

An introduction to statistical inference

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http://bit.ly/frod_san

Why statistics?

To answer questions like...

- ▶ what's the probability that something occurs?

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- ▶ does X influence Y? How much?

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- ▶ what's the probability that something occurs?
- ▶ does X influence Y? How much?
- ▶ can we predict Y knowing X, Z... How well?

To ensure correct inferences



Inference



Bolker et al 2009 TREE

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

To get answers to tough problems

For example...

How many seeds do trees produce?



A. torrenegra

Inferring tree fecundity



Course goals

- ▶ **Understand** statistical inference

Course goals

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- ▶ 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

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- ▶ Graphics

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- ▶ Graphics
- ▶ Sampling

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- ▶ Experimental design

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- ▶ Hypothesis testing

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- ▶ Bayesian inference
- ▶ Linear models & GLMs

Topics

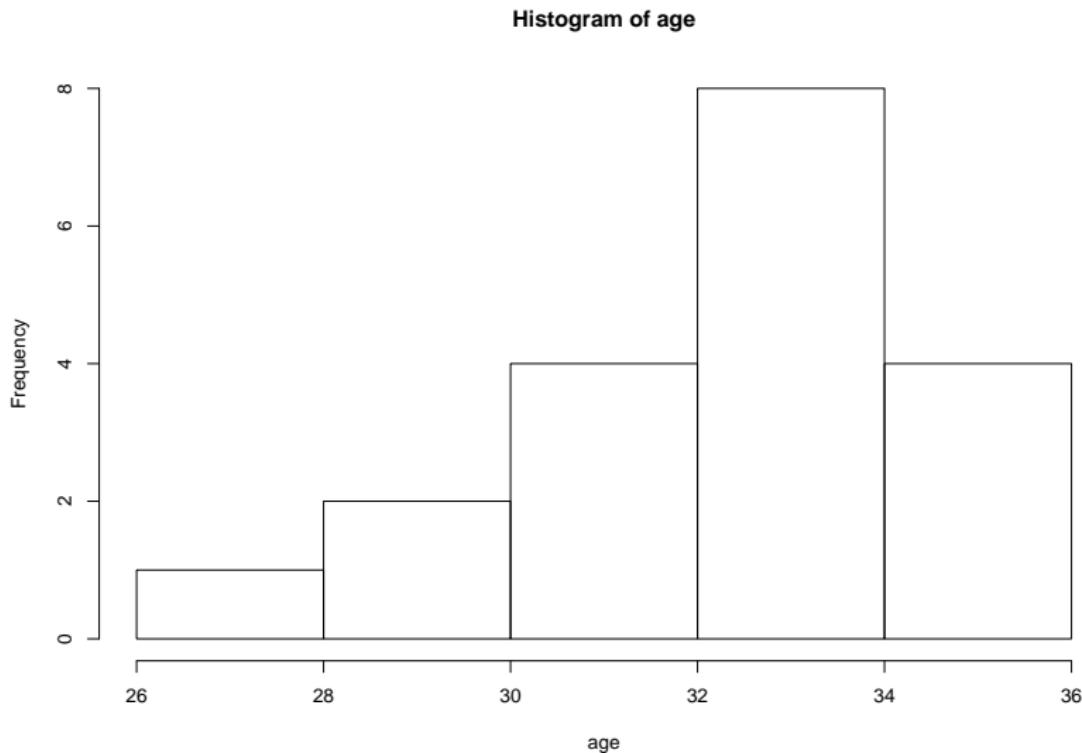
- ▶ Descriptive statistics
- ▶ Graphics
- ▶ Sampling
- ▶ Experimental design
- ▶ Hypothesis testing
- ▶ Bayesian inference
- ▶ Linear models & GLMs
- ▶ Model selection

Descriptive statistics

Guess my age

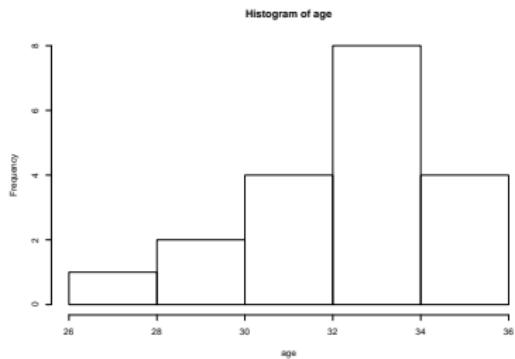
Graph your estimates

```
hist(age)
```



Do you think these data are good estimates of my age?

<https://pollev.com/franciscorod726>



Why / Why not?

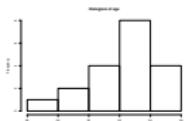
Data are hardly ever objective.

We decide **what to measure, when, where, and how.**

Always consider:

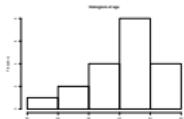
How well do these numbers reflect what we are trying to measure?

Summarise that distribution



- ▶ Central tendency / location

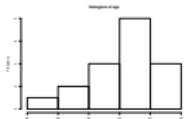
Summarise that distribution



- ▶ **Central tendency / location**

- ▶ mean:
$$\frac{a_1 + a_2 + a_3}{n}$$

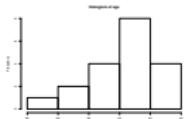
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► Central tendency / location

- mean: $\frac{a_1 + a_2 + a_3}{n}$
- median (50% percentile)

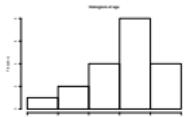
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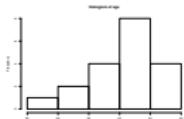


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- ▶ **Variation / Spread**

Summarise that distribution



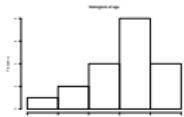
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- ▶ min, max, range

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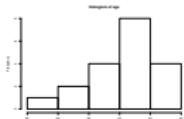
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- min, max, range
- quantiles (quartiles, percentiles. . .)

Summarise that distribution



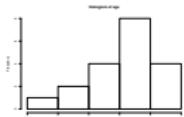
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Summarise that distribution



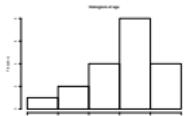
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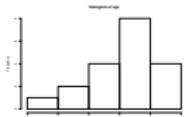
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- coefficient of variation (CV = SD / mean)

Summarise that distribution



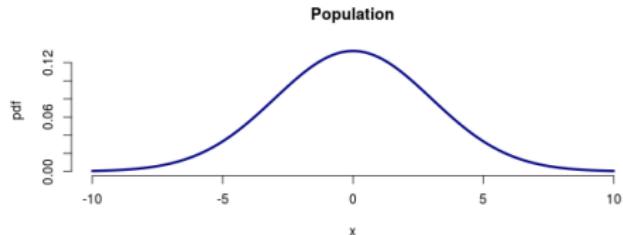
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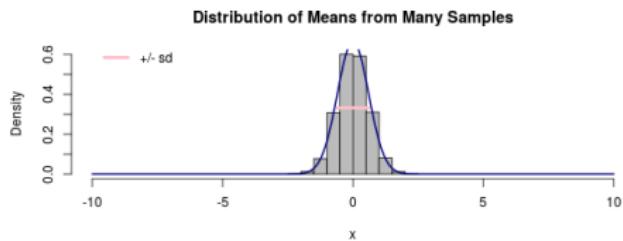
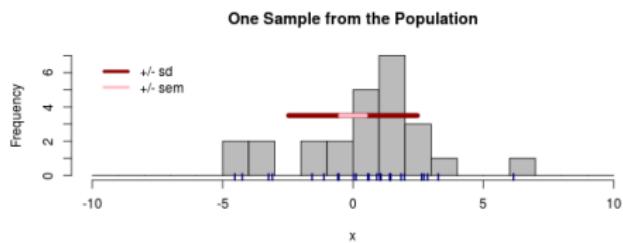
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- standard deviation: $SD = \sqrt{\frac{\sum (x - \mu)^2}{n - 1}}$
- standard error: $SEM = \frac{SD}{\sqrt{n}}$
- coefficient of variation ($CV = SD / \text{mean}$)
- confidence intervals

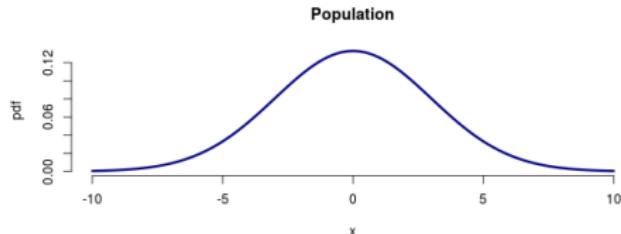
Relationship between SD and SEM



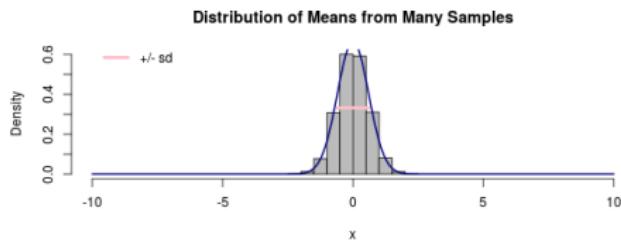
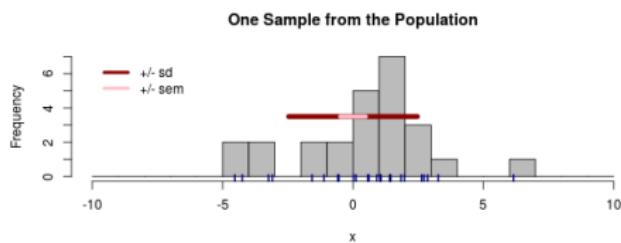
► SD quantifies scatter in population



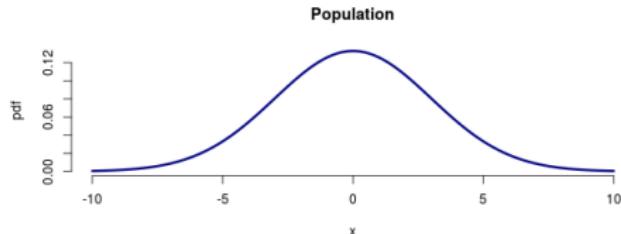
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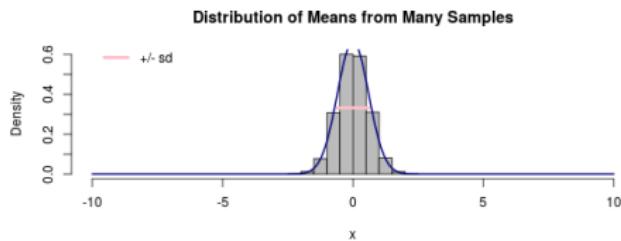
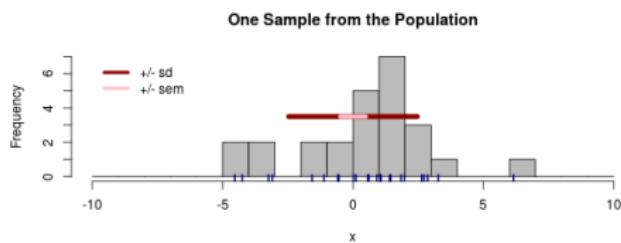
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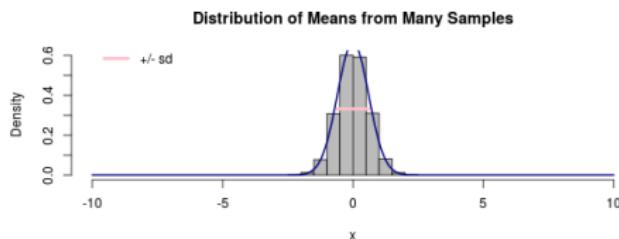
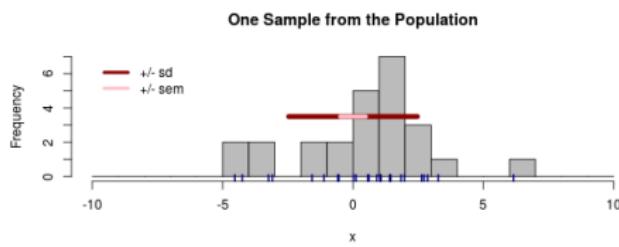
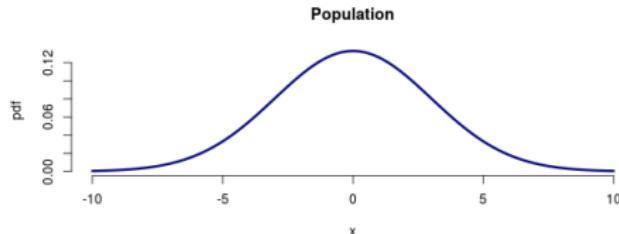
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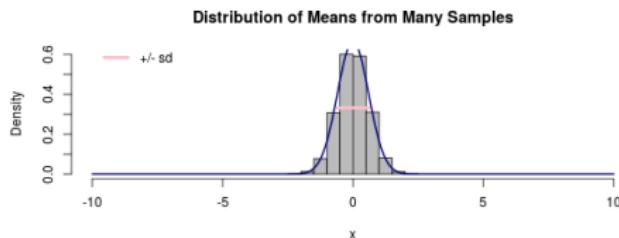
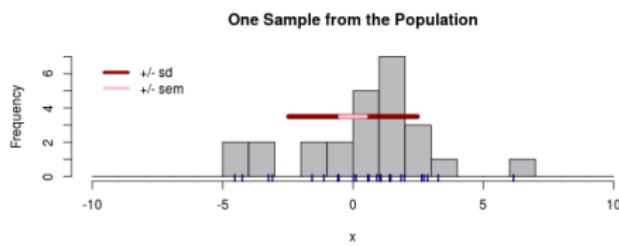
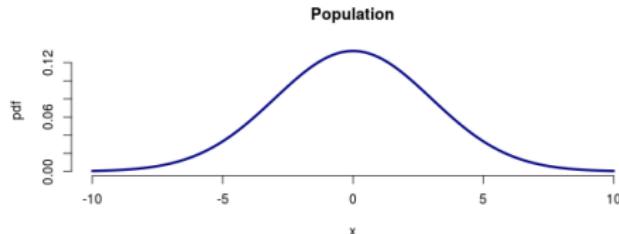


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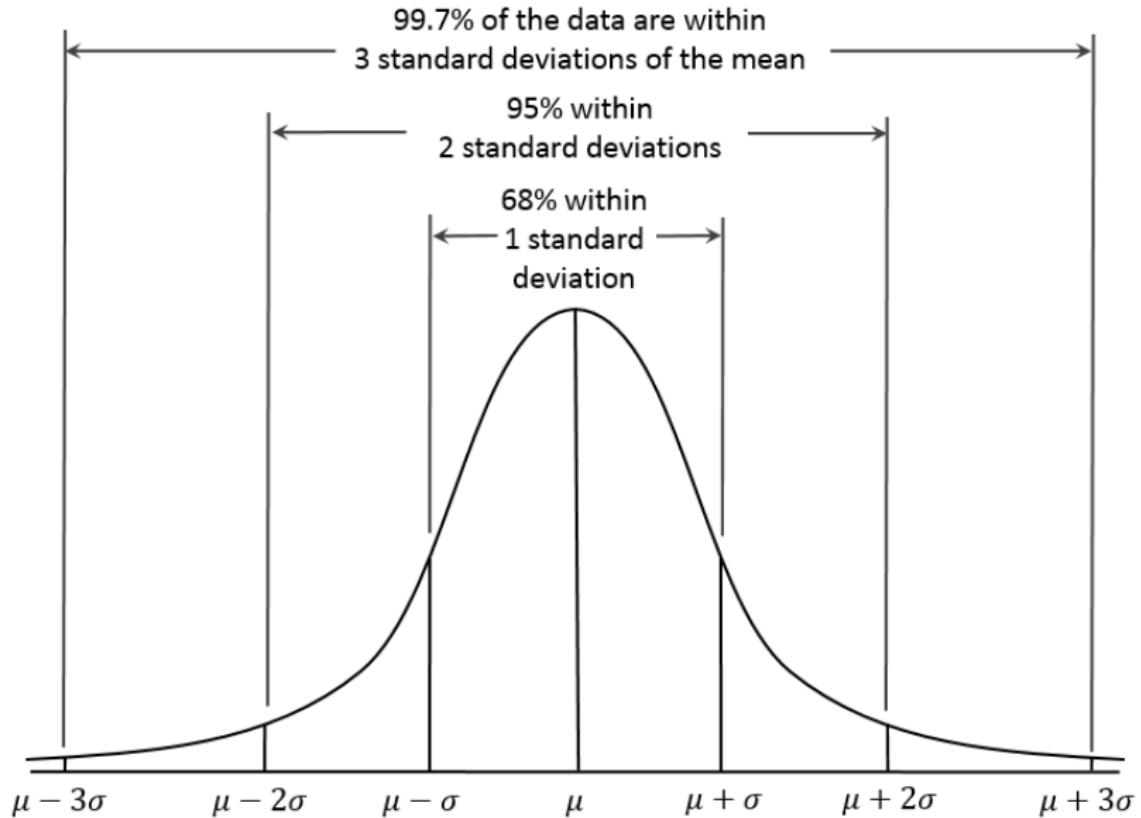
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Relationship between SD and SEM



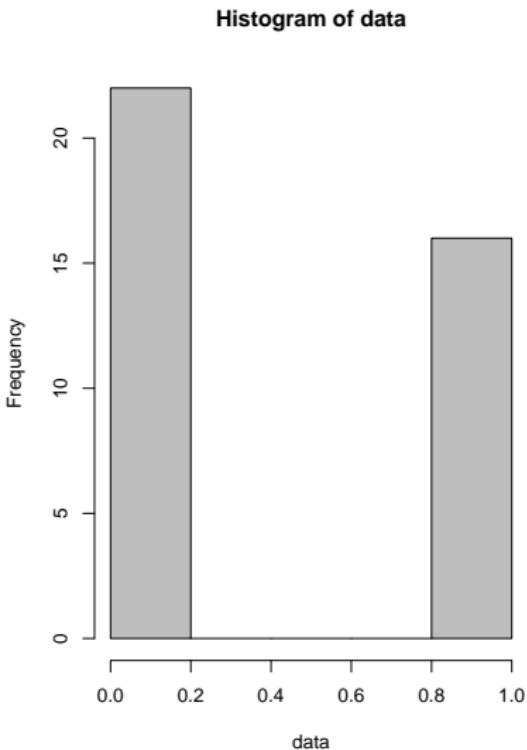
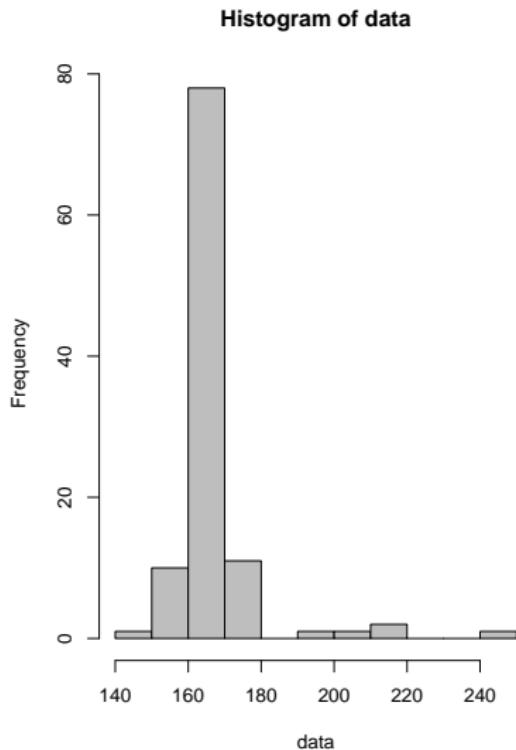
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- ▶ https://gallery.shinyapps.io/sampling_and_stderr/

In a Normal distribution



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.



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5. Do all CIs contain true mean height?

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

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- ▶ 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%

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Understanding confidence intervals

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- ▶ It's a frequentist, long-run property.
- ▶ To read more: Morey et al (2015)

What happens if we increase sample size?

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- ▶ CI width *decreases* . . .

What happens if we increase sample size?

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- ▶ 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.

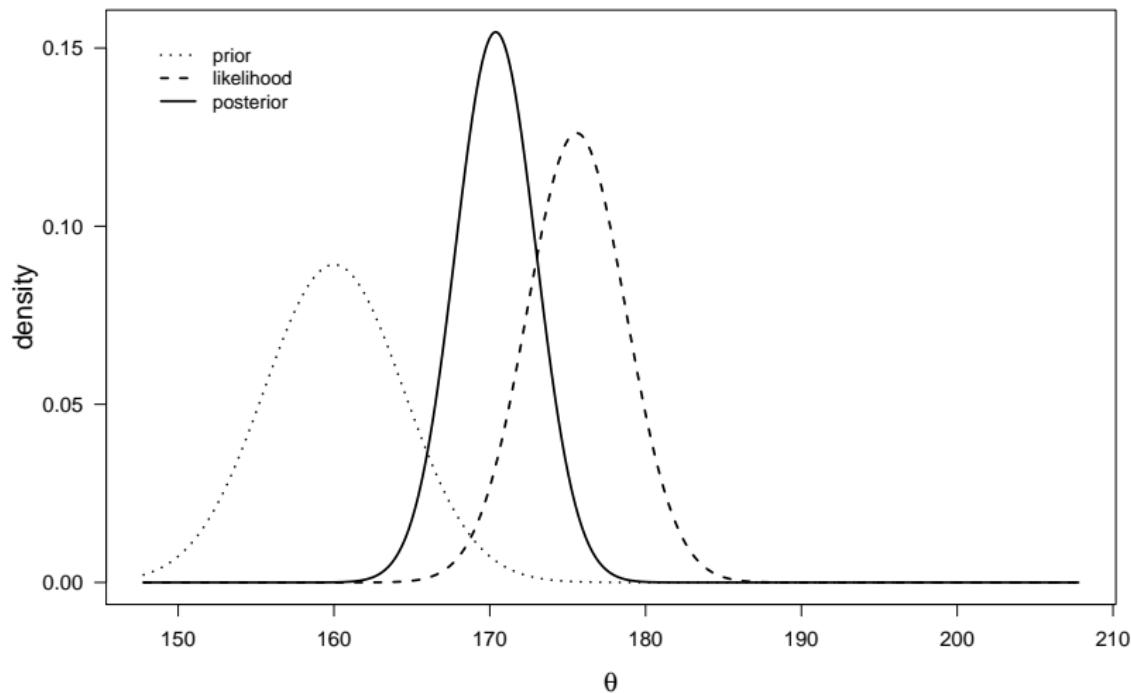
Bayesian credible intervals

- ▶ 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

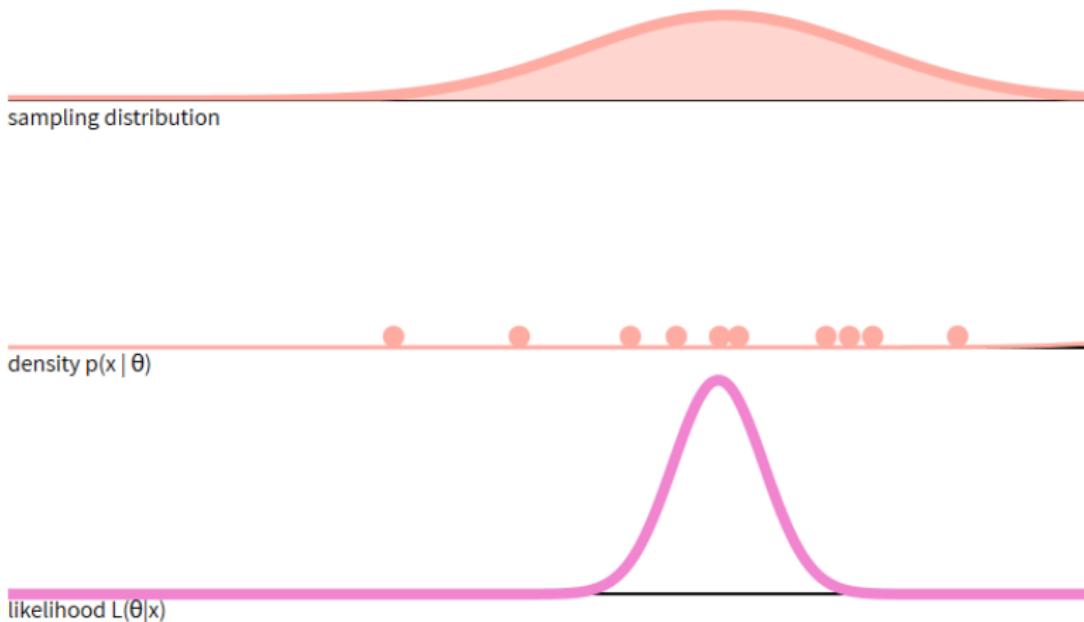
$$P(H|D) \propto P(D|H) \times P(H)$$

$$\text{Posterior} \propto \text{Likelihood} \cdot \text{Prior}$$



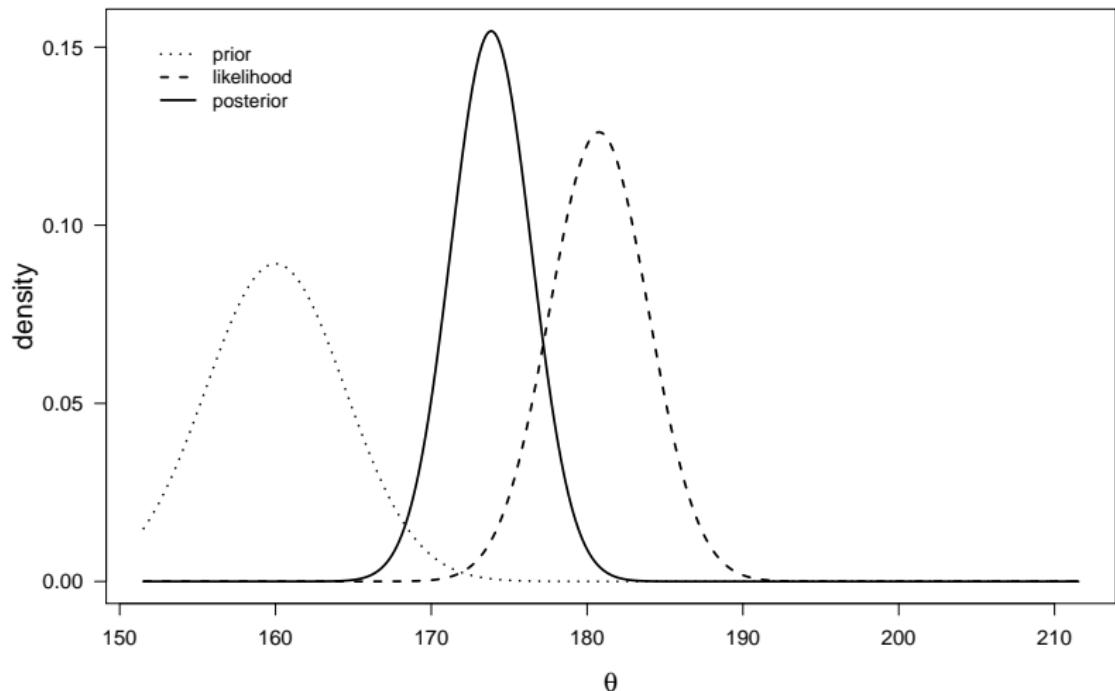
What is the likelihood?

$$L(\theta|x) = P(x|\theta)$$



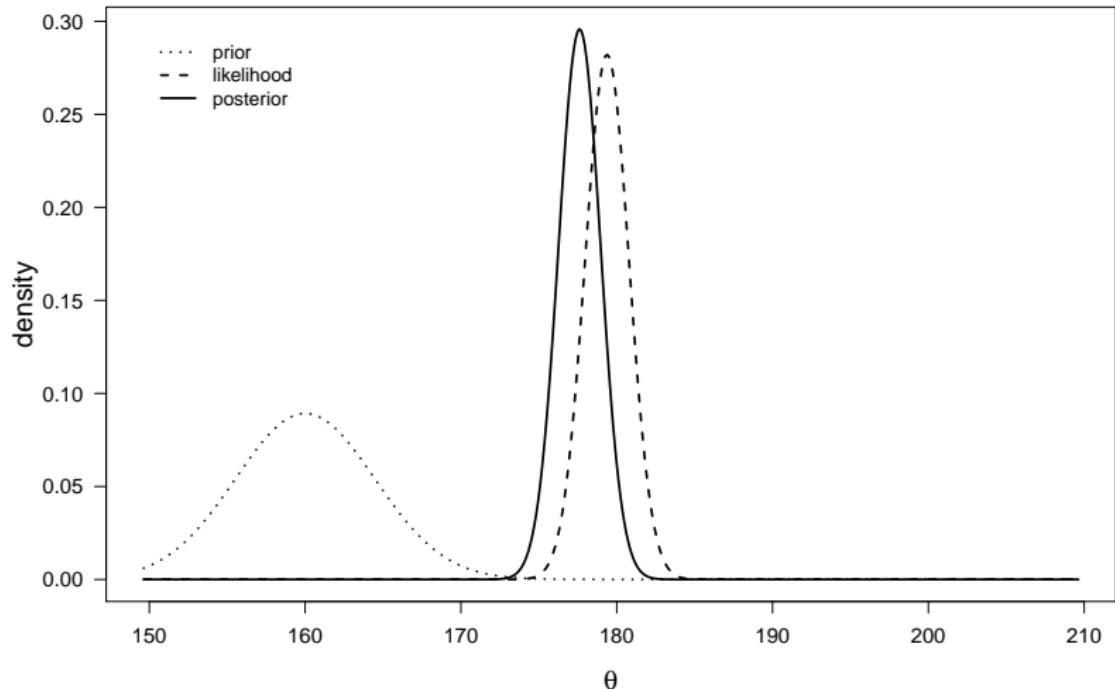
<https://seeing-theory.brown.edu/bayesian-inference/index.html>

Bayesian inference: prior and likelihood produce posterior



\$posterior.mean

With increasing sample size, likelihood dominates prior



\$posterior.mean

More apps to introduce Bayesian inference

- ▶ Bayesian Demo

More apps to introduce Bayesian inference

- ▶ Bayesian Demo
- ▶ Bayesian inference for a population mean

More apps to introduce Bayesian inference

- ▶ Bayesian Demo
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- ▶ Normal

More apps to introduce Bayesian inference

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- ▶ Normal
- ▶ Binomial

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More apps to introduce Bayesian inference

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- ▶ Bayesian t-test

Experimental Design

How would you evaluate fertilizer effect?

Discuss with partner (5')



Experimental design principles

Replication

Replication!



Replication

- ▶ Replication is key: we need several samples.

Replication

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- ▶ How many? As much as you can! See Gelman & Carlin 2014.

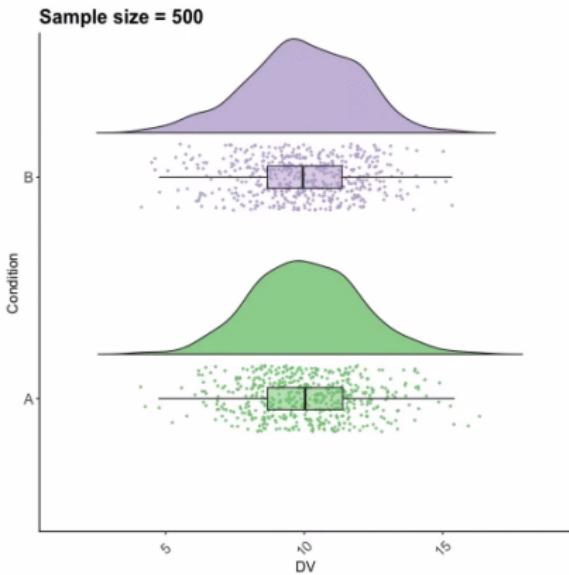
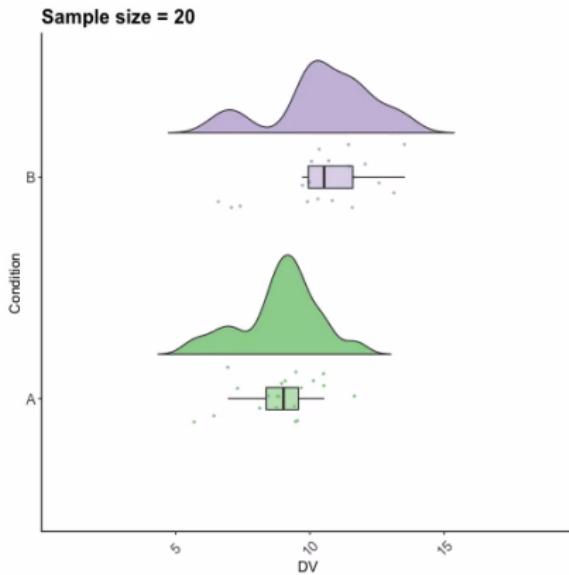
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- ▶ Traditionally, ecology studies have had **too low sample sizes**.

Replication

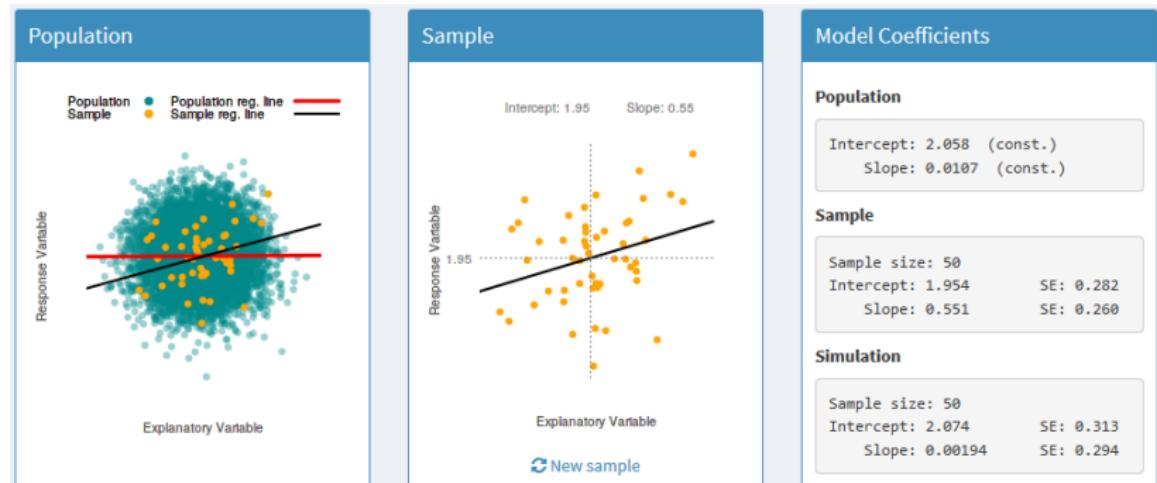
- ▶ Replication is key: we need several samples.
- ▶ How many? As much as you can! See Gelman & Carlin 2014.
- ▶ Traditionally, ecology studies have had **too low sample sizes**.
- ▶ Low sample sizes miss subtle effects, but also **prone to bias**.

Low sample sizes very sensitive to random noise



https://twitter.com/ajstewart_lang/status/1020038488278945797

Low sample sizes may bias inferences about population



<http://statisticalgate.com/regression-simulation/>

Low sample sizes may bias inferences

See *The evolution of correlations*

Stopping rules

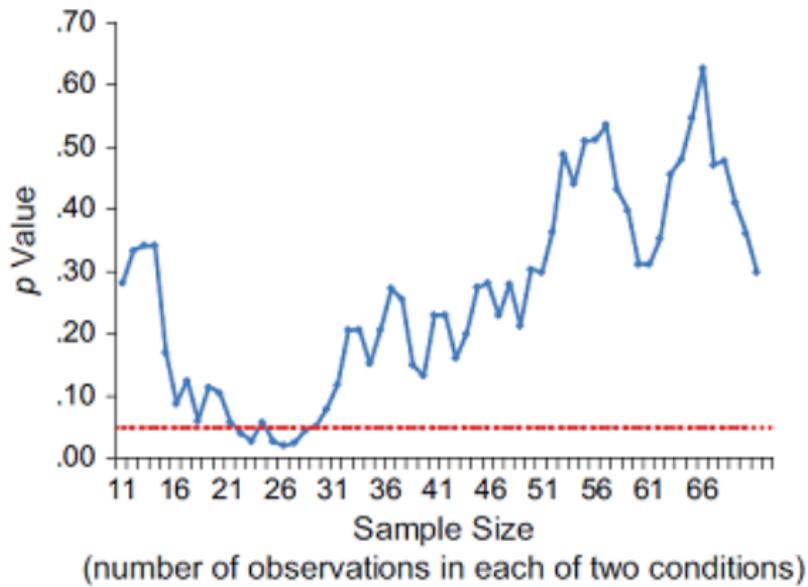


Fig. 2. Illustrative simulation of p values obtained by a researcher who continuously adds an observation to each of two conditions, conducting a t test after each addition. The dotted line highlights the conventional significance criterion of $p \leq .05$.

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- ▶ **Do simulations.** Power/Sample size/Precision analyses (e.g. this or this).
- ▶ Plan to have at least **10-30 observations per predictor.**
- ▶ Complex models (w/ many predictors, interactions etc) require **high** sample sizes.

Randomization

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Randomization

- ▶ Haphazard \neq Random

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- ▶ Stratify: randomize within groups (e.g. species, soil types)

Controls

Have controls

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

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- ▶ **Must differ only in treatment** (i.e. homogeneous environment).
- ▶ Measure **before & after** treatment.
- ▶ Consider **blind designs** to avoid observer bias.

Experimental design principles

1. Replication

Experimental design principles

1. Replication
2. Randomization

Experimental design principles

1. Replication
2. Randomization
3. Controls

To read more

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

Hypothesis testing

Does height differ between local and foreign students?

- ▶ Local people heights:

173 172 170 180 159

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
159.0	170.0	172.0	170.8	173.0	180.0

186 175 182 174 181 183 174 177 169 168

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
168.0	174.0	176.0	176.9	181.8	186.0

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Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
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- ▶ 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

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

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 - ▶ this class?
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 - ▶ 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

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- ▶ **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.

In ecology, everything is somewhat different

Are there any differences? A non-sensical question in ecology

Alejandro Martínez-Abrán

IMEDEA (CSIC-UIB), C/Miquel Marquès 21, 07190 Esporles, Majorca, Spain

ARTICLE INFO

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ABSTRACT

One of the main questions that ecologists pose in their investigations includes the analysis of differences in some trait between two or more populations. I argue here that asking whether there are differences or not between populations is biologically irrelevant, since no two living things are ever equal. On the contrary the appropriate question to pose is how large differences are between populations. That is, we urge a shift in interest from statistical significance to biological relevance for proper knowledge accumulation. I empha-

What is the p-value?

<https://pollev.com/franciscorod726>

P value

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

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- ▶ 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** H_0 .

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- ▶ P-value is continuous. We must **avoid binary decisions** based on **arbitrary thresholds**.
- ▶ More on this later.

Let's do the test

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

Welch Two Sample t-test

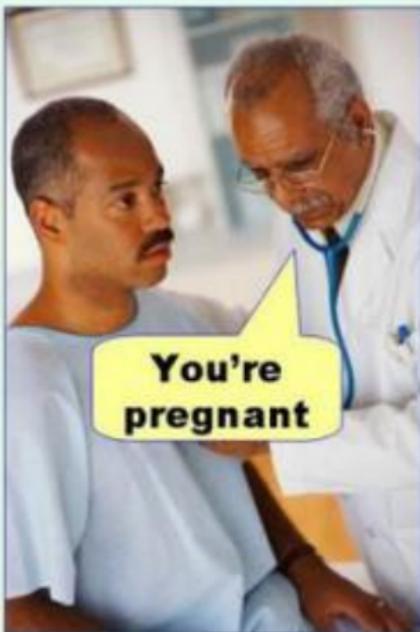
```
data: h.sevi and h.out
t = -1.4375, df = 12.714, p-value = 0.1747
alternative hypothesis: true difference in means is not equal to
95 percent confidence interval:
-12.531389  2.531389
sample estimates:
mean of x mean of y
171.4      176.4
```

Are heights different then?

Rejecting hypotheses: two types of error

Type I error

(false positive)



Type II error

(false negative)



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

Power: Probability of detecting true difference (rejecting H₀ when it's false).

Understanding NHST

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

Example: biased coin

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

```
1-sample proportions test with continuity correction
```

```
data: sum(coin) out of ntrials, null probability 0.5  
X-squared = 0.9, df = 1, p-value = 0.3428
```

```
alternative hypothesis: true p is not equal to 0.5
```

```
95 percent confidence interval:
```

```
0.3536707 0.9190522
```

```
sample estimates:
```

```
p  
0.7
```

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



ESSAY

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

Sander Greenland¹ · Stephen J. Senn² · Kenneth J. Rothman³ · John B. Carlin⁴ ·
Charles Poole⁵ · Steven N. Goodman⁶ · Douglas G. Altman⁷

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

Good read

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. STANOVICK⁴

<https://doi.org/10.1890/ES13-00160.1>
[Also http://www.statisticsonewrong.com/](http://www.statisticsonewrong.com/)

Good read



Twenty tips for
interpreting
scientific claims

<https://doi.org/10.1038/503335a>

Visualisation of data and models is key

First things first

- ▶ Always

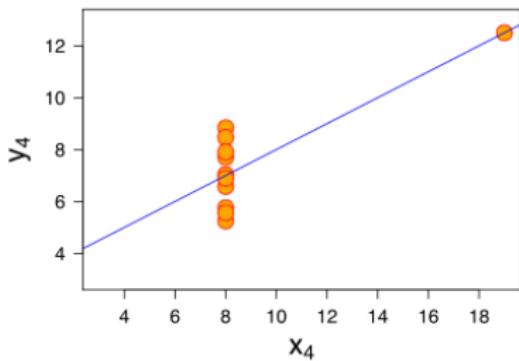
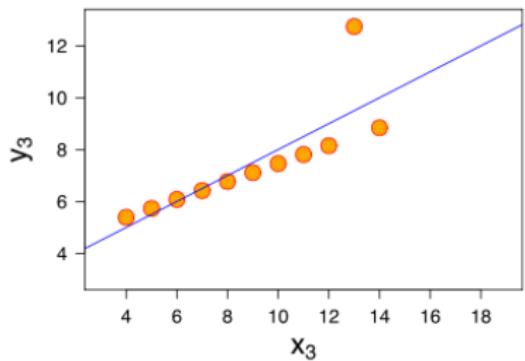
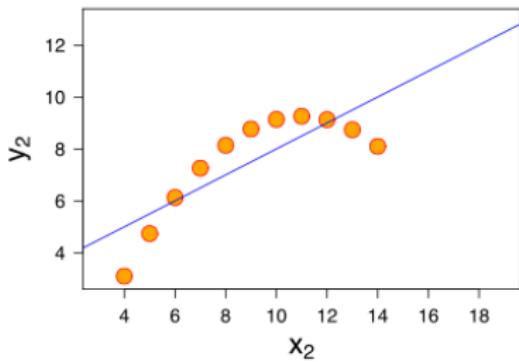
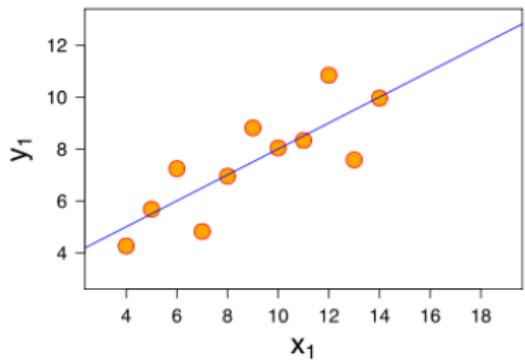
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First things first

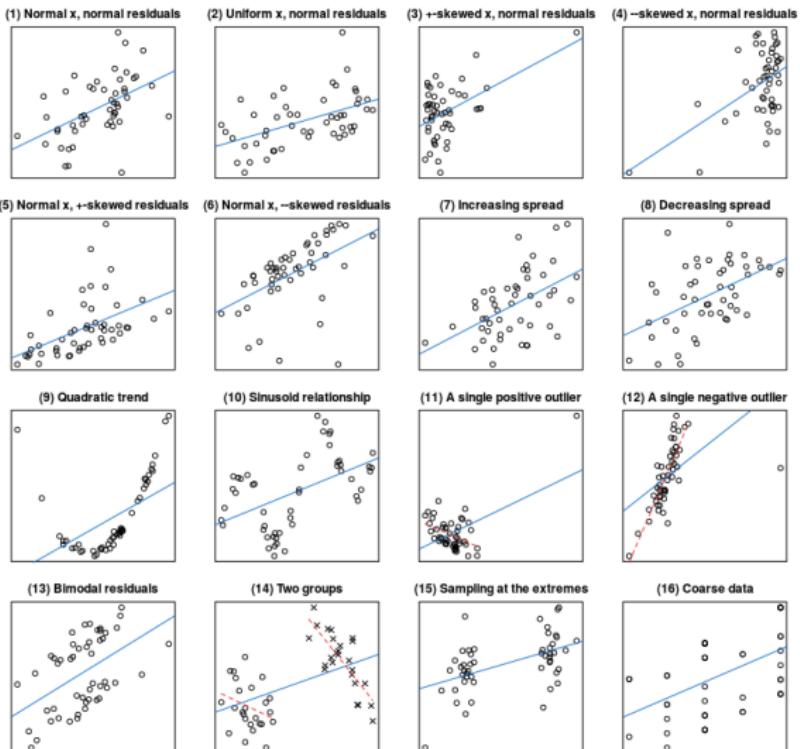
- ▶ Always
- ▶ Always
- ▶ Always

Plot data and models



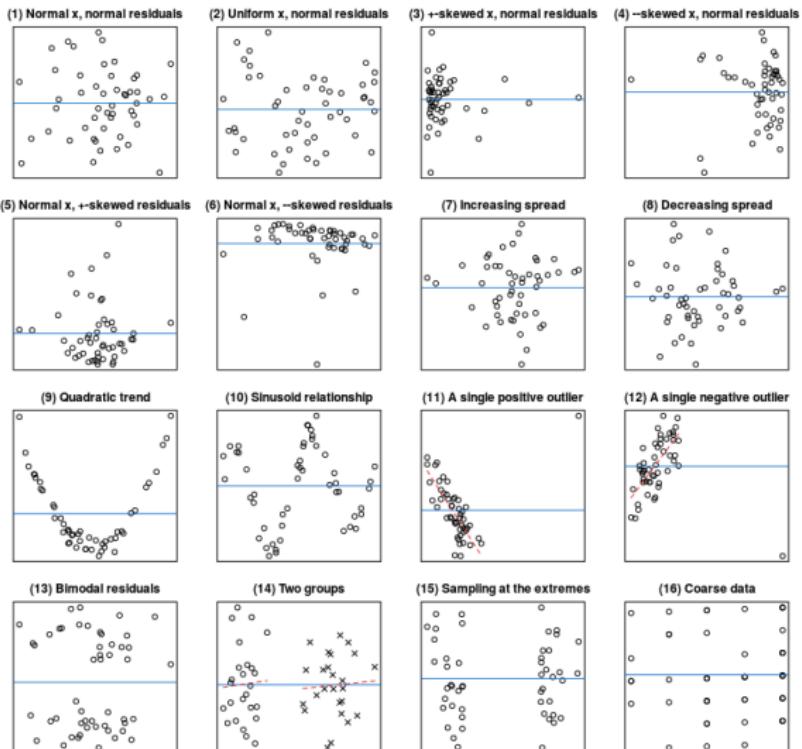
Don't use statistics blindly: Visualise

All correlations: $r(50) = 0.5$



Don't use statistics blindly: Visualise

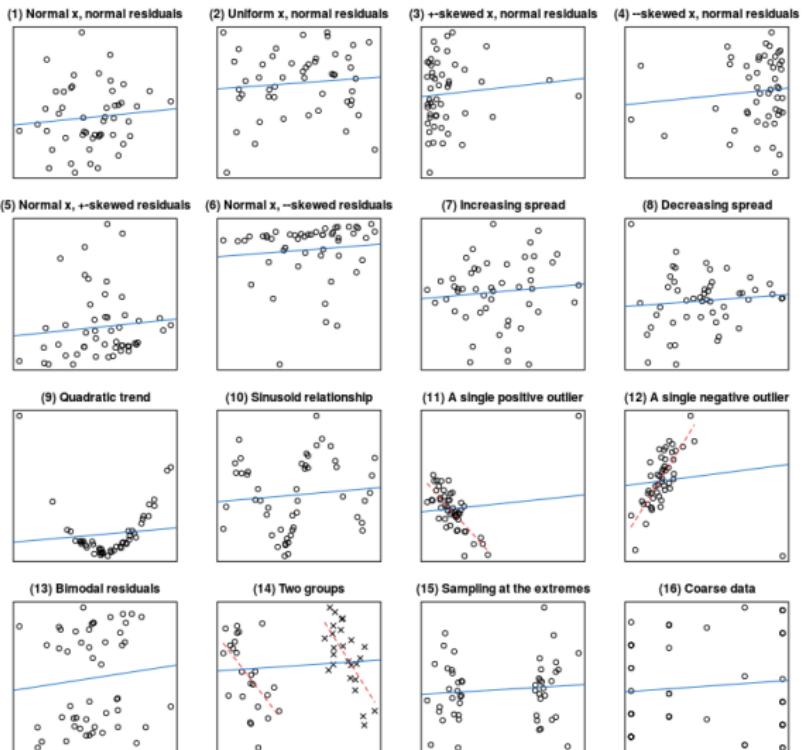
All correlations: $r(50) = 0$



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

Don't use statistics blindly: Visualise

All correlations: $r(50) = 0.1$



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

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

Lavine 2014 *Ecology*

Inference from observational studies

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

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- ▶ **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...

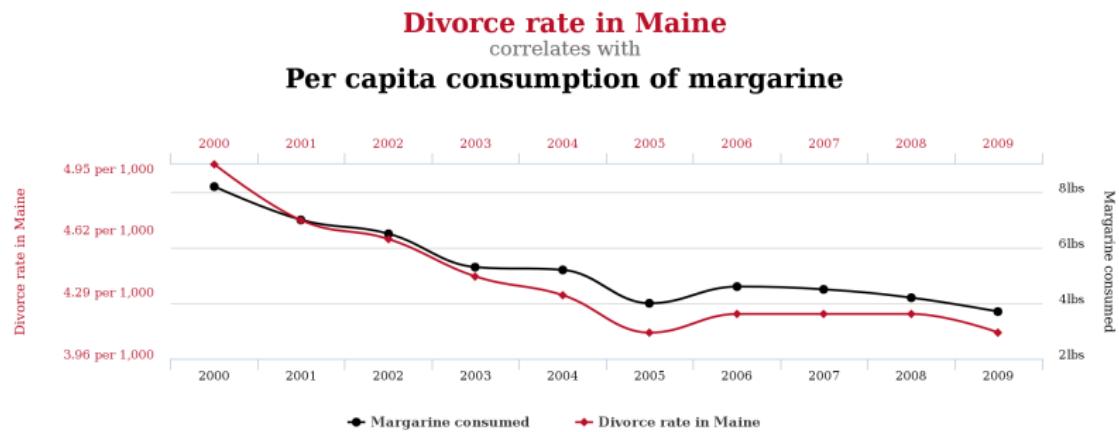
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Bigger flowers increase reproductive success

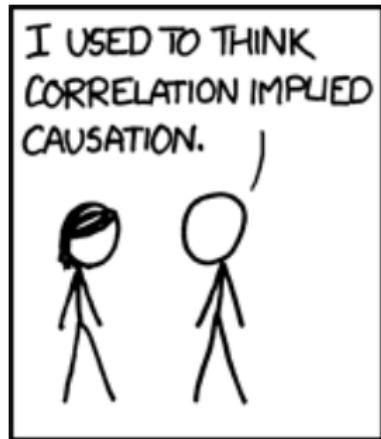
- ▶ We found that plants with big flowers produced 30% more seeds...
- ▶ **Do big flowers increase reproductive success?**
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Correlation vs Causation



<http://tylervigen.com/spurious-correlations>

Learning statistics through xkcd



NHST and p-values

In ecology, everything is somewhat different

Are there any differences? A non-sensical question in ecology

Alejandro Martínez-Abrán

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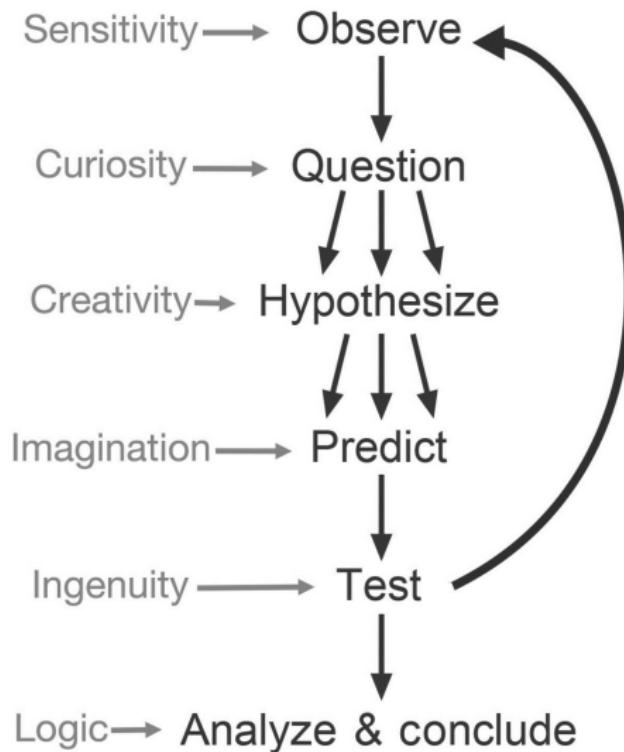
Published online 13 June 2007

Keywords:

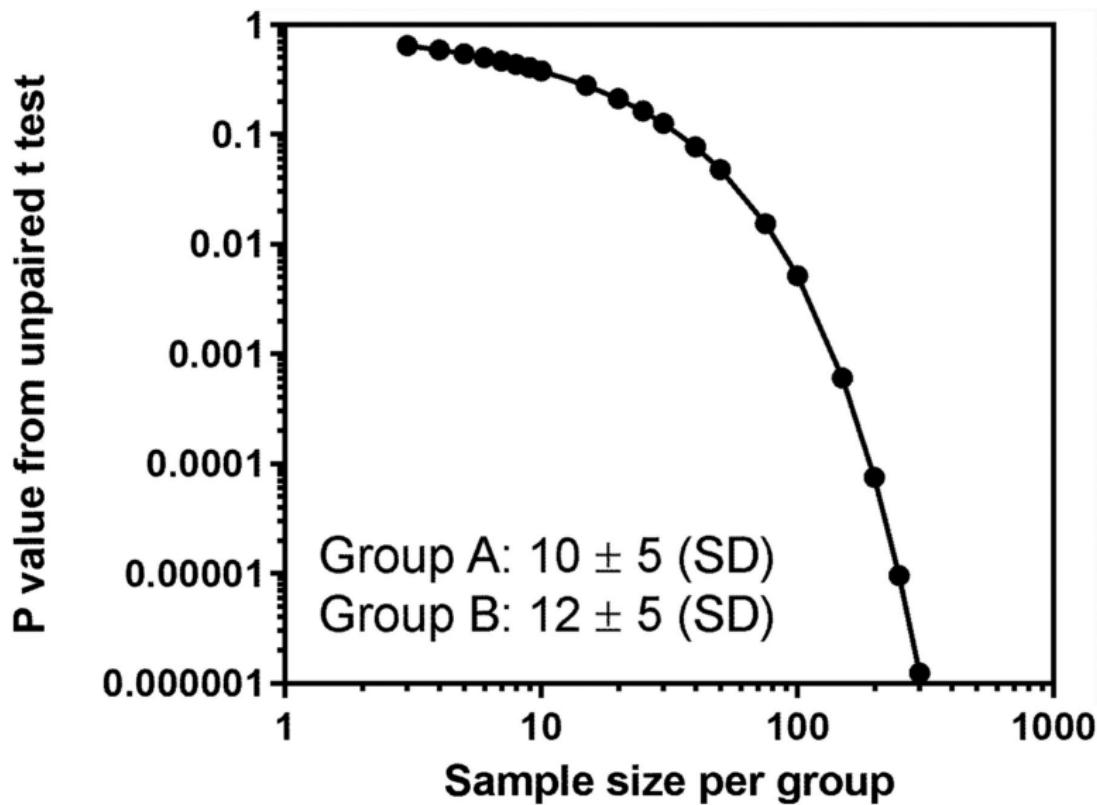
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One of the main questions that ecologists pose in their investigations includes the analysis of differences in some trait between two or more populations. I argue here that asking whether there are differences or not between populations is biologically irrelevant, since no two living things are ever equal. On the contrary the appropriate question to pose is how large differences are between populations. That is, we urge a shift in interest from statistical significance to biological relevance for proper knowledge accumulation. I empha-

Instead of falsifying a null model, estimate effects and compare meaningful models



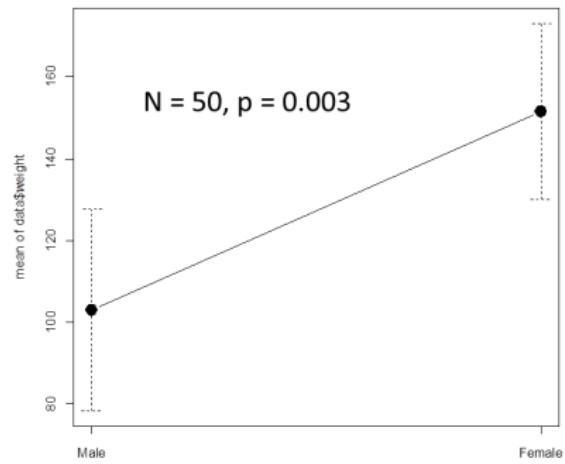
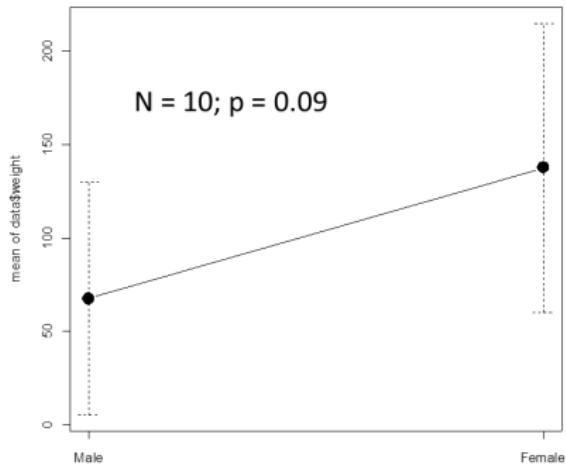
P-value depends on sample size



P-value depends on sample size

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

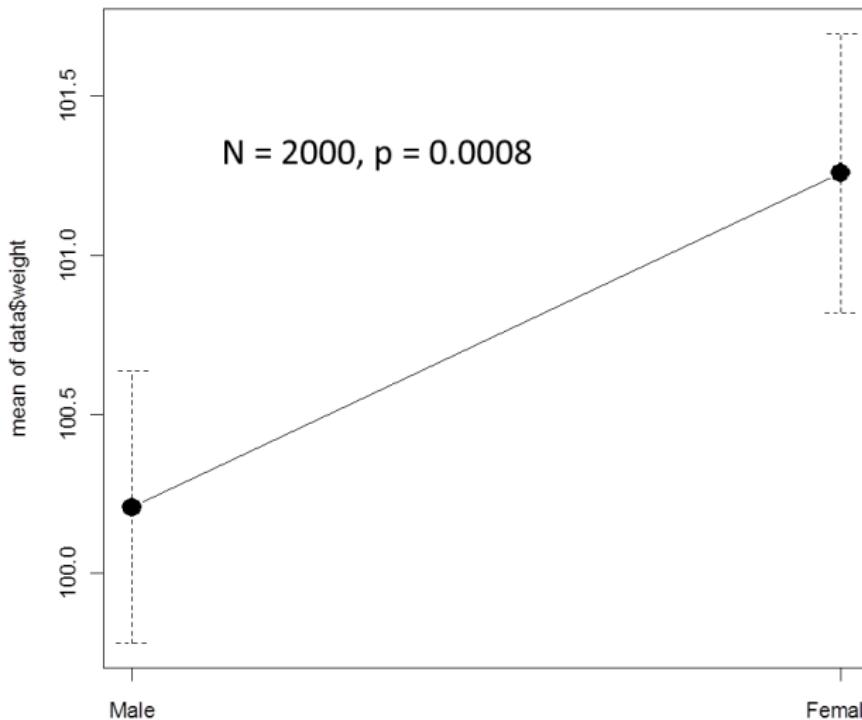
Real difference = 40 g



Statistically significant != biologically important

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

Real difference = 1 g



Statistically significant \neq biologically important

- ▶ Statistically significant = unlikely to be zero

Statistically significant != biologically important

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- ▶ Good read: *significantly misleading*

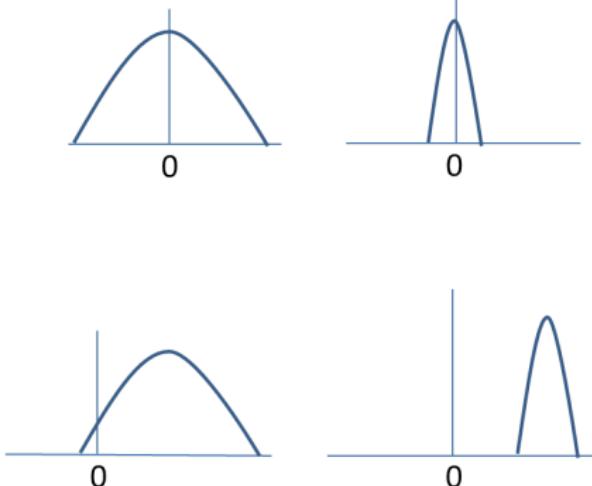
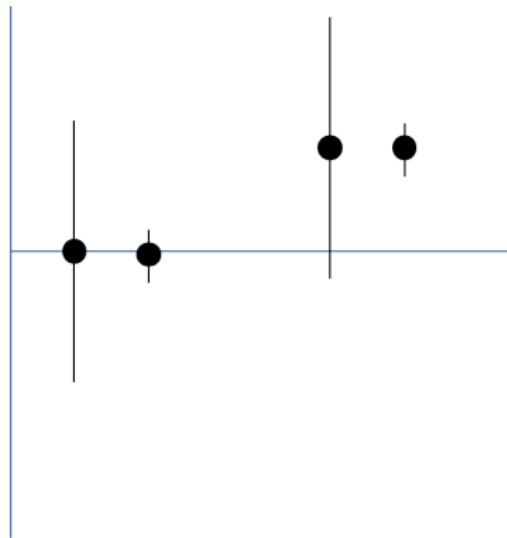
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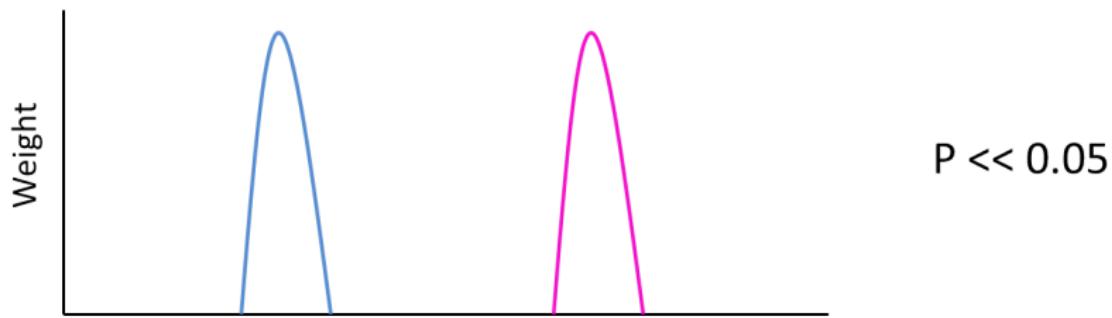
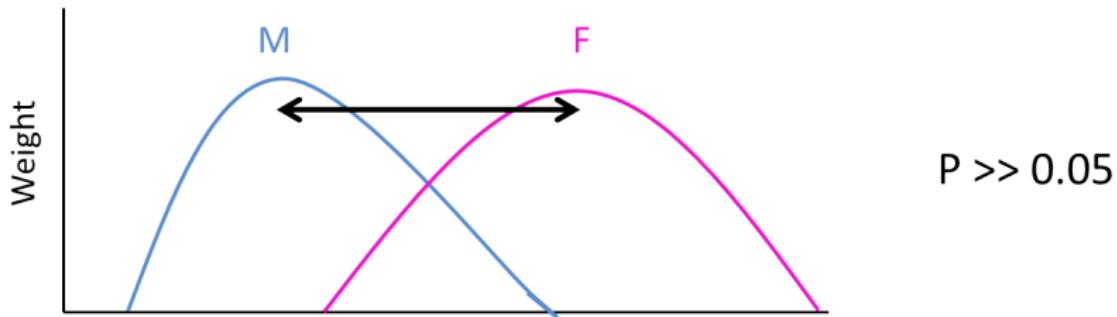
- ▶ Statistically significant = unlikely to be zero
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- ▶ My suggestion: avoid significant/not significant (and maybe p-values too)
- ▶ Beyond significance, look at *effect sizes*.

'Not significant' does NOT mean 'there is no effect'



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

Failure to reject H_0 $\neq H_0$ is true



p-value > 0.05?

- ▶ “We were **unable to find evidence** against the hypothesis that A = B **with the current sample size**” (Harrell)

p-value > 0.05?

- ▶ “We were **unable to find evidence** against the hypothesis that A = B **with the current sample size**” (Harrell)
- ▶ “Differences between groups were **not statistically clear**” (Dushoff et al)

Is it safe to allow right turn with red lights?

- ▶ Right turn not allowed: 308 accidents

<https://www.statisticsonthewrong.com/power.html#the-wrong-turn-on-red>

Is it safe to allow right turn with red lights?

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- ▶ Misinterpretation of underpowered study cost lives

<https://www.statisticssdonewrong.com/power.html#the-wrong-turn-on-red>

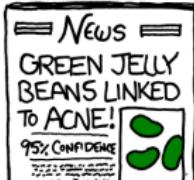
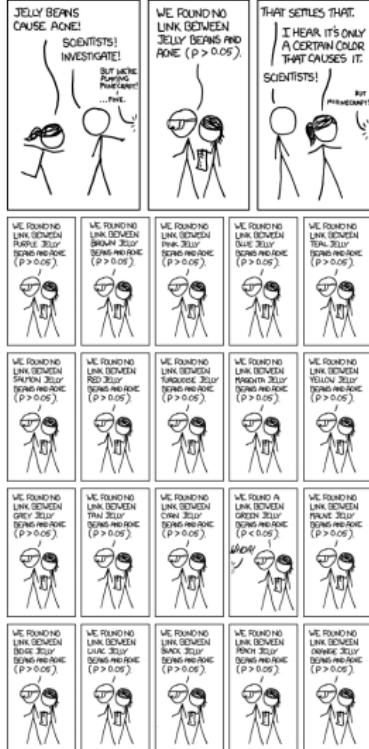
0.05 is an arbitrary threshold

**The Difference Between “Significant” and “Not Significant” is not
Itself Statistically Significant**

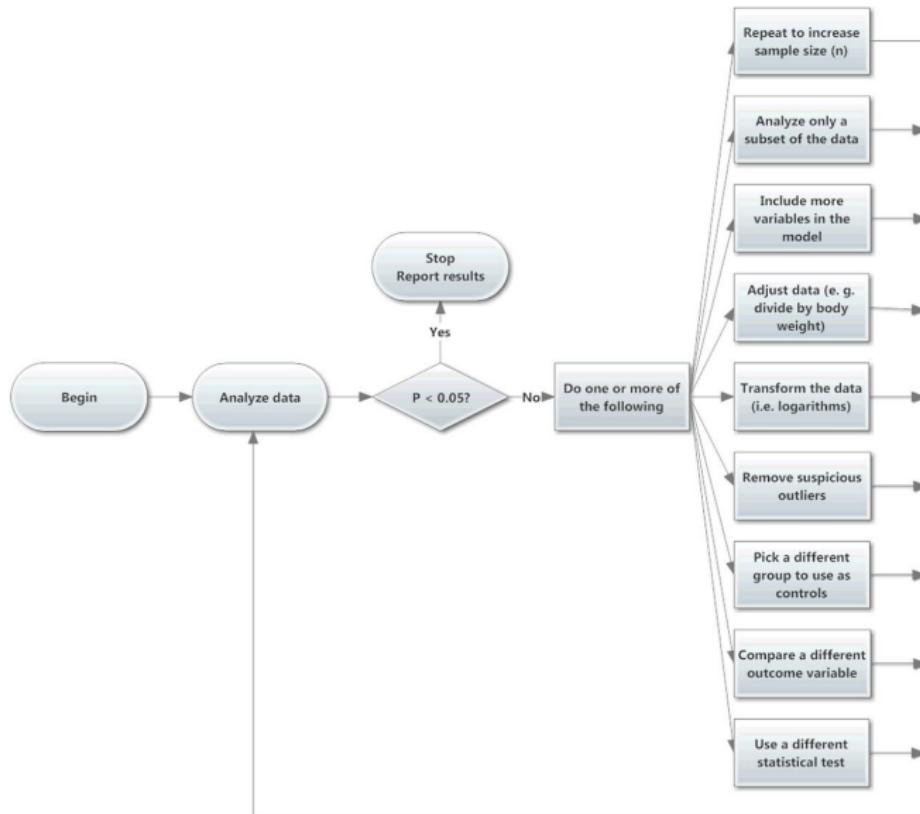
Andrew GELMAN and Hal STERN

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

Multiple hypothesis testing



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



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

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 2. Artificially choose when to end your experiment.
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- 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>

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- ▶ 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 (SE, CI...)



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
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sagepub.com/journalsPermissions.nav
DOI: 10.1177/0956797613504966
pss.sagepub.com



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

How many types of errors?

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- ▶ Beyond Power Calculations: Assessing Type S (Sign) and Type M (Magnitude) Errors

END



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