lectures will be held from noon to 1 pm in Hughes Auditorium, Robert H. Lurie Medical Research Center, 303 E. Superior St.
BCC: Biostatistics Collaboration Center

Contact Us

• Request an Appointment
  - [http://www.feinberg.northwestern.edu/sites/bcc/contact-us/request-form.html](http://www.feinberg.northwestern.edu/sites/bcc/contact-us/request-form.html)

• General Inquiries
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