Hypothesis testing

NHST concepts

Null and alternative hypotheses

- Tell me...

Null and alternative hypotheses

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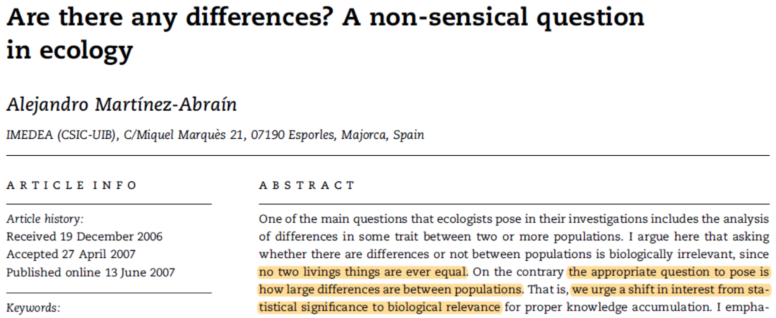
- **Null hypothesis**: there is no difference between groups.

Null and alternative hypotheses

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

In biology, everything is somewhat different



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

Alejandro Martínez-Abraín

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

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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 livings 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-

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- The probability that the observed data were produced by chance

`https://pollev.com/franciscorod726`

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    - Null hypothesis is true

P-value

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- Probability of observing data as or more extreme than these *if every model assumption were correct*
- What assumptions?
  - Null hypothesis is true
  - No uncontrolled sources of bias (measurement or programming error, p-hacking, etc)

How to interpret P-values

- **Low P-value**: data unlikely if every model assumption (including H0) were true.

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    - But also that some auxiliary assumption is not true (e.g. sampling not random, measurement error, p-hacking…)
- See Greenland et al 2016

For example

- A famous experiment found neutrinos faster than light

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- p-value < 10^{-7} -> reject null hypothesis of equal speed

For example

- A famous experiment found neutrinos faster than light
- p-value < 10^{-7} -> reject null hypothesis of equal speed
- In reality, measurement error (loose cable)

If p-value > 0.05

- the null hypothesis is false, i.e. the alternative hypothesis must be true

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Are differences *significant*?

Common practice:

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

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- **CAUTION:** P-value is continuous. We must **avoid binary decisions** based on **arbitrary thresholds**.

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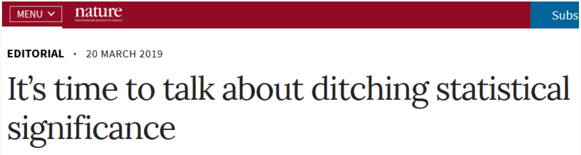


EDITORIAL · 20 MARCH 2019

It’s time to talk about ditching statistical significance

https://doi.org/10.1038/d41586-019-00857-9

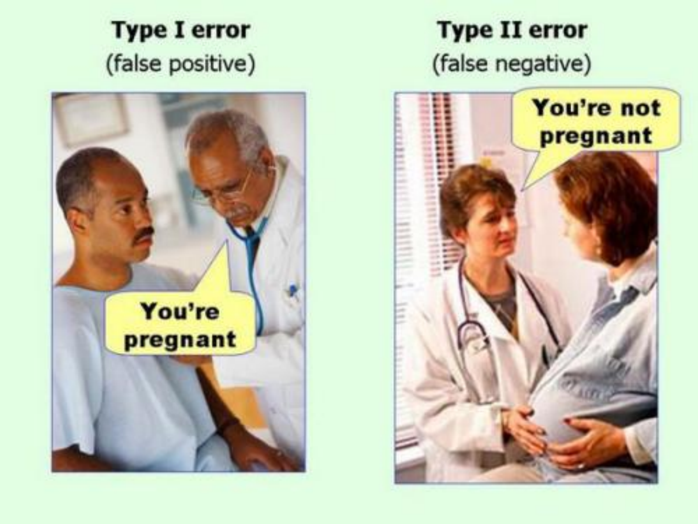
Are these two groups different?

```
t.test(group.A, group.B)
```

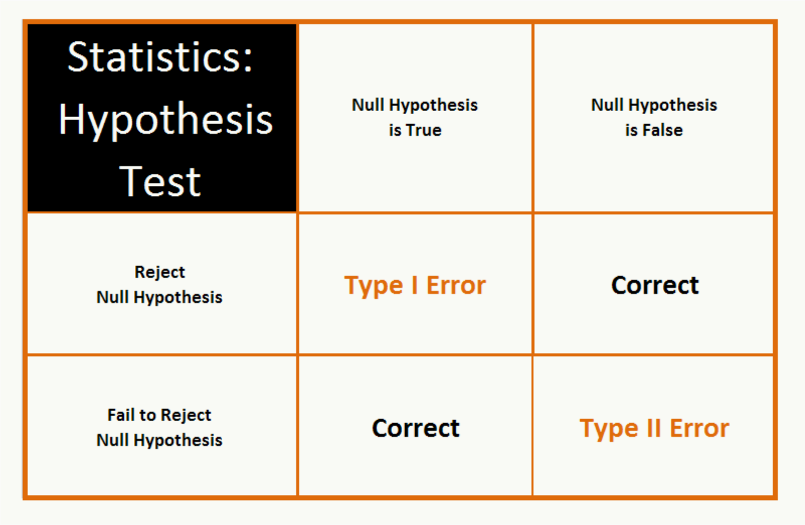
```

    Welch Two Sample t-test

data:  group.A and group.B
t = -0.17796, df = 5.0294, p-value = 0.8657
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -12.33558  10.73558
sample estimates:
mean of x mean of y
    175.6     176.4
```

`https://pollev.com/franciscorod726`

Rejecting hypotheses: two types of error


Type I error
(false positive)
You're pregnant
Type II error
(false negative)
You're not pregnant

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).

Is this coin biased?

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


	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 
```

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Understanding NHST

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

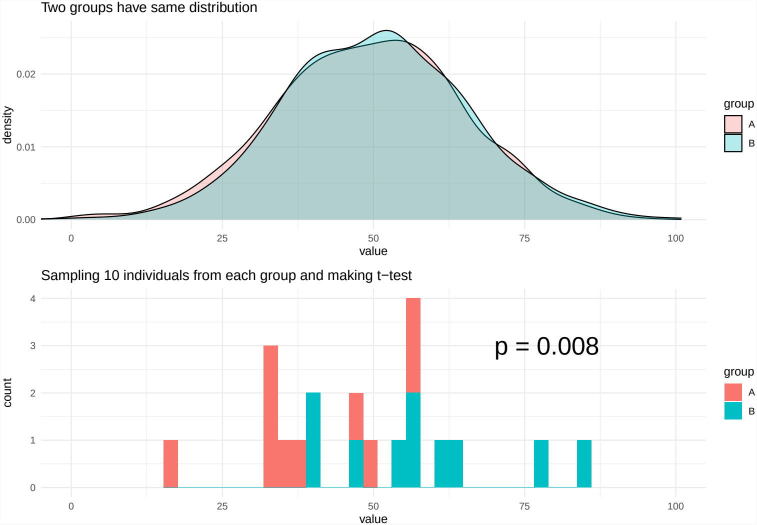
http://daniellakens.blogspot.com/2017/12/understanding-common-misconceptions.html

NHST and p-values: common pitfalls

A significant p-value
does NOT mean
we found a true difference

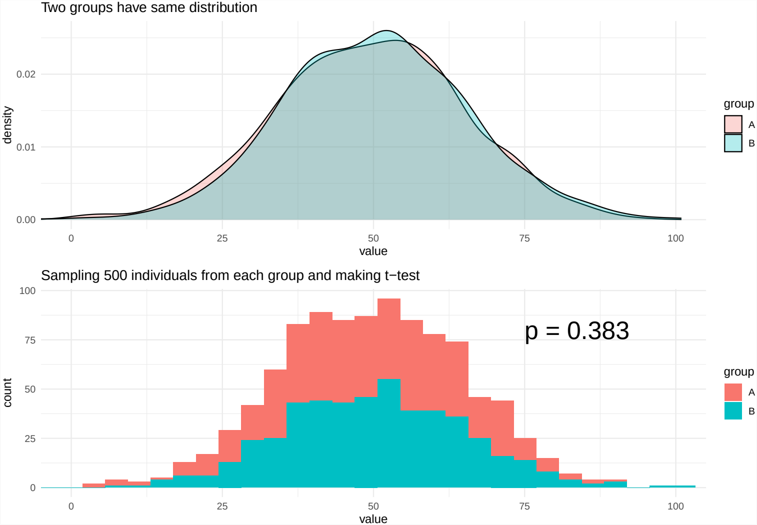
A significant p-value does not mean we found a true difference

Particularly with low sample sizes


Two groups have same distribution

Sampling 10 individuals from each group and making t−test

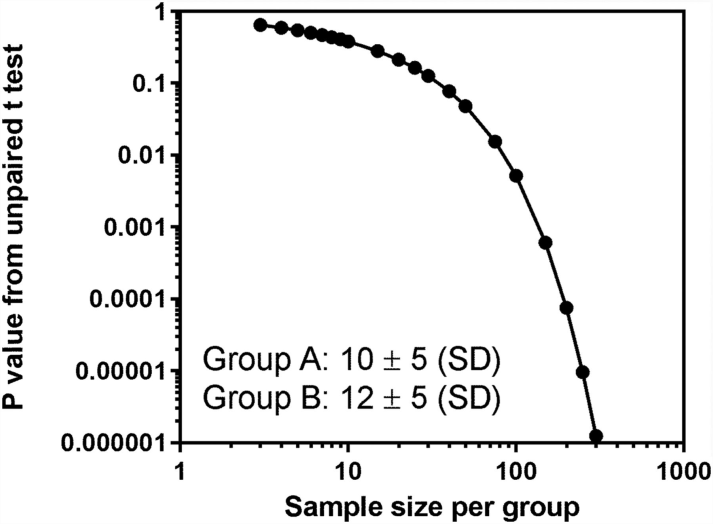
If sample size was larger...



With low sample size (power),
significant p-values
are most likely overestimates

Loken & Gelman 2014, Vasisth et al. 2018

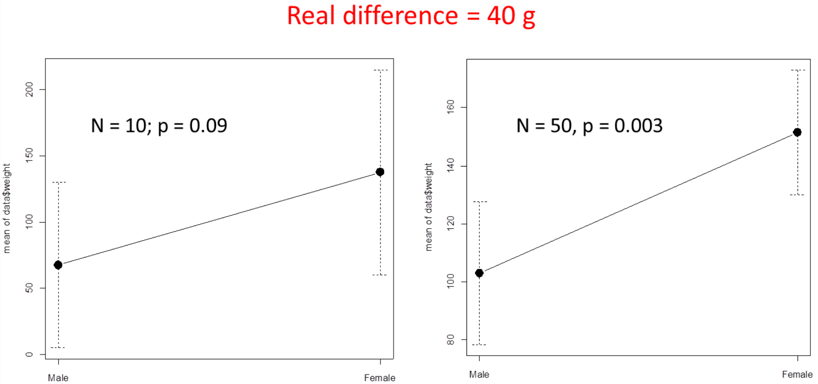
P-value depends on sample size



https://doi.org/10.1002/prp2.93

P-value depends on sample size

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



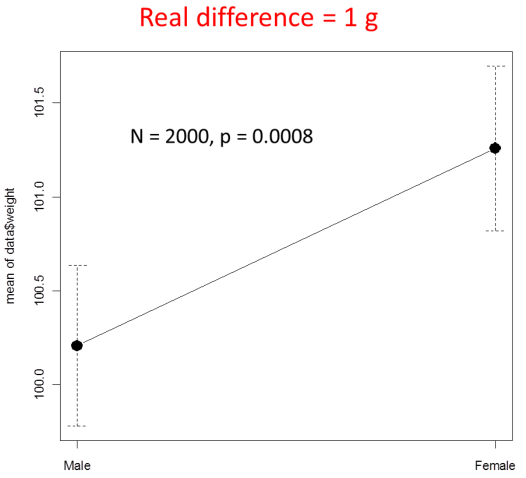
Statistically significant

!=

biologically important

Statistically significant != biologically important

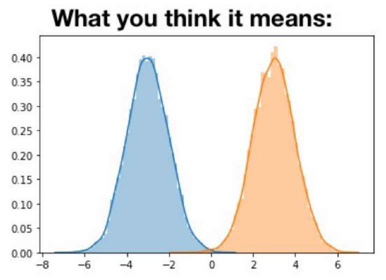
With big sample size, we can find **highly significant but biologically unimportant** differences.

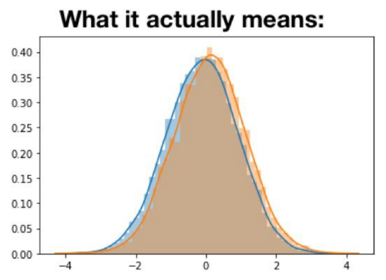


Statistically significant != biologically important

zara weinberg
@weinberz

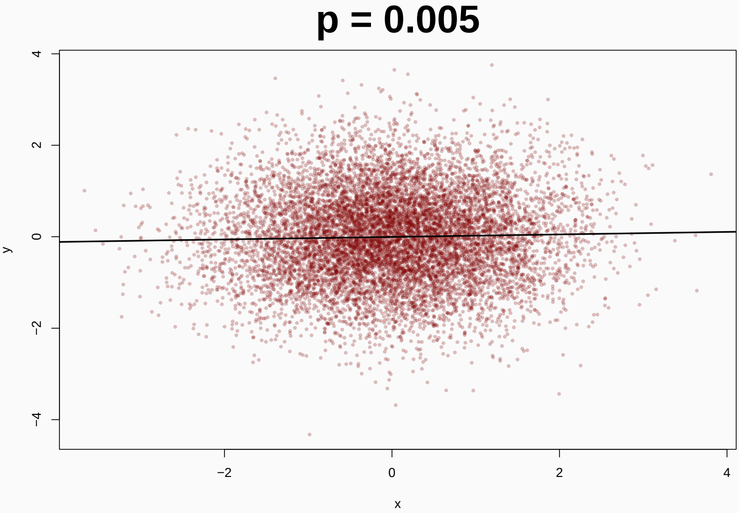
friendly reminder about $p < 0.0001$:





https://twitter.com/weinberz/status/1422405165236178947?s=20

Statistically significant != biologically important



Statistically significant != biologically important

- Statistically significant = unlikely to be zero

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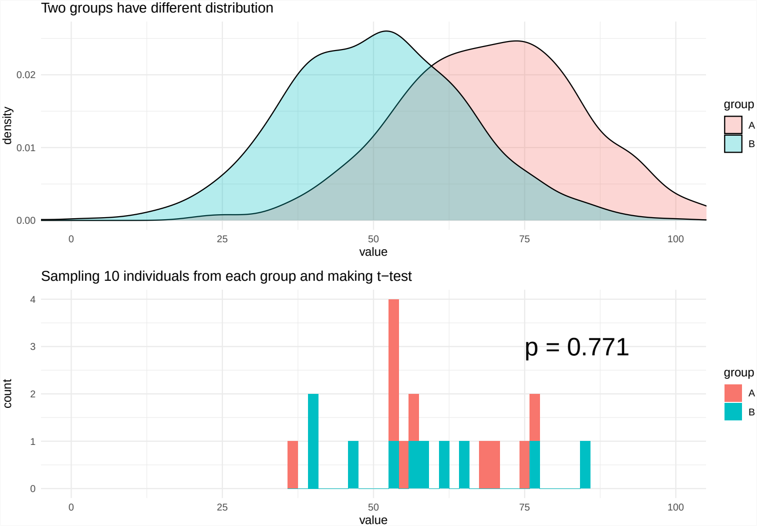
- Good read: *significantly misleading*

Statistically significant != biologically important

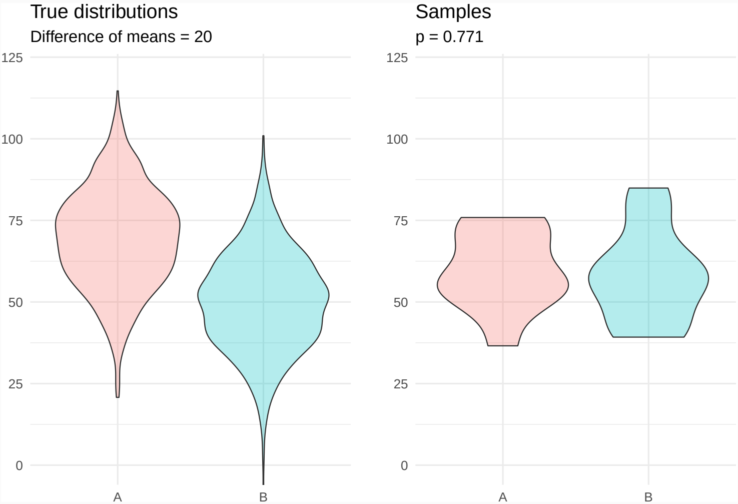
- Statistically significant = unlikely to be zero
- Good read: *significantly misleading*
- Beyond significant/not significant, look at **effect sizes and their uncertainty**.

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

‘Not significant’ does NOT mean ‘they are equal’



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



Failure to reject H0 != H0 is true

Absence of evidence != Evidence of absence

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

NO
TURN
ON RED

https://www.statisticsdonewrong.com/power.html#the-wrong-turn-on-red

Is it safe to allow right turn with red lights?

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- Right turn allowed: 337 accidents

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- Misinterpretation of underpowered study cost lives

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TURN
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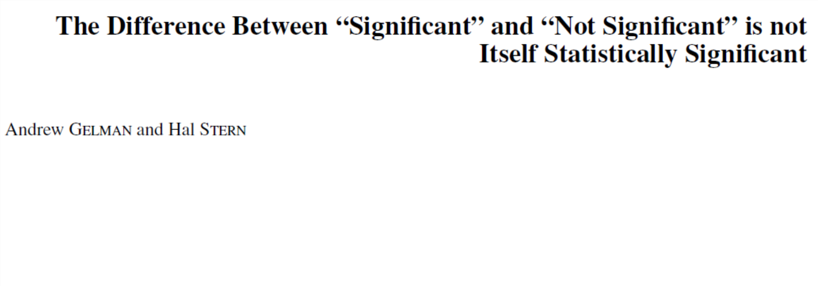
https://www.statisticsdonewrong.com/power.html#the-wrong-turn-on-red

0.05 is an arbitrary threshold

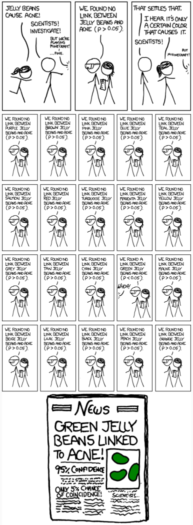


The Difference Between “Significant” and “Not Significant” is not Itself Statistically Significant

Andrew GELMAN and Hal STERN

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

Multiple hypothesis testing


JELLY BEANS CAUSE ACNE!
SCIENTISTS! INVESTIGATE!
BUT WE'RE PLAYING MINECRAFT!
...FINE.
WE FOUND NO LINK BETWEEN JELLY BEANS AND ACNE (P > 0.05).
THAT SETTLES THAT.
I HEAR IT'S ONLY A CERTAIN COLOR THAT CAUSES IT.
SCIENTISTS!
BUT MIIIINECRAFT!
WE FOUND NO LINK BETWEEN PURPLE JELLY BEANS AND ACNE (P > 0.05).
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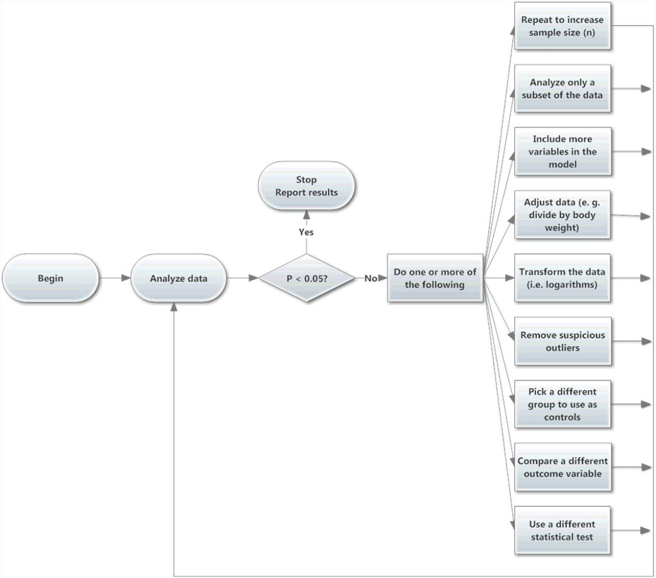
WE FOUND NO LINK BETWEEN TEAL JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN SALMON JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN RED JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN TURQUOISE JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN MAGENTA JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN YELLOW JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN GREY JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN TAN JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN CYAN JELLY BEANS AND ACNE (P > 0.05).
WE FOUND A LINK BETWEEN GREEN JELLY BEANS AND ACNE (P < 0.05).
WHOA!
WE FOUND NO LINK BETWEEN MAUVE JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN BEIGE JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN LILAC JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN BLACK JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN PEACH JELLY BEANS AND ACNE (P > 0.05).
WE FOUND NO LINK BETWEEN ORANGE JELLY BEANS AND ACNE (P > 0.05).
NEWS
GREEN JELLY BEANS LINKED TO ACNE!
95% CONFIDENCE
ONLY 5% CHANCE OF COINCIDENCE!
SCIENTISTS...

https://xkcd.com/882

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



Begin

Analyze data

P < 0.05?

Yes

Stop
Report results

No

Do one or more of the following

Repeat to increase sample size (n)

Analyze only a subset of the data

Include more variables in the model

Adjust data (e. g. divide by body weight)

Transform the data (i.e. logarithms)

Remove suspicious outliers

Pick a different group to use as controls

Compare a different outcome variable

Use a different statistical test

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.

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- To read more: Simmons et al 2011

p-hacking: try it yourself

https://www.shinyapps.org/apps/p-hacker/

https://shiny.psy.lmu.de/felix/ShinyPHack/

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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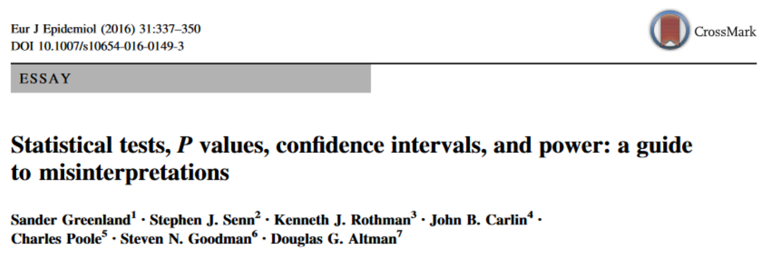
- Scientific conclusions or policy decisions should NOT be based only on **whether a p-value passes a specific threshold**.
- P-value, or statistical significance, does not measure the **size of an effect** or the **importance** of a result.
- By itself, a p-value does NOT provide a good **measure of evidence** regarding a model or hypothesis.

`https://doi.org/10.1080/00031305.2016.1154108`

Good practice

A must read



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

CrossMark

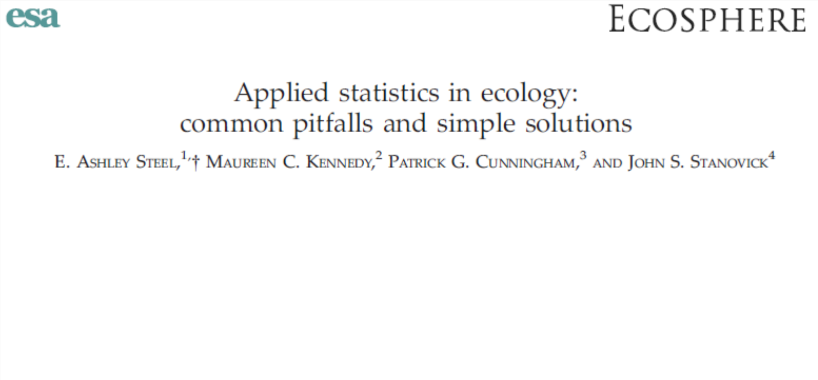
ESSAY

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 read



esa ECOSPHERE

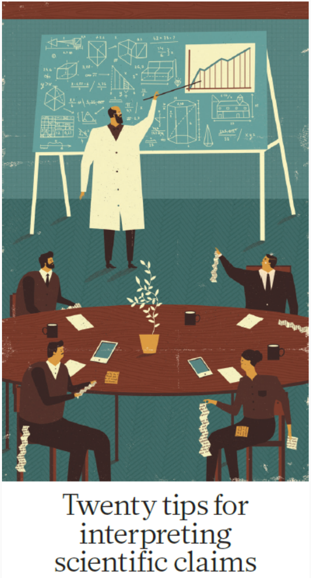
Applied statistics in ecology: common pitfalls and simple solutions

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

https://doi.org/10.1890/ES13-00160.1

Also http://www.statisticsdonewrong.com/

Good read

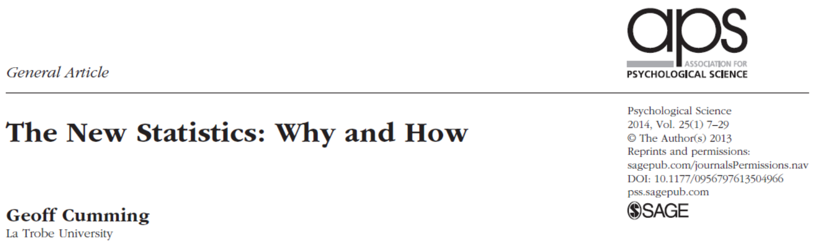


Twenty tips for interpreting scientific claims

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

The New Statistics

Aim for estimation of effects and their uncertainty (SE, CI...)



aps
ASSOCIATION FOR
PSYCHOLOGICAL SCIENCE

General Article

Psychological Science
2014, Vol. 25(1) 7–29
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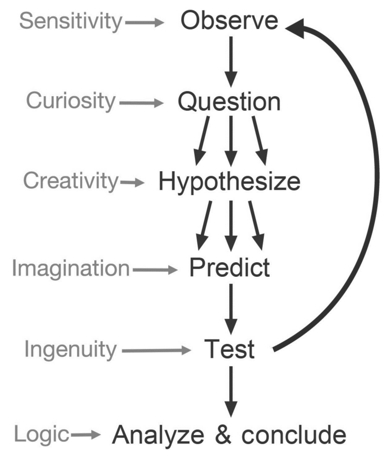
sagepub.com/journalsPermissions.nav
DOI: 10.1177/0956797613504966
pss.sagepub.com
SAGE

The New Statistics: Why and How

Geoff Cumming
La Trobe University

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

Instead of falsifying null model, compare meaningful models



Sensitivity → Observe

Curiosity → Question

Creativity → Hypothesize

Imagination → Predict

Ingenuity → Test

Logic → Analyze & conclude

https://doi.org/10.1242/jeb.104976

How many types of errors?

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

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