

# Ch 20: Inference for comparing two proportions

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## Learning objectives for today

1. Learn about two methods to make confidence intervals for the difference between two proportions: i) the large sample methods, and ii) the plus four method
2. Conduct a hypothesis test for the difference between two proportions using a z-test
3. Leave how to use `prop.test()`, a function introduced last class, to conduct the hypothesis test in R.

## Comparing two proportions (Chapter 20)

- Two SRS from independent populations

Notation:

Population	Population proportion	Sample size	Sample proportion
1	$p_1$	$n_1$	$\hat{p}_1$
2	$p_2$	$n_2$	$\hat{p}_2$

## Large-sample confidence interval for the difference of two proportions

- Use when the number of observed successes and failures are  $> 10$  for both samples

$$(\hat{p}_1 - \hat{p}_2) \pm z^* \sqrt{\frac{\hat{p}_1(1 - \hat{p}_1)}{n_1} + \frac{\hat{p}_2(1 - \hat{p}_2)}{n_2}}$$

- Just like for the difference between two means, the SE of the difference is the square root of the sum of the variances.
- This large-sample interval often has low coverage. That is, if you repeated the method 100 times, less than 95 of the 100 created intervals would contain the true value for the difference between the proportions for a 95% CI.
- This is the same issue as the large sample method for one proportion.

## Example using the large sample method

Patients in a randomized controlled trial who were severely immobilized were randomly assigned to receive either Fragamin (to prevent blood clots) or a placebo. The number of patients experiencing deep vein thrombosis (DVT) was recorded:

	DVT	no DVT	Total	$\hat{p}$
Fragamin	42	1476	1518	$\frac{42}{1518} = 2.77\%$
Placebo	73	1400	1473	$\frac{73}{1473} = 4.96\%$

Check the conditions:

- We can apply the large study method because the sample sizes are large
- The number of observed successes and failures are larger than 10 (i.e., 42, 73, 1476, and 1400 all larger than 10).
- The estimate of the difference between the two proportions is  $4.96\% - 2.77\% = 2.19\%$
- We can use the large sample method to make a confidence interval for this difference

### Example using the large sample method

$$(\hat{p}_1 - \hat{p}_2) \pm z^* \sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}}$$

$$(0.0496 - 0.0277) \pm z^* \sqrt{\frac{0.0496(1-0.0496)}{1473} + \frac{0.0277(1-0.0277)}{1518}}$$

$$0.0219 \pm 1.96 \times 0.0071 = 0.008 \text{ to } 0.0358$$

Thus, the 95% confidence interval for the difference goes from 0.8% to 3.58%

### When dataset is small: Plus 4 method for the comparison of two proportions

- When the assumptions of the large sample method are not satisfied, we use the plus four method.
- When you have two samples this method says: add 4 observations total (2 to each sample), and 1 success and 1 failure to each of the two samples:

$$\tilde{p}_1 = \frac{\text{no. of successes in pop1} + 1}{n_1 + 2}$$

$$\tilde{p}_2 = \frac{\text{no. of successes in pop2} + 1}{n_2 + 2}$$

$$(\tilde{p}_1 - \tilde{p}_2) \pm z^* \sqrt{\frac{\tilde{p}_1(1-\tilde{p}_1)}{n_1+2} + \frac{\tilde{p}_2(1-\tilde{p}_2)}{n_2+2}}$$

- Use when the sample size is at least five, with any counts of success and failure (can even use when number of successes or failures = 0)
- Much more accurate when the sample sizes are small
- May be conservative (has higher coverage than suggested by the confidence level)

### Example using the Plus Four Method

	Flu	no Flu	Total	$\hat{p}$
Vaccine	4	96	100	0.04
Placebo	11	89	100	0.11

Here, we don't have 10 "successes" (flu) in both groups, so we cannot use the large sample method.

### Example using the Plus Four Method

$$\tilde{p}_1 = \frac{\text{no. of successes in pop1} + 1}{n_1 + 2} = \frac{4+1}{100+2} = 0.04901961$$

$$\tilde{p}_2 = \frac{\text{no. of successes in pop2} + 1}{n_2 + 2} = \frac{11+1}{100+2} = 0.1176471$$

$$(\tilde{p}_1 - \tilde{p}_2) \pm z^* \sqrt{\frac{\tilde{p}_1(1-\tilde{p}_1)}{n_1+2} + \frac{\tilde{p}_2(1-\tilde{p}_2)}{n_2+2}}$$

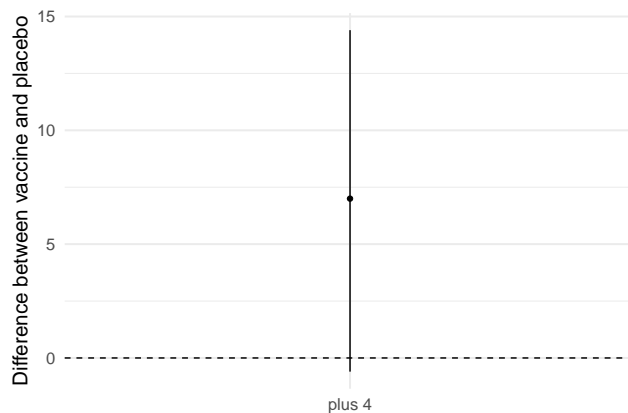
Filling in  $p_1 = 0.04901961$ ,  $p_2 = 0.1176471$  and  $n_1=n_2=100$  gives:

$$\left(\frac{12}{102} - \frac{5}{102}\right) \pm 1.96 \times 0.0384 = -0.6\% \text{ to } 14.4\%$$

The 95% CI of the difference ranges from -0.6 percentage points to 14.4% percentage points. While this CI contains 0 (the null hypothesized value for no difference) most of the values contained within it are positive, perhaps suggesting support for the alternative hypothesis. In this case, we might want to collect more data to create a more precise CI.

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### Hypothesis testing when you have two samples and binary data

$H_0 : p_1 = p_2$ , which can also be written as  $p_1 - p_2 = 0$

$H_a :$

- Two-sided:  $p_1 \neq p_2$  or  $p_1 - p_2 \neq 0$
- One-sided upper tail:  $p_1 > p_2$  or  $p_1 - p_2 > 0$
- One-sided lower tail:  $p_1 < p_2$  or  $p_1 - p_2 < 0$

### What does it mean to assume the null is true?

- If the null hypothesis is true, then  $p_1$  is truly equal to  $p_2$ . In this case, our best estimate of the underlying proportion that they are both equal to is

$$\hat{p} = \frac{\text{no. successes in both samples}}{\text{no. individuals in both samples}}$$

- Also, our best guess at the SE for  $\hat{p}$  is calculated by taking the formula for the SE for the difference between the two proportions and substituting in  $\hat{p}$  for  $p_1$  and  $p_2$ :

$$\sqrt{\frac{\hat{p}(1-\hat{p})}{n_1} + \frac{\hat{p}(1-\hat{p})}{n_2}}$$

$$\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

### Hypothesis testing when you have two samples and binary data

Using the information from the previous slide, we can create the z-test for the difference between two proportions as:

$$z = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\hat{p}(1 - \hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Use this z-test when the counts of successes and failures are 5 or larger in both samples

### Example of hypothesis testing when you have two samples and binary data

Recall the RCT data on the occurrence of deep vein thrombosis between Fragamin vs. placebo groups:

	DVT	no DVT	Total	$\hat{p}$
Fragamin	42	1476	1518	0.0277
Placebo	73	1400	1473	0.0496

$H_0 : p_1 = p_2$ , or that the rate of DVT is the same between Fragamin and placebo groups.

Suppose you're interested in knowing whether these two groups had different rates of DVT. Then,  $H_a : p_1 \neq p_2$

### Example of hypothesis testing when you have two samples and binary data

1. Compute  $\hat{p} = \frac{42+73}{1518+1473} = \frac{115}{2991} = 0.03844868$
2. Compute the SE:  $\sqrt{0.0384(1 - 0.0384)\left(\frac{1}{1518} + \frac{1}{1473}\right)} = 0.007032308$
3. Compute the test statistic:

$$z = \frac{\hat{p}_1 - \hat{p}_2}{SE}$$

$$z = \frac{0.04955872 - 0.02766798}{0.007032308} = 3.11$$

4. Calculate the p-value

```
pnorm(q = 3.112881, lower.tail = F)*2
```

```
## [1] 0.001852707
```

The p-value is equal to 0.19%. Under the null hypothesis of no difference between the proportions, there is a 0.19% chance of observing the difference we saw (or more extreme) which provides evidence in favor of the alternative hypothesis that these proportions are different.

### Example of hypothesis testing when you have two samples and binary data

Here is how to conduct the hypothesis test using R:

```
prop.test(x = c(42, 73), # x is a vector of number of successes
          n = c(1518, 1473)) # n is a vector of sample sizes
```

```
##
## 2-sample test for equality of proportions with continuity correction
##
## data:  c(42, 73) out of c(1518, 1473)
## X-squared = 9.107, df = 1, p-value = 0.002546
## alternative hypothesis: two.sided
## 95 percent confidence interval:
## -0.036376917 -0.007404562
## sample estimates:
##      prop 1      prop 2
## 0.02766798 0.04955872
```

Interpreting this output:

- Focus on the **p-value** output
- R is actually doing a chi-squared test (which we learn soon!). This test provides identical findings to performing a z-test for the equality of two proportions.
- In the output **X-squared = 9.69** is the test statistic for the Chi-squared test (where Chi is the greek letter  $\chi$ ). The X-squared test statistic is the z-test statistic squared. That is  $\sqrt{9.69} = 3.11$ , which is what we found on previous slide.
- R provides a slightly different p-value than we calculated because the test it performs has a continuity correction, which makes its test a bit better than the one we did by hand. This is okay. If you want to use R to check your hand calculation, you need to add the argument **correct = F** to the calculation.

### Comparing treatments for UTIs

- In a study of urinary tract infections, patients were randomly assigned to one of two treatment regimes:
  - i) trimethoprim / sulfamethoxazole or,
  - ii) fosfomycin / trometamol
- 92 of the 100 patients assigned to treatment (i) showed bacteriological cure while 61 of 100 assigned to treatment (ii) showed bacteriological cure.

### Comparing treatments for UTIs

- What is the estimate of the difference in proportions?
- Perform a test to provide evidence whether or not this difference in proportions reflects a true difference between treatments.

### Comparing treatments for UTIs

- What is the estimate of the difference in proportions?

$.92 - .61 = .31$ . There is a 31 percentage point difference between the two proportions.

### Comparing treatments for UTIs

- Perform a test to provide evidence whether or not this difference in proportions reflects a true difference between treatments.

Large sample z-test of the form  $\frac{p_1 - p_2}{SE}$ , where  $SE = \sqrt{\hat{p}(1 - \hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$  and  $\hat{p} = \frac{92+61}{200} = 0.765$

$$SE = \sqrt{0.765(1 - 0.765)\left(\frac{1}{100} + \frac{1}{100}\right)} = 0.05996249$$

$$z = 0.31 / 0.05996249 = 5.169899$$

Without using R, we know the corresponding p-value will be very small.

```
pnorm(5.169899, lower.tail = F)*2
```

```
## [1] 2.342205e-07
```

Interpretation of the p-value: Assuming the null hypothesis of no difference between the proportions, there is less than a 0.0001% chance of seeing a difference of the magnitude that we saw (or larger). This provides evidence in favor of the alternative hypothesis of a difference between the proportions