An introduction to statistical inference

Francisco Rodríguez-Sánchez

http://bit.ly/frod_san

Why statistics?

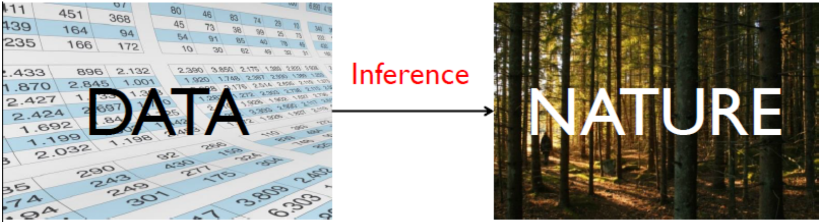
To answer questions like…

- what's the probability that something occurs?

To answer questions like...

- what's the probability that something occurs?
- does X influence Y? How much?

To ensure correct inferences



Bolker et al 2009 TREE:

'311 out of 537 GLMM analyses (58%) used these tools inappropriately'

Figure 1:

To get answers to tough problems

For example. . .

Figure 2:

Inferring tree fecundity

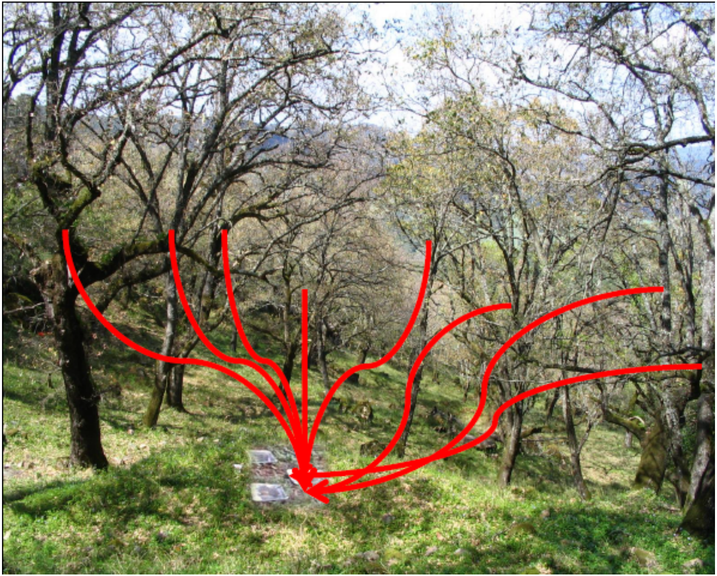


Figure 3:

Course goals

- **Understand** statistical inference

Course goals

- **Understand** statistical inference
- Avoid **misconceptions**

Course goals

- **Understand** statistical inference
- Avoid **misconceptions**
- Promote **good practices**

The purpose of models is not to fit data but to sharpen thinking

Sam Karlin

Topics

- Descriptive statistics

Topics

- Descriptive statistics
- Graphics

Topics

- Descriptive statistics
- Graphics
- Sampling

Topics

- Descriptive statistics
- Graphics
- Sampling
- Experimental design

Topics

- Descriptive statistics
- Graphics
- Sampling
- Experimental design
- Hypothesis testing

Topics

- Descriptive statistics
- Graphics
- Sampling
- Experimental design
- Hypothesis testing
- Bayesian inference

Topics

- Descriptive statistics
- Graphics
- Sampling
- Experimental design
- Hypothesis testing
- Bayesian inference
- Linear models & GLMs

Topics

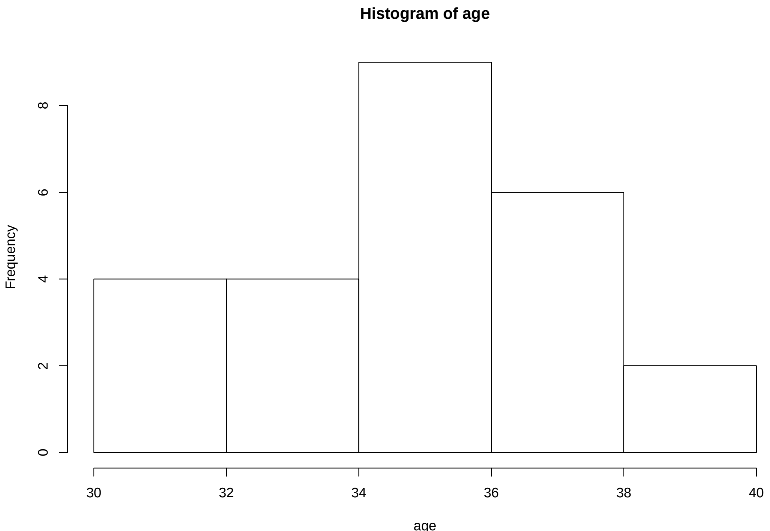
- Descriptive statistics
- Graphics
- Sampling
- Experimental design
- Hypothesis testing
- Bayesian inference
- Linear models & GLMs
- Model selection

Descriptive statistics

Guess my age

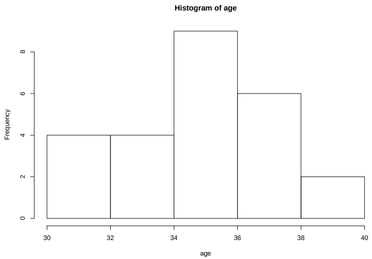
Graph your estimates

```r
hist(age)
```



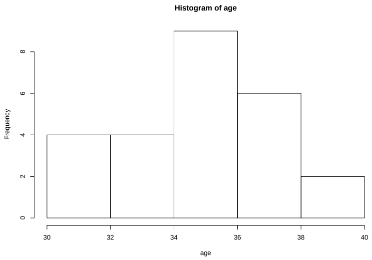
Summarise that distribution

- **Central tendency / location**



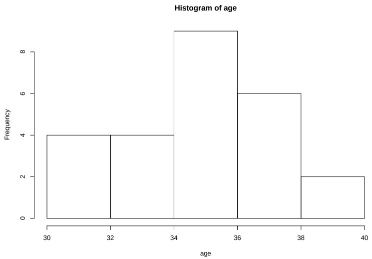
Summarise that distribution

- **Central tendency / location**
  - mean



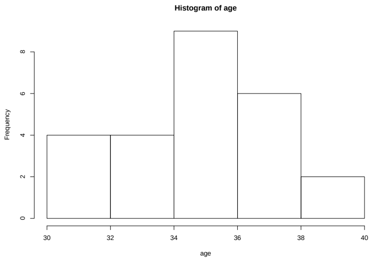
Summarise that distribution

- **Central tendency / location**
  - mean
  - median



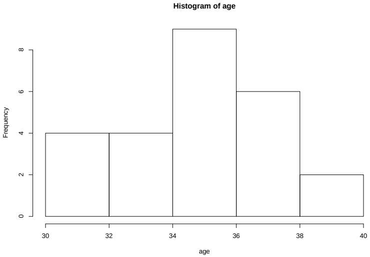
Summarise that distribution

- **Central tendency / location**
  - mean
  - median
  - mode



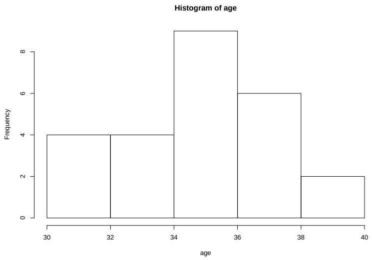
Summarise that distribution

- **Central tendency / location**
  - mean
  - median
  - mode
- **Variation / Spread**



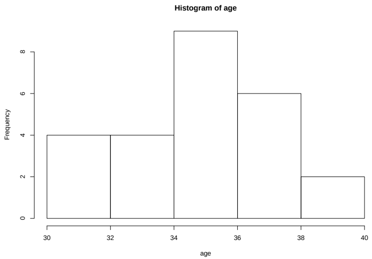
Summarise that distribution

- **Central tendency / location**
  - mean
  - median
  - mode
- **Variation / Spread**
  - min, max, range



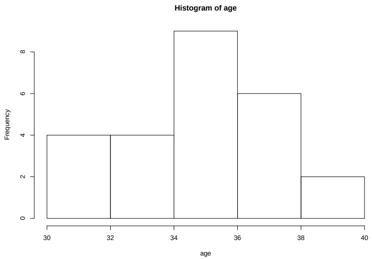
Summarise that distribution

- **Central tendency / location**
  - mean
  - median
  - mode
- **Variation / Spread**
  - min, max, range
  - quantiles



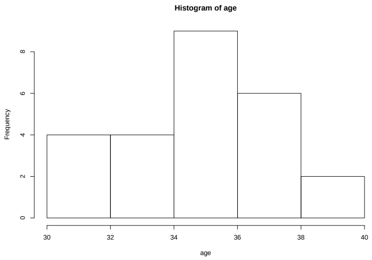
Summarise that distribution

- **Central tendency / location**
  - mean
  - median
  - mode
- **Variation / Spread**
  - min, max, range
  - quantiles
  - standard deviation



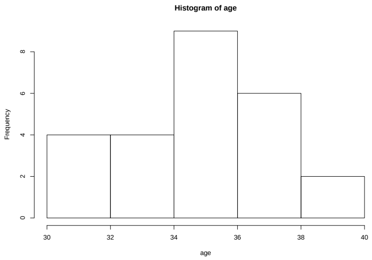
Summarise that distribution

- **Central tendency / location**
  - mean
  - median
  - mode
- **Variation / Spread**
  - min, max, range
  - quantiles
  - standard deviation
  - standard error



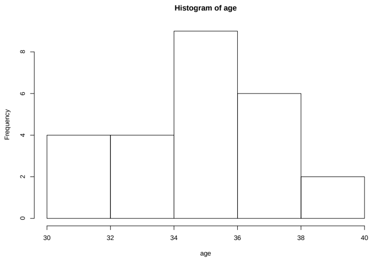
Summarise that distribution

- **Central tendency / location**
  - mean
  - median
  - mode
- **Variation / Spread**
  - min, max, range
  - quantiles
  - standard deviation
  - standard error
  - coefficient of variation



Summarise that distribution

- **Central tendency / location**
  - mean
  - median
  - mode
- **Variation / Spread**
  - min, max, range
  - quantiles
  - standard deviation
  - standard error
  - coefficient of variation
  - confidence intervals



In a Normal distribution

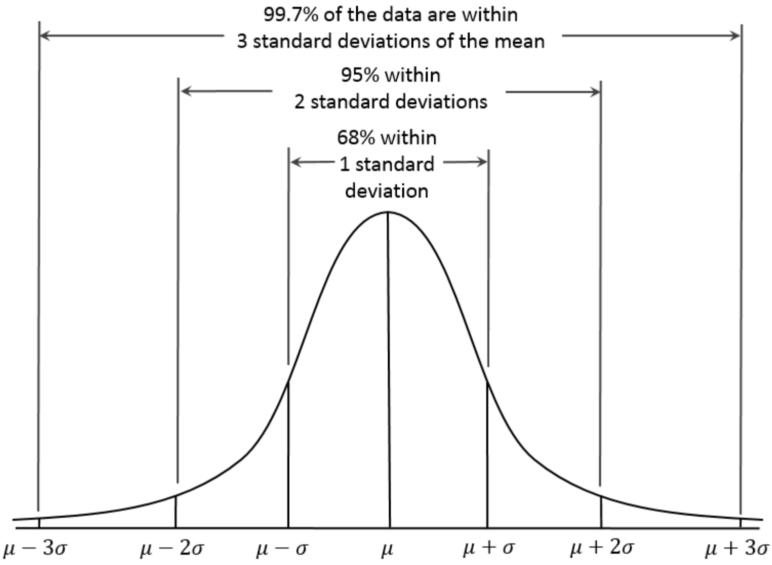
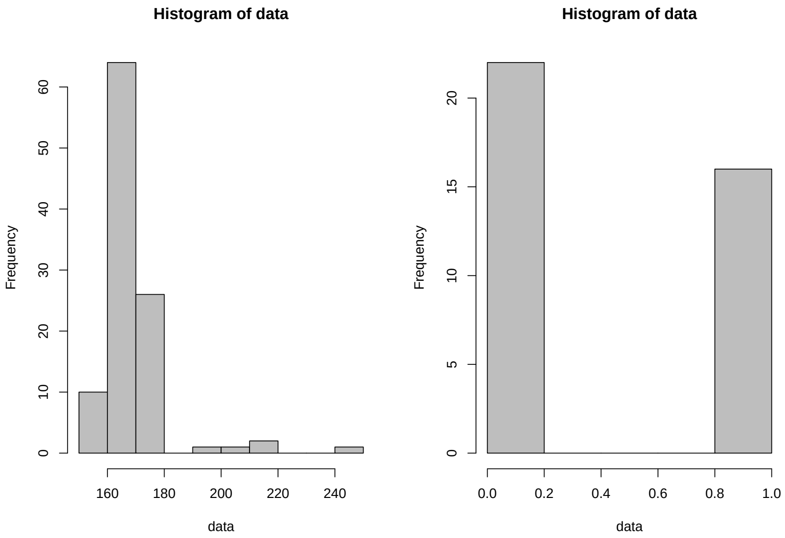


Figure 4:

What statistical descriptors are best? (and why)

https://pollev.com/franciscorod726



Sampling, confidence intervals, and Bayesian inference

Inference: from samples to population

We rarely measure the whole **population**, but take **samples** instead.

Figure 5:

What's the average height in this class?

1. Write down your height and place of origin (Sevilla or other) in a piece of paper and put it in the bag.

What's the average height in this class?

1. Write down your height and place of origin (Sevilla or other) in a piece of paper and put it in the bag.
2. Now everyone **sample** 5 individuals from the whole **population** of heights.

What's the average height in this class?

1. Write down your height and place of origin (Sevilla or other) in a piece of paper and put it in the bag.
2. Now everyone **sample** 5 individuals from the whole **population** of heights.
3. Calculate the mean and 95% CI for your sample (http://graphpad.com/quickcalcs/CImean1/).

What's the average height in this class?

1. Write down your height and place of origin (Sevilla or other) in a piece of paper and put it in the bag.
2. Now everyone **sample** 5 individuals from the whole **population** of heights.
3. Calculate the mean and 95% CI for your sample (http://graphpad.com/quickcalcs/CImean1/).
4. Draw on blackboard.

What's the average height in this class?

1. Write down your height and place of origin (Sevilla or other) in a piece of paper and put it in the bag.
2. Now everyone **sample** 5 individuals from the whole **population** of heights.
3. Calculate the mean and 95% CI for your sample (http://graphpad.com/quickcalcs/CImean1/).
4. Draw on blackboard.
5. Do all CIs contain true mean height?

If the 95% CI of X is (120, 150)...

- There is a 95% probability that X lies between 120 and 150

https://pollev.com/franciscorod726

If the 95% CI of X is (120, 150)...

- There is a 95% probability that X lies between 120 and 150
- We can be 95% confident that X lies between 120 and 150

https://pollev.com/franciscorod726

If the 95% CI of X is (120, 150)...

- There is a 95% probability that X lies between 120 and 150
- We can be 95% confident that X lies between 120 and 150
- If we repeated the experiment, 95% of the time X would fall between 120 and 150

https://pollev.com/franciscorod726

If the 95% CI of X is (120, 150)...

- There is a 95% probability that X lies between 120 and 150
- We can be 95% confident that X lies between 120 and 150
- If we repeated the experiment, 95% of the time X would fall between 120 and 150
- If we repeated the experiment, 95% of the CIs would contain the true value of X

https://pollev.com/franciscorod726

If the 95% CI of X is (120, 150)...

- There is a 95% probability that X lies between 120 and 150
- We can be 95% confident that X lies between 120 and 150
- If we repeated the experiment, 95% of the time X would fall between 120 and 150
- If we repeated the experiment, 95% of the CIs would contain the true value of X
- The probability that X is greater than 0 is at least 95%

https://pollev.com/franciscorod726

If the 95% CI of X is (120, 150)...

- There is a 95% probability that X lies between 120 and 150
- We can be 95% confident that X lies between 120 and 150
- If we repeated the experiment, 95% of the time X would fall between 120 and 150
- If we repeated the experiment, 95% of the CIs would contain the true value of X
- The probability that X is greater than 0 is at least 95%
- The probability that X equals 0 is smaller than 5%

https://pollev.com/franciscorod726

Understanding confidence intervals

- Summarise *uncertainty* in parameter estimates.

Understanding confidence intervals

- Summarise *uncertainty* in parameter estimates.
- http://rpsychologist.com/d3/CI/ (or here)

Understanding confidence intervals

- Summarise *uncertainty* in parameter estimates.
- http://rpsychologist.com/d3/CI/ (or here)
- A 95% CI is **NOT** 95% likely to contain the true parameter value!

Understanding confidence intervals

- Summarise *uncertainty* in parameter estimates.
- http://rpsychologist.com/d3/CI/ (or here)
- A 95% CI is **NOT** 95% likely to contain the true parameter value!
- Instead, 95% of the CIs obtained with this sampling will contain the true value.

Understanding confidence intervals

- Summarise *uncertainty* in parameter estimates.
- http://rpsychologist.com/d3/CI/ (or here)
- A 95% CI is **NOT** 95% likely to contain the true parameter value!
- Instead, 95% of the CIs obtained with this sampling will contain the true value.
- Like person who tells truth 95% of the time, but we can't tell if a particular statement is true.

Understanding confidence intervals

- Summarise *uncertainty* in parameter estimates.
- http://rpsychologist.com/d3/CI/ (or here)
- A 95% CI is **NOT** 95% likely to contain the true parameter value!
- Instead, 95% of the CIs obtained with this sampling will contain the true value.
- Like person who tells truth 95% of the time, but we can't tell if a particular statement is true.
- It's a frequentist, long-run property.

Understanding confidence intervals

- Summarise *uncertainty* in parameter estimates.
- http://rpsychologist.com/d3/CI/ (or here)
- A 95% CI is **NOT** 95% likely to contain the true parameter value!
- Instead, 95% of the CIs obtained with this sampling will contain the true value.
- Like person who tells truth 95% of the time, but we can't tell if a particular statement is true.
- It's a frequentist, long-run property.
- To read more: Morey et al (2015)

What happens if we increase sample size?

- CI width *decreases*...

What happens if we increase sample size?

- CI width *decreases*. . .
- but still 5% of CIs will NOT contain true mean!

Bayesian credible intervals

- Bayesian **credible** intervals do give the probability that true parameter value is contained within them.

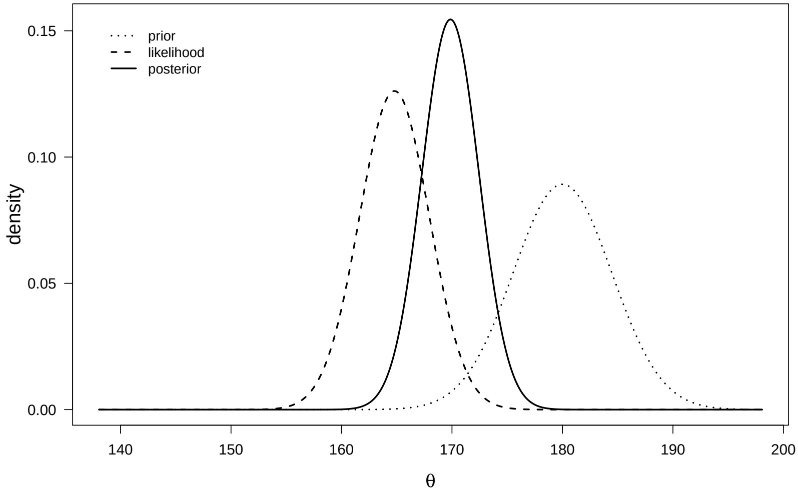
Bayesian credible intervals

- Bayesian **credible** intervals do give the probability that true parameter value is contained within them.
- Frequentist CIs and Bayesian credible intervals can be similar, but not always.

Bayesian inference: prior, posterior, and likelihood

$$P(H|D) \propto P(D|H) x P(H)$$

$$Posterior \propto Likelihood x Prior$$



More apps to introduce Bayesian inference

- Normal

More apps to introduce Bayesian inference

- Normal
- Binomial

More apps to introduce Bayesian inference

- Normal
- Binomial
- Own data

More apps to introduce Bayesian inference

- Normal
- Binomial
- Own data
- Bayesian t-test

Experimental Design

How would you evaluate fertilizer effect?

Discuss with partner (5')

Figure 6:

Replication!

Figure 7:

Replication

- Replication is key: we need several samples.

Replication

- Replication is key: we need several samples.
- How many? As much as you can! See Gelman & Carlin 2014.

Replication

- Replication is key: we need several samples.
- How many? As much as you can! See Gelman & Carlin 2014.
- Traditionally, ecology studies have had too low sample sizes.

Replication

- Replication is key: we need several samples.
- How many? As much as you can! See Gelman & Carlin 2014.
- Traditionally, ecology studies have had too low sample sizes.
- Hence missing many subtle effects, and prone to bias.

Replication

- Replication is key: we need several samples.
- How many? As much as you can! See Gelman & Carlin 2014.
- Traditionally, ecology studies have had too low sample sizes.
- Hence missing many subtle effects, and prone to bias.
- Complex models (w/ many predictors, interactions etc) require **high** sample sizes.

Sample size is very important

See *The evolution of correlations*

Stopping rules:

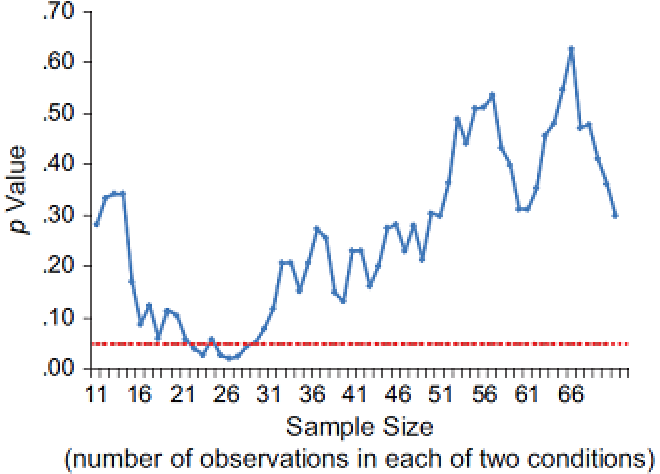


Fig. 2. Illustrative simulation of *p* values obtained by a researcher who continuously adds an observation to each of two conditions, conducting a *t* test after each addition. The dotted line highlights the conventional

Randomization

Figure 9:

Randomization

- Haphazard $\neq$ Random

Randomization

- Haphazard $\neq$ Random
- Stratify: randomize within groups (e.g. species, soil types)

Have controls

- Untreated individuals, plots... (assigned randomly, of course).

Have controls

- Untreated individuals, plots... (assigned randomly, of course).
- Must differ only in treatment (i.e. homogeneous environment).

Have controls

- Untreated individuals, plots... (assigned randomly, of course).
- Must differ only in treatment (i.e. homogeneous environment).
- Measure before & after treatment.

Have controls

- Untreated individuals, plots... (assigned randomly, of course).
- Must differ only in treatment (i.e. homogeneous environment).
- Measure before & after treatment.
- Consider blind designs to avoid observer bias.

To read more

- Ruxton & Colegrave. Experimental Design for the Life Sciences. OUP

Hypothesis testing

Does height differ between local and foreign students?

- Local people heigths:

```
171 168 182 164 160

   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
    160     164     168     169     171     182
```

```
177 172 195 174 173 182 163 169 170 180

   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  163.0   170.5   173.5   175.5   179.2   195.0
```

Does height differ between local and foreign students?

- Local people heigths:

```
171 168 182 164 160

   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
    160     164     168     169     171     182
```

- Other heights:

```
177 172 195 174 173 182 163 169 170 180

   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  163.0   170.5   173.5   175.5   179.2   195.0
```

Does height differ between local and foreign students?

- Local people heigths:

```
171 168 182 164 160

   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
    160     164     168     169     171     182
```

- Other heights:

```
177 172 195 174 173 182 163 169 170 180

   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  163.0   170.5   173.5   175.5   179.2   195.0
```

- We know what happens in **our samples**, but want to extrapolate to the whole **population**.

If we sample students' heights in this class...

- Can we extrapolate results to

If we sample students' heights in this class...

- Can we extrapolate results to
  - this class?

If we sample students' heights in this class...

- Can we extrapolate results to
  - this class?
  - this university?

If we sample students' heights in this class. . .

- Can we extrapolate results to
  - this class?
  - this university?
  - this city?

If we sample students' heights in this class...

- Can we extrapolate results to
  - this class?
  - this university?
  - this city?
  - the world?

If we sample students' heights in this class. . .

- Can we extrapolate results to
  - this class?
  - this university?
  - this city?
  - the world?
- What's the **suitable population** to make inferences given this sample?

NHST concepts

Null and alternative hypotheses

- Tell me. . .

Null and alternative hypotheses

- Tell me. . .
- **Null hypothesis**: there is no difference between groups.

Null and alternative hypotheses

- Tell me...
- **Null hypothesis**: there is no difference between groups.
- **Alternative hypothesis**: groups are different.

P value

- Tell me...

P value

- Tell me. . .
- Very complicated concept: even statisticians fail to describe it well.

P value

- Tell me...
- Very complicated concept: even statisticians fail to describe it well.
- Probability of observing data as or more extreme than these *if H0 was true*.

P value

- Tell me...
- Very complicated concept: even statisticians fail to describe it well.
- Probability of observing data as or more extreme than these *if H0 was true*.
- Low P-value: data unlikely if H0 was true.

P value

- Tell me. . .
- Very complicated concept: even statisticians fail to describe it well.
- Probability of observing data as or more extreme than these *if H0 was true*.
- Low P-value: data unlikely if H0 was true.
- Large P-value: data not unusual if H0 was true.

Are differences *significant*?

- If $p < 0.05$, we **reject** H0.

Are differences *significant*?

- If $p < 0.05$, we **reject** H0.
- If $p > 0.05$, we **fail to reject** H0

Are differences *significant*?

- If $p < 0.05$, we **reject** H0.
- If $p > 0.05$, we **fail to reject** H0
- (which is **NOT** the same as ‘H0 is true’)

Are differences *significant*?

- If $p < 0.05$, we **reject** H0.
- If $p > 0.05$, we **fail to reject** H0
- (which is **NOT** the same as 'H0 is true')
- **CAUTION:**

Are differences *significant*?

- If $p < 0.05$, we **reject** H0.
- If $p > 0.05$, we **fail to reject** H0
- (which is **NOT** the same as 'H0 is true')
- **CAUTION:**
- This is **very widespread, but incorrect** practice.

Are differences *significant*?

- If $p < 0.05$, we **reject** H0.
- If $p > 0.05$, we **fail to reject** H0
- (which is **NOT** the same as 'H0 is true')
- **CAUTION:**
- This is **very widespread, but incorrect** practice.
- P-value is continuous. We must **avoid binary decisions** based on **arbitrary thresholds**.

Are differences *significant*?

- If $p < 0.05$, we **reject** H0.
- If $p > 0.05$, we **fail to reject** H0
- (which is **NOT** the same as 'H0 is true')
- **CAUTION:**
- This is **very widespread, but incorrect** practice.
- P-value is continuous. We must **avoid binary decisions** based on **arbitrary thresholds**.
- More on this later.

Let's do the test

```r
t.test(h.sevi, h.out)
```

```

    Welch Two Sample t-test

data:  h.sevi and h.out
t = -0.20558, df = 6.346, p-value = 0.8436
alternative hypothesis: true difference in means is not equal to
95 percent confidence interval:
 -14.0216  11.8216
sample estimates:
mean of x mean of y 
    172.2     173.3 
```

Are heights different then?

Rejecting hypotheses: two types of error

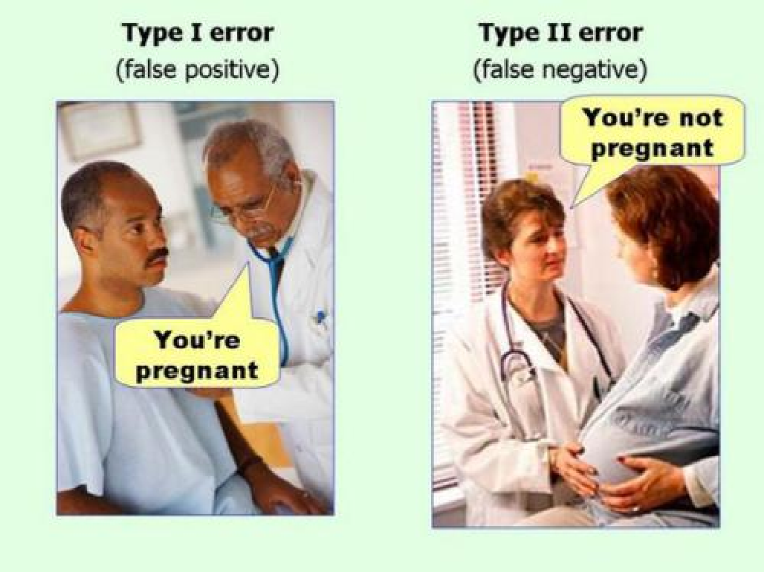


Figure 10:

Rejecting hypotheses: two types of error

Statistics: Hypothesis Test	Null Hypothesis is True	Null Hypothesis is False
Reject Null Hypothesis	Type I Error	Correct
Fail to Reject Null Hypothesis	Correct	Type II Error

Figure 11:

Understanding NHST

http://rpsychologist.com/d3/NHST/

Example: biased coin

```
 [1] 0 1 1 1 0 1 1 0 1 0

	1-sample proportions test with continuity correction

data:  sum(coin) out of ntrials, null probability 0.5
X-squared = 0.1, df = 1, p-value = 0.7518
alternative hypothesis: true p is not equal to 0.5
95 percent confidence interval:
 0.2736697 0.8630694
sample estimates:
  p
0.6
```

Correlation between variables

http://rpsychologist.com/d3/correlation/

Common pitfalls and good practice

A must read

Eur J Epidemiol (2016) 31:337–350
DOI 10.1007/s10654-016-0149-3

CrossMark

ESSAY

Statistical tests, *P* values, confidence intervals, and power: a guide to misinterpretations

Sander Greenland[1] · Stephen J. Senn[2] · Kenneth J. Rothman[3] · John B. Carlin[4] · Charles Poole[5] · Steven N. Goodman[6] · Douglas G. Altman[7]

https://doi.org/10.1007/s10654-016-0149-3

Good reading

esa ECOSPHERE

Applied statistics in ecology:
common pitfalls and simple solutions

E. Ashley Steel,[1,†] Maureen C. Kennedy,[2] Patrick G. Cunningham,[3] and John S. Stanovick[4]

Figure 12:

http://dx.doi.org/10.1890/ES13-00160.1
Also http://www.statisticsdonewrong.com/

First things first

- Always

First things first

- Always
- Always

First things first

- Always
- Always
- Always

Plot data and models

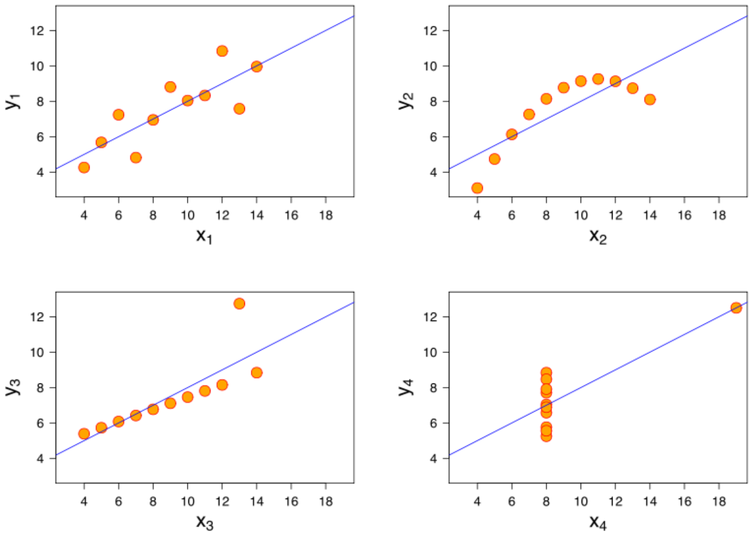
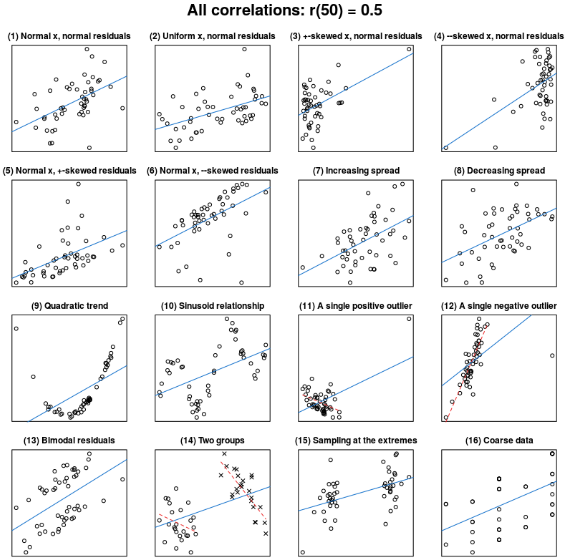


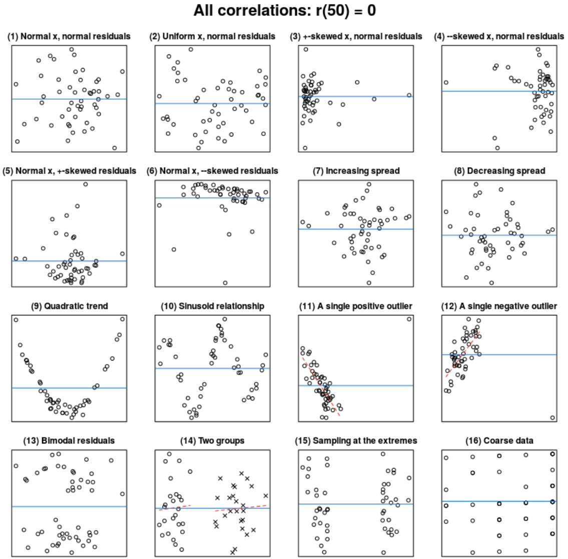
Figure 13:

Don't use statistics blindly: *Visualise*



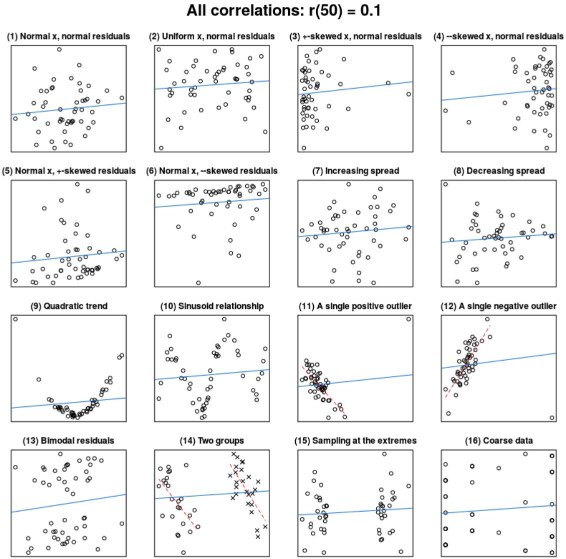
https://ianhove.github.io/teaching/2016/11/21/what-correlations-look-like

Don't use statistics blindly: *Visualise*



https://janhove.github.io/teaching/2016/11/21/what-correlations-look-like

Don’t use statistics blindly: *Visualise*



https://ianhove.github.io/teaching/2016/11/21/what-correlations-look-like

Plot. Check models. Plot. Check assumptions. Plot.

Lavine 2014 *Ecology*

News: Hamburgers increase risk of heart attack

- In a sample of 10,000 people, it was found that people eating >2 hamburgers a week had 20% higher probability of heart attack.

News: Hamburgers increase risk of heart attack

- In a sample of 10,000 people, it was found that people eating >2 hamburgers a week had 20% higher probability of heart attack.
- **Do hamburgers increase heart attacks?**

News: Hamburgers increase risk of heart attack

- In a sample of 10,000 people, it was found that people eating >2 hamburgers a week had 20% higher probability of heart attack.
- **Do hamburgers increase heart attacks?**
- https://pollev.com/franciscorod726

Bigger flowers increase reproductive success

- We found that plants with big flowers produced 30% more seeds...

Bigger flowers increase reproductive success

- We found that plants with big flowers produced 30% more seeds...
- **Do big flowers increase reproductive success?**

Bigger flowers increase reproductive success

- We found that plants with big flowers produced 30% more seeds...
- **Do big flowers increase reproductive success?**
- https://pollev.com/franciscorod726

Correlation vs Causation

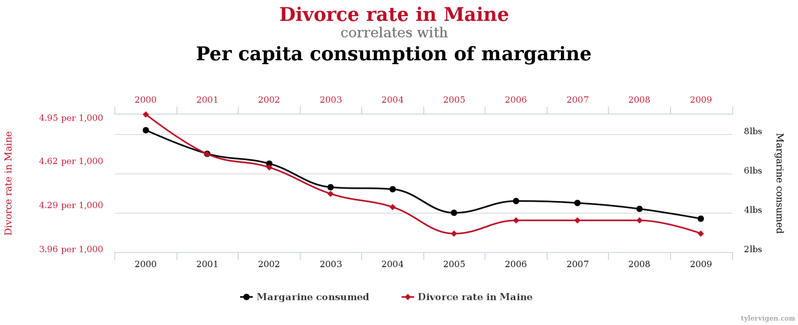
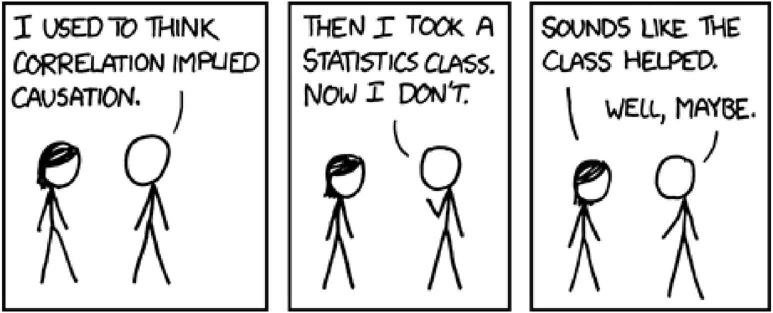


Figure 14:

http://tylervigen.com/spurious-correlations

Learning statistics through xkcd



P-value depends on sample size

- Same real difference is detected as significant or not depending on sample size:

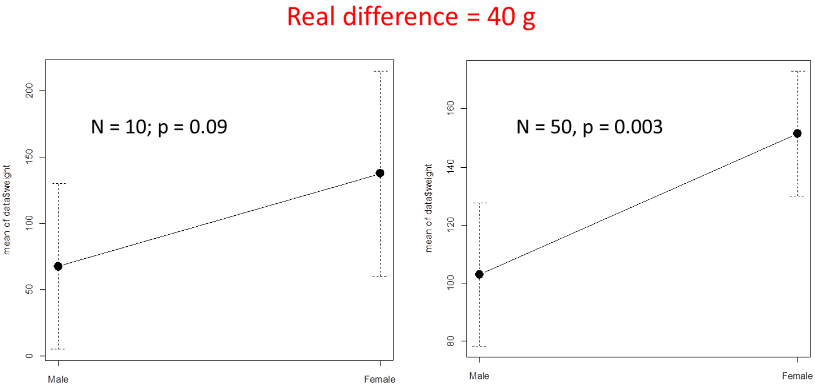
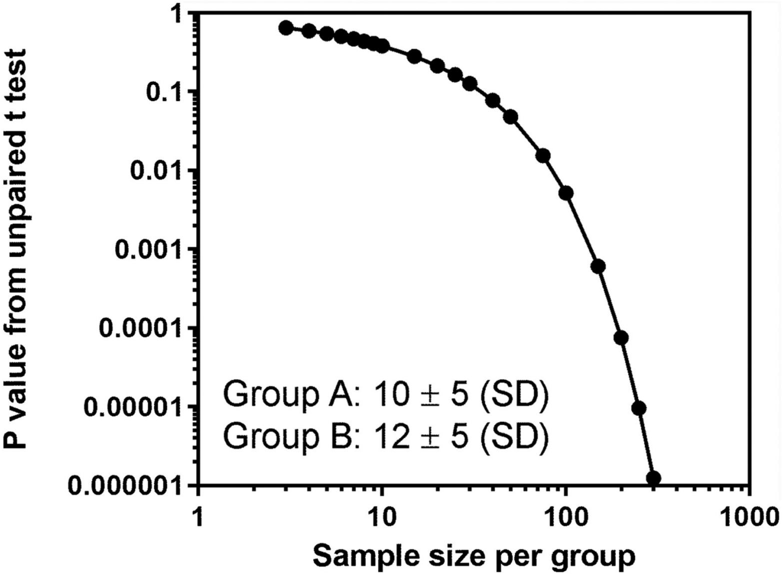


Figure 15:

P-value depends on sample size

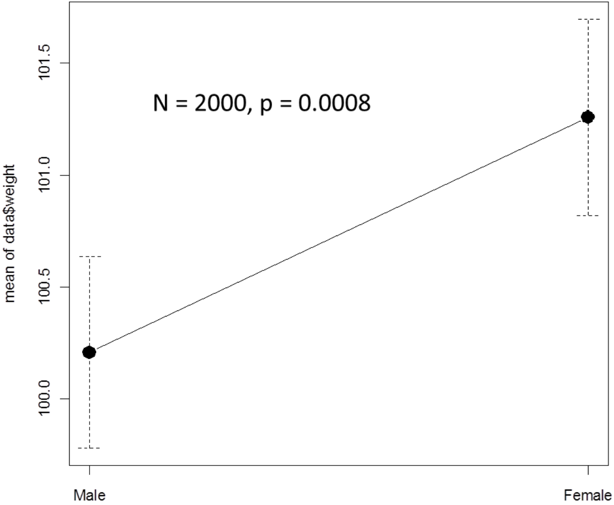


http://dx.doi.org/10.1002/prp2.93

Statistically significant != biologically important

- With big sample size, we can find **highly significant but biologically unimportant** differences.

Real difference = 1 g



Statistically significant != biologically important

- Statistically significant = unlikely to be zero

Statistically significant != biologically important

- Statistically significant = unlikely to be zero
- Suggestion: Try to avoid ‘significant’ all together

Statistically significant != biologically important

- Statistically significant = unlikely to be zero
- Suggestion: Try to avoid 'significant' all together
- Suggested reading: *significantly misleading*

Statistically significant != biologically important

- Statistically significant = unlikely to be zero
- Suggestion: Try to avoid ‘significant’ all together
- Suggested reading: *significantly misleading*
- Beyond significance, look at *effect sizes*.

‘Not significant’ does NOT mean ‘there is no effect’

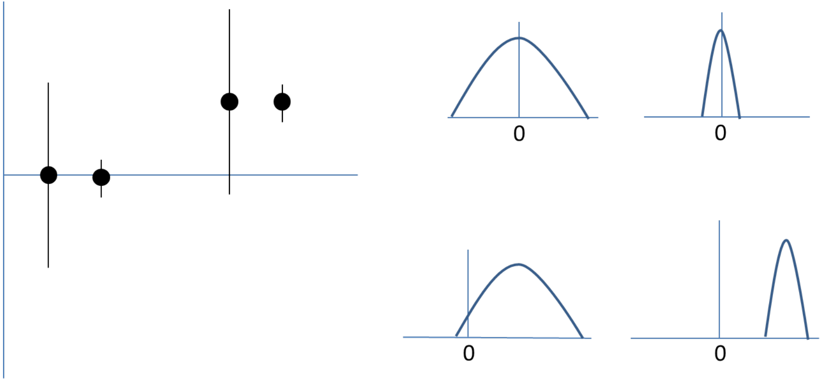


Figure 17:

- **Absence of evidence != Evidence of absence**

Failure to reject H0 != H0 is true

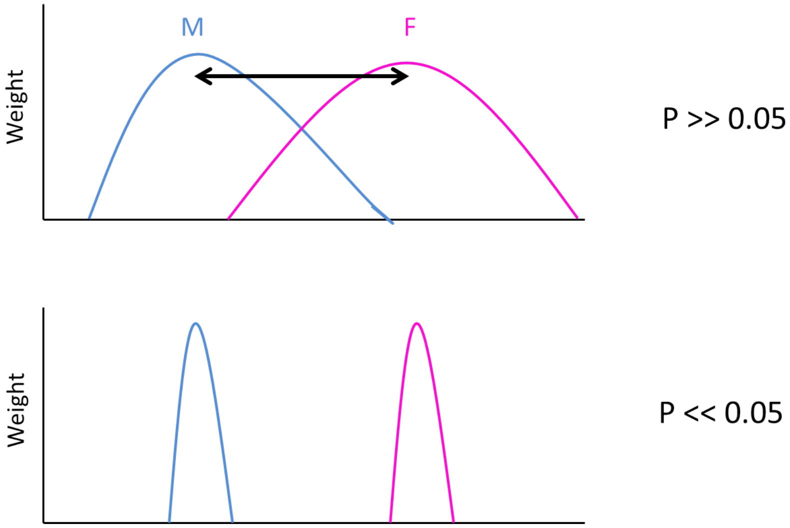


Figure 18:

0.05 is an arbitrary threshold

The Difference Between "Significant" and "Not Significant" is not Itself Statistically Significant

Andrew GELMAN and Hal STERN

Figure 19:

http://dx.doi.org/10.1198/000313006X152649

Multiple hypothesis testing

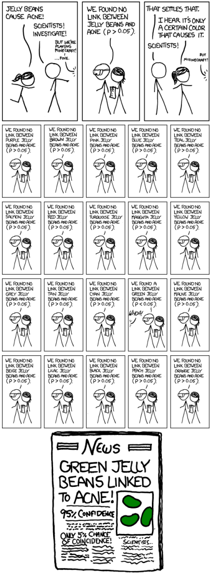
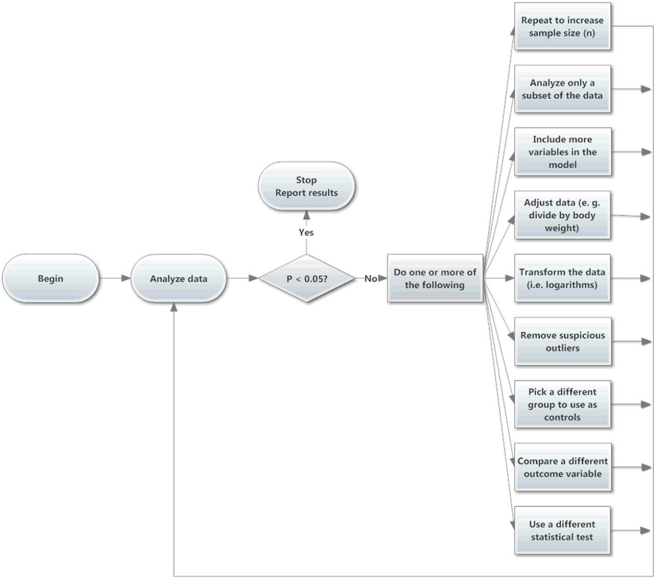


Figure 20:

How to make your results significant: *p-hacking*



http://dx.doi.org/10.1002/prp2.93

How to make your results significant: *p-hacking*

1. Test multiple variables, then report the ones that are significant.

How to make your results significant: *p-hacking*

1. Test multiple variables, then report the ones that are significant.
2. Artificially choose when to end your experiment.

How to make your results significant: *p-hacking*

1. Test multiple variables, then report the ones that are significant.
2. Artificially choose when to end your experiment.
3. Add covariates until effects are significant.

How to make your results significant: *p-hacking*

1. Test multiple variables, then report the ones that are significant.
2. Artificially choose when to end your experiment.
3. Add covariates until effects are significant.
4. Test different conditions (e.g. different levels of a factor) and report the ones you like.

How to make your results significant: *p-hacking*

1. Test multiple variables, then report the ones that are significant.
2. Artificially choose when to end your experiment.
3. Add covariates until effects are significant.
4. Test different conditions (e.g. different levels of a factor) and report the ones you like.

- To read more: Simmons et al 2011

How to make your results significant: *p-hacking*

https://www.youtube.com/watch?v=ZaNtz76dNSI

ASA statement on p-values

- P-values do not measure the **probability of hypothesis** being true, or the probability that the data were produced by **random chance** alone.

https://doi.org/10.1080/00031305.2016.1154108

ASA statement on p-values

- P-values do not measure the **probability of hypothesis** being true, or the probability that the data were produced by **random chance** alone.
- Scientific conclusions or policy decisions should NOT be based only on **whether a p-value passes a specific threshold**.

https://doi.org/10.1080/00031305.2016.1154108

ASA statement on p-values

- P-values do not measure the **probability of hypothesis** being true, or the probability that the data were produced by **random chance** alone.
- Scientific conclusions or policy decisions should NOT be based only on **whether a p-value passes a specific threshold**.
- P-value, or statistical significance, does not measure the **size of an effect** or the **importance** of a result.

https://doi.org/10.1080/00031305.2016.1154108

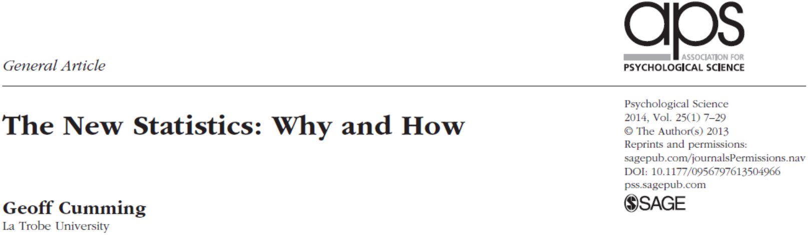
ASA statement on p-values

- P-values do not measure the **probability of hypothesis** being true, or the probability that the data were produced by **random chance** alone.
- Scientific conclusions or policy decisions should NOT be based only on **whether a p-value passes a specific threshold**.
- P-value, or statistical significance, does not measure the **size of an effect** or the **importance** of a result.
- By itself, a p-value does NOT provide a good **measure of evidence** regarding a model or hypothesis.

https://doi.org/10.1080/00031305.2016.1154108

The New Statistics

Aim for estimation of effects and their uncertainty.


General Article

The New Statistics: Why and How

Geoff Cumming
La Trobe University

Psychological Science
2014, Vol. 25(1) 7–29
© The Author(s) 2013
Reprints and permissions:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/0956797613504966
pss.sagepub.com

Figure 21:

http://dx.doi.org/10.1177/0956797613504966

How many types of errors?

- **Type I**: False positive (incorrect rejection of null hypothesis).

How many types of errors?

- **Type I**: False positive (incorrect rejection of null hypothesis).
- **Type II**: False negative (failure to reject false null hypothesis).

How many types of errors?

- **Type I**: False positive (incorrect rejection of null hypothesis).
- **Type II**: False negative (failure to reject false null hypothesis).
- **Type S (Sign)**: estimating effect in opposite direction.

How many types of errors?

- **Type I**: False positive (incorrect rejection of null hypothesis).
- **Type II**: False negative (failure to reject false null hypothesis).
- **Type S (Sign)**: estimating effect in opposite direction.
- **Type M (Magnitude)**: Misestimating magnitude of the effect (under or overestimating).

How many types of errors?

- **Type I**: False positive (incorrect rejection of null hypothesis).
- **Type II**: False negative (failure to reject false null hypothesis).
- **Type S (Sign)**: estimating effect in opposite direction.
- **Type M (Magnitude)**: Misestimating magnitude of the effect (under or overestimating).
- Beyond Power Calculations: Assessing Type S (Sign) and Type M (Magnitude) Errors

END

Figure 22:

Source code and materials: https://github.com/Pakillo/stats-intro