Statistical Inference: Power

Packages

```
library(tidyverse)
```

Errors in testing

What can happen:

	Decision	
Truth	**Do not reject**	**Reject null**
Null true	Correct	Type I error
Null false	Type II error	Correct

Tension between truth and decision about truth (imperfect).

- Prob. of type I error denoted α. Usually fix α, eg. $\alpha = 0.05$.
- Prob. of type II error denoted β. Determined by the planned experiment. Low β good.
- Prob. of not making type II error called **power** ($= 1 - \beta$). *High* power good.

Power

- Suppose $H_0 : \mu = 10$, $H_a : \mu \neq 10$ for some population mean μ.
- Suppose H_0 wrong. What does that say about μ?
- Not much. Could have $\mu = 11$ or $\mu = 8$ or $\mu = 496$. In each case, H_0 wrong.
- How likely a type II error is depends on what μ is:
    - If $\mu = 496$, should be able to reject $H_0 : \mu = 10$ even for small sample, so β should be small (power large).
    - If $\mu = 11$, might have hard time rejecting H_0 even with large sample, so β would be larger (power smaller).
- Power depends on true parameter value, and on sample size.
- So we play "what if": "if μ were 11 (or 8 or 496), what would power be?".

Figuring out power

- Time to figure out power is before you collect any data, as part of planning process.
- Need to have idea of what kind of departure from null hypothesis of interest to you, eg. average improvement of 5 points on reading test scores. (Subject-matter decision, not statistical one.)
- Then, either:
  - "I have this big a sample and this big a departure I want to detect. What is my power for detecting it?"
  - "I want to detect this big a departure with this much power. How big a sample size do I need?"

How to understand/estimate power?

- Suppose we test $H_0 : \mu = 10$ against $H_a : \mu \neq 10$, where μ is population mean.
- Suppose in actual fact, $\mu = 8$, so H_0 is wrong. We want to reject it. How likely is that to happen?
- Need population SD (take $\sigma = 4$) and sample size (take $n = 15$). In practice, get σ from pilot/previous study, and take the n we plan to use.
- Idea: draw a random sample from the true distribution, test whether its mean is 10 or not.
- Repeat previous step "many" times.
- "Simulation".

Making it go

- Random sample of 15 normal observations with mean 8 and SD 4:

```
x <- rnorm(15, 8, 4)
x
```

```
 [1] 14.487469  5.014611  6.924277  5.201860  8.852952
 [6] 10.835874  3.686684 11.165242  8.016188 12.383518
[11]  1.378099  3.172503 13.074996 11.353573  5.015575
```

- Test whether `x` from population with mean 10 or not (over):

…continued

```r
t.test(x, mu = 10)
```

```
	One Sample t-test

data:  x
t = -1.8767, df = 14, p-value = 0.08157
alternative hypothesis: true mean is not equal to 10
95 percent confidence interval:
  5.794735 10.280387
sample estimates:
mean of x
 8.037561
```

- Fail to reject the mean being 10 (a Type II error).

or get just P-value

```r
ans <- t.test(x, mu = 10)
ans$p.value
```

```
[1] 0.0815652
```

How I knew it was called that

```
str(ans)
```

```
List of 10
 $ statistic  : Named num -1.88
  ..- attr(*, "names")= chr "t"
 $ parameter  : Named num 14
  ..- attr(*, "names")= chr "df"
 $ p.value    : num 0.0816
 $ conf.int   : num [1:2] 5.79 10.28
  ..- attr(*, "conf.level")= num 0.95
 $ estimate   : Named num 8.04
  ..- attr(*, "names")= chr "mean of x"
 $ null.value : Named num 10
  ..- attr(*, "names")= chr "mean"
 $ stderr     : num 1.05
 $ alternative: chr "two.sided"
 $ method     : chr "One Sample t-test"
 $ data.name  : chr "x"
 - attr(*, "class")= chr "htest"
```

Run this lots of times

- without a loop!
- use `rowwise` to work one random sample at a time
- draw random samples from the truth
- test that $\mu = 10$
- get P-value
- Count up how many of the P-values are 0.05 or less.

In code

```
library(tidyverse)
tibble(sim = 1:1000) %>%
  rowwise() %>%
  mutate(my_sample = list(rnorm(15, 8, 4))) %>%
  mutate(t_test = list(t.test(my_sample, mu = 10))) %>%
  mutate(p_val = t_test$p.value) %>%
  count(p_val <= 0.05)
```

```
# A tibble: 2 x 2
# Rowwise:
  `p_val <= 0.05`     n
  <lgl>           <int>
1 FALSE             578
2 TRUE              422
```

We correctly rejected 422 times out of 1000, so the estimated power is 0.422.

Aside: Try again with bigger sample

```
tibble(sim = 1:1000) %>%
  rowwise() %>%
  mutate(my_sample = list(rnorm(40, 8, 4))) %>%
  mutate(t_test = list(t.test(my_sample, mu = 10))) %>%
  mutate(p_val = t_test$p.value) %>%
  count(p_val <= 0.05)
```

```
# A tibble: 2 x 2
# Rowwise:
  `p_val <= 0.05`     n
  <lgl>           <int>
1 FALSE             119
2 TRUE              881
```

Calculating power

- Simulation approach very flexible: will work for any test. But answer different each time because of randomness.
- In some cases, for example 1-sample and 2-sample t-tests, power can be calculated.
- `power.t.test`. Input `delta` is difference between null and true mean:

```
power.t.test(n = 15, delta = 10-8, sd = 4,
             type = "one.sample")
```

Results

```r
power.t.test(n = 15, delta = 10-8, sd = 4,
             type = "one.sample")
```

```
     One-sample t test power calculation

              n = 15
          delta = 2
             sd = 4
      sig.level = 0.05
          power = 0.4378466
    alternative = two.sided
```

Comparison of results

Method	Power
Simulation	0.422
`power.t.test`	0.4378

- Simulation power is similar to calculated power; to get more accurate value, repeat more times (eg. 10,000 instead of 1,000), which takes longer.
- CI for power based on simulation approx. 0.42 ± 0.03.
- With this small a sample size, the power is not great. With a bigger sample, the sample mean should be closer to 8 most of the time, so would reject $H_0 : \mu = 10$ more often.

Calculating required sample size

- Often, when planning a study, we do not have a particular sample size in mind. Rather, we want to know how big a sample to take. This can be done by asking how big a sample is needed to achieve a certain power.
- The simulation approach does not work naturally with this, since you have to supply a sample size.
  - For that, you try different sample sizes until you get power close to what you want.
- For the power-calculation method, you supply a value for the power, but leave the sample size missing.
- Re-use the same problem: $H_0 : \mu = 10$ against 2-sided alternative, true $\mu = 8$, $\sigma = 4$, but now aim for power 0.80.

Using power.t.test

- No `n=`, replaced by a `power=`:

```
power.t.test(power=0.80, delta=10-8, sd=4, type="one.sample")
```

```
     One-sample t test power calculation

              n = 33.3672
          delta = 2
             sd = 4
      sig.level = 0.05
          power = 0.8
    alternative = two.sided
```

- Sample size must be a whole number, so round up to 34 (to get at least as much power as you want).

One-sided test

```r
power.t.test(power=0.80, delta=10-8, sd=4,
             type="one.sample", alternative = "one.sided")
```

```
     One-sample t test power calculation

              n = 26.13751
          delta = 2
             sd = 4
      sig.level = 0.05
          power = 0.8
    alternative = one.sided
```

By simulation

Try a sample size and see what power you get. Here's $n = 15$ from before:

```
tibble(sim = 1:1000) %>%
  rowwise() %>%
  mutate(my_sample = list(rnorm(15, 8, 4))) %>%
  mutate(t_test = list(t.test(my_sample, mu = 10))) %>%
  mutate(p_val = t_test$p.value) %>%
  count(p_val <= 0.05)
```

```
# A tibble: 2 x 2
# Rowwise:
  `p_val <= 0.05`     n
  <lgl>           <int>
1 FALSE             578
2 TRUE              422
```

To get power 0.80, two-sided, need a *bigger sample*.

To get a bigger power

How much bigger? No idea. *Make any guess.* What about $n = 50$?

```
tibble(sim = 1:1000) %>%
  rowwise() %>%
  mutate(my_sample = list(rnorm(50, 8, 4))) %>%
  mutate(t_test = list(t.test(my_sample, mu = 10))) %>%
  mutate(p_val = t_test$p.value) %>%
  count(p_val <= 0.05)
```

```
# A tibble: 2 x 2
# Rowwise:
  `p_val <= 0.05`     n
  <lgl>           <int>
1 FALSE              76
2 TRUE              924
```

Power now *too big*.

Try again

sample size between 15 and 50, say $n = 30$:

```
tibble(sim = 1:1000) %>%
  rowwise() %>%
  mutate(my_sample = list(rnorm(30, 8, 4))) %>%
  mutate(t_test = list(t.test(my_sample, mu = 10))) %>%
  mutate(p_val = t_test$p.value) %>%
  count(p_val <= 0.05)
```

```
# A tibble: 2 x 2
# Rowwise:
  `p_val <= 0.05`     n
  <lgl>           <int>
1 FALSE             252
2 TRUE              748
```

Now a little too small, hence right answer between 30 and 50, closer to 30.

One last try ($n = 35$)

```
tibble(sim = 1:1000) %>%
  rowwise() %>%
  mutate(my_sample = list(rnorm(35, 8, 4))) %>%
  mutate(t_test = list(t.test(my_sample, mu = 10))) %>%
  mutate(p_val = t_test$p.value) %>%
  count(p_val <= 0.05)
```

```
# A tibble: 2 x 2
# Rowwise:
  `p_val <= 0.05`     n
  <lgl>           <int>
1 FALSE             179
2 TRUE              821
```

But...

... simulation has randomness: limit to how close you can get.

Rule of thumb: with 1000 simulations, estimated power within 0.03 (3%).

Power curves

- Rather than calculating power for one sample size, or sample size for one power, might want a picture of relationship between sample size and power.
- Or, likewise, picture of relationship between difference between true and null-hypothesis means and power.
- Called power curve.
- Build and plot it yourself.

Building it 1/2

- If you feed `power.t.test` a collection ("vector") of values, it will do calculation for each one.
- Do power for variety of sample sizes, from 10 to 100 in steps of 10:

```
ns <- seq(10,100,10)
ns
```

```
 [1]  10  20  30  40  50  60  70  80  90 100
```

Building it 2/2

- Calculate powers:

```
ans<- power.t.test(n=ns, delta=10-8, sd=4, type="one.sample")
ans
```

```
     One-sample t test power calculation

              n = 10, 20, 30, 40, 50, 60, 70, 80, 90, 100
          delta = 2
             sd = 4
      sig.level = 0.05
          power = 0.2928286, 0.5644829, 0.7539627, 0.8693979, 0.933
    alternative = two.sided
```

Just the power

```
str(ans)
```

```
List of 8
 $ n          : num [1:10] 10 20 30 40 50 60 70 80 90 100
 $ delta      : num 2
 $ sd         : num 4
 $ sig.level  : num 0.05
 $ power      : num [1:10] 0.293 0.564 0.754 0.869 0.934 ...
 $ alternative: chr "two.sided"
 $ note       : NULL
 $ method     : chr "One-sample t test power calculation"
 - attr(*, "class")= chr "power.htest"
```

```
ans$power
```

```
 [1] 0.2928286 0.5644829 0.7539627 0.8693979 0.9338976
 [6] 0.9677886 0.9847848 0.9929987 0.9968496 0.9986097
```

Building a plot (1/2)

- Make a data frame out of the values to plot:

```
d <- tibble(n=ns, power=ans$power)
d
```

```
# A tibble: 10 x 2
       n power
   <dbl> <dbl>
 1    10 0.293
 2    20 0.564
 3    30 0.754
 4    40 0.869
 5    50 0.934
 6    60 0.968
 7    70 0.985
 8    80 0.993
 9    90 0.997
10   100 0.999
```

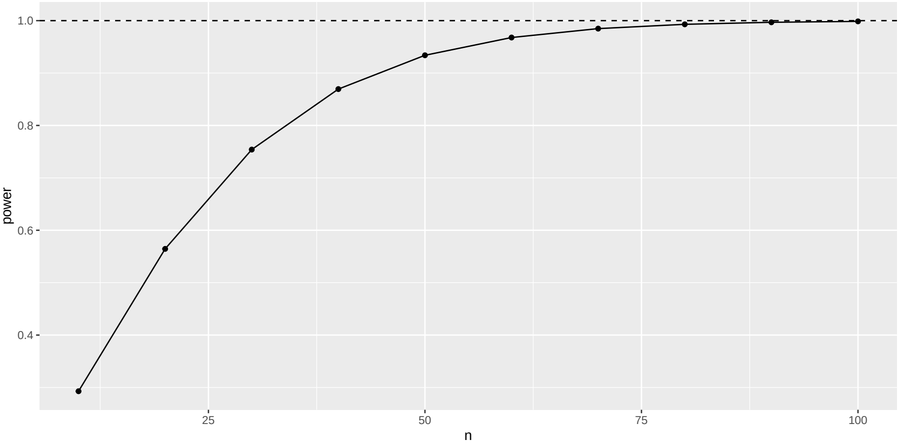
Building a plot (2/2)

- Plot these as points joined by lines, and add horizontal line at 1 (maximum power):

```
ggplot(d, aes(x = n, y = power)) + geom_point() +
  geom_line() +
  geom_hline(yintercept = 1, linetype = "dashed") -> g
```

The power curve

```
g
```

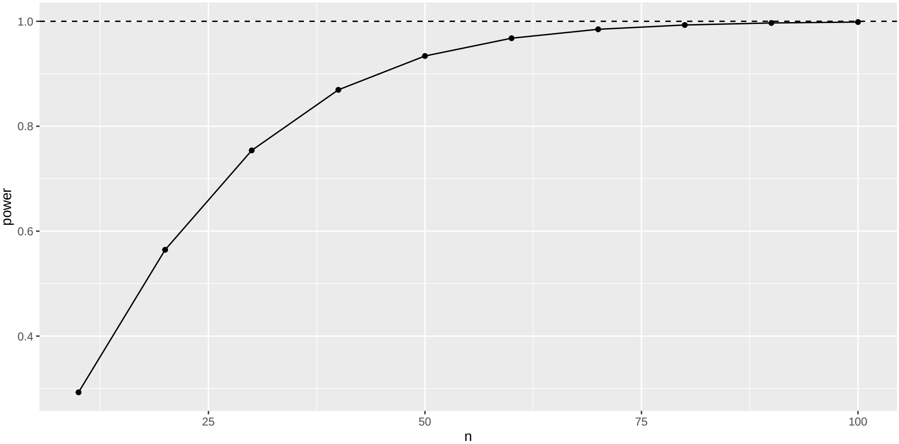


Another way to do it:

```
tibble(n=ns) %>% rowwise() %>%
  mutate(power_output =
           list(power.t.test(n = n, delta = 10-8, sd = 4,
                             type = "one.sample"))) %>%
  mutate(power = power_output$power) %>%
  ggplot(aes(x=n, y=power)) + geom_point() + geom_line() +
    geom_hline(yintercept=1, linetype="dashed") -> g2
```

The power curve done the other way

```
g2
```



Power curves for means

- Can also investigate power as it depends on what the true mean is (the farther from null mean 10, the higher the power will be).
- Investigate for two different sample sizes, 15 and 30.
- First make all combos of mean and sample size:

```
means <- seq(6,10,0.5)
means
```

```
[1]  6.0  6.5  7.0  7.5  8.0  8.5  9.0  9.5 10.0
```

```
ns <- c(15,30)
ns
```

```
[1] 15 30
```

```
combos <- crossing(mean=means, n=ns)
```

The combos

```
combos
```

```
# A tibble: 18 x 2
    mean     n
   <dbl> <dbl>
 1   6      15
 2   6      30
 3   6.5    15
 4   6.5    30
 5   7      15
 6   7      30
 7   7.5    15
 8   7.5    30
 9   8      15
10   8      30
11   8.5    15
12   8.5    30
13   9      15
14   9      30
15   9.5    15
16   9.5    30
17  10      15
18  10      30
```

Calculate and plot

- Calculate the powers, carefully:

```
ans <- with(combos, power.t.test(n=n, delta=10-mean, sd=4,
                                 type="one.sample"))
ans$power
```

```
 [1] 0.94908647 0.99956360 0.88277128 0.99619287
 [5] 0.77070660 0.97770385 0.61513033 0.91115700
 [9] 0.43784659 0.75396272 0.27216777 0.51028173
[13] 0.14530058 0.26245348 0.06577280 0.09719303
[17] 0.02500000 0.02500000
```

Make a data frame to plot

pulling things from the right places:

```
d <- tibble(n=factor(combos$n), mean=combos$mean,
            power=ans$power)
d
```

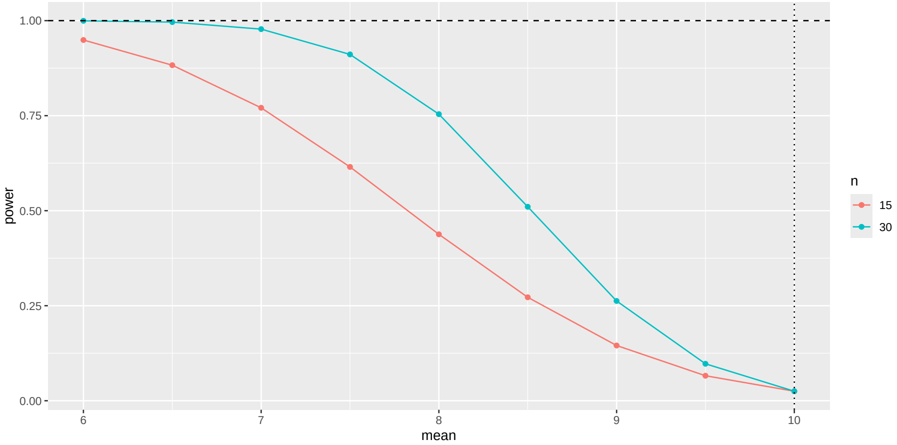
```
# A tibble: 18 x 3
   n      mean  power
   <fct> <dbl>  <dbl>
 1 15      6   0.949
 2 30      6   1.00
 3 15      6.5 0.883
 4 30      6.5 0.996
 5 15      7   0.771
 6 30      7   0.978
 7 15      7.5 0.615
 8 30      7.5 0.911
 9 15      8   0.438
```

then make the plot:

```
g  <-  ggplot(d, aes(x = mean, y = power, colour = n)) +
  geom_point() + geom_line() +
  geom_hline(yintercept = 1, linetype = "dashed") +
  geom_vline(xintercept = 10, linetype = "dotted")
```

The power curves

```
g
```



Comments

- When `mean=10`, that is, the true mean equals the null mean, H_0 is actually true, and the probability of rejecting it then is $\alpha = 0.05$.
- As the null gets more wrong (mean decreases), it becomes easier to correctly reject it.
- The blue power curve is above the red one for any mean $<$ 10, meaning that no matter how wrong H_0 is, you always have a greater chance of correctly rejecting it with a larger sample size.
- Previously, we had $H_0 : \mu = 10$ and a true $\mu = 8$, so a mean of 8 produces power 0.42 and 0.80 as shown on the graph.
- With $n = 30$, a true mean that is less than about 7 is almost certain to be correctly rejected. (With $n = 15$, the true mean needs to be less than 6.)

Two-sample power

- For kids learning to read, had sample sizes of 22 (approx) in each group
- and these group SDs:

```
kids %>% group_by(group) %>%
  summarize(n = n(), s = sd(score))
```

```
# A tibble: 2 x 3
  group     n     s
  <chr> <int> <dbl>
1 c        23  17.1
2 t        21  11.0
```

Setting up

- suppose a 5-point improvement in reading score was considered important (on this scale)
- in a 2-sample test, nul(difference of) mean is zero, so `delta` is true difference in means
- what is power for these sample sizes, and what sample size would be needed to get power up to 0.80?
- SD in both groups has to be same in `power.t.test`, so take as 14.

Calculating power for sample size 22 (per group)

```
power.t.test(n=22, delta=5, sd=14, type="two.sample",
             alternative="one.sided")
```

```
     Two-sample t test power calculation

              n = 22
          delta = 5
             sd = 14
      sig.level = 0.05
          power = 0.3158199
    alternative = one.sided

NOTE: n is number in *each* group
```

sample size for power 0.8

```
power.t.test(power=0.80, delta=5, sd=14, type="two.sample",
             alternative="one.sided")
```

```
     Two-sample t test power calculation

              n = 97.62598
          delta = 5
             sd = 14
      sig.level = 0.05
          power = 0.8
    alternative = one.sided

NOTE: n is number in *each* group
```

Comments

- The power for the sample sizes we have is very small (to detect a 5-point increase).
- To get power 0.80, we need 98 kids in *each* group!