Lecture 10: Z-test, T-test, and test the difference in the mean

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Z-test: Example

- Example: A battery manufacturer claims that the average lifespan of their batteries is 1000 hours and standard deviation of 50 hours. A consumer protection agency takes a random sample of 50 batteries and finds that the sample mean lifespan is 990 hours.
- We want to test whether the manufacturer’s claim is true at a **5% significance level**.

Z-test

Z-test: whether the sample mean $\bar{X}$ differs significantly from a known population mean μ_0.

$$Z = \frac{\bar{X} - \mu_0}{\sigma/\sqrt{n}}$$

One-sided or two-sided

- Use a one-sided test when you want to test whether the population parameter is greater than or less than a specific value.
  - **Left-tailed test**:
  - **Right-tailed test:**
- A **one-sided test** is used when your research hypothesis is **directional**—that is, you expect the parameter to be either greater than or less than a specific value, but not both.
  - if prior research or theory strongly suggests that a new drug increases response time compared to a known standard, you would use a one-sided test to check if the mean response time is significantly higher.
  - If our study strongly suggests that the manufacture may be lie about the average lifetime about their product, then you would use a one-sided test to check if the lifetime is significantly lower than what they claims.

(significantly higher/lower) → with (rare event) probability smaller than a given threshold.

Two-sided test

- Use when you are testing for any deviation from a specified value without assuming a direction.
  - For instance, if you are testing whether a new process leads to a different average performance (without a clear expectation of it being higher or lower), a two-sided test is used.

Example: Evaluating the effect of a curriculum re-design on student performance.

- 1. The previous average score was 75.
- 2. We collect a sample of 100 students who followed the new curriculum, and their average score is 78.
- 3. The population standard deviation is known to be 10.

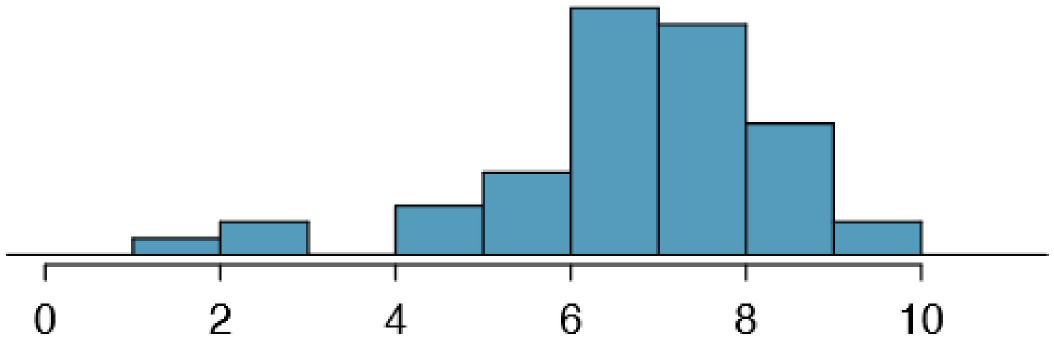
Is the new mean significantly different from the previous mean? With significance level 0.05.

T-test: Unknown variance.

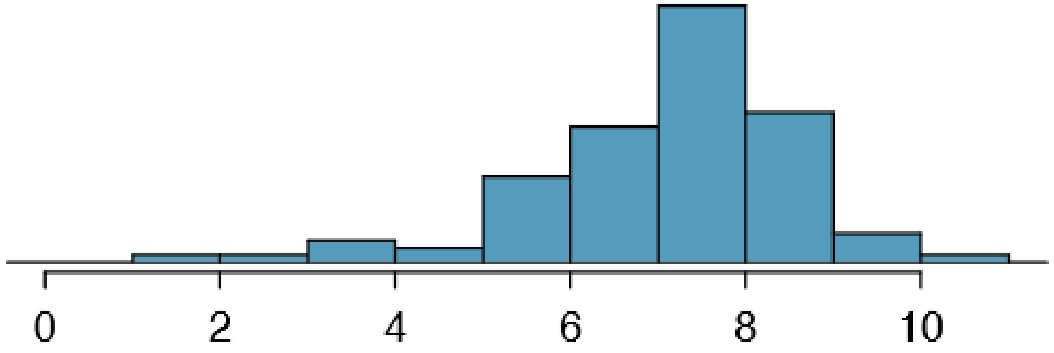
- A battery manufacturer claims that the **average lifespan** of their batteries is **1000 hours**. A consumer protection agency takes a **random sample of 50 batteries** and the lifetime is reported as follows:

Test of difference in the mean

- A data set called baby smoke represents a random sample of 150 cases of mothers and their newborns in North Carolina over a year.
- We are particularly interested in two variables: weight and smoke.
- The weight variable represents the weights of the newborns and the smoke variable describes which mothers smoked during pregnancy.
- We would like to know if there is convincing evidence that newborns from mothers who smoke have a different average birth weight than newborns from mothers who don't smoke?



Newborn weights (lbs) from mothers who smoked



Newborn weights (lbs) from mothers who did not smoke

Hypothesis testing: Difference in the mean

- The null hypothesis represents the case of no difference between the groups.

- H_0: There is no difference in average birth weight for newborns from mothers who did and did not smoke.

- H_1: There is some difference in average newborn weights from mothers who did and did not smoke.

Testing a difference of two means

- Testing the difference of two means:

$$\text{Given two data samples } \mathbf{X} = [X_0, X_1, \cdots, X_{n_X-1}] \text{ and } \mathbf{Y} = [Y_0, Y_1, \cdots, Y_{n_Y-1}],$$
$$\text{where all data samples are assumed to be independent}$$

- Test statistics: difference between sample mean estimators.

$$T = \hat{\mu}_X - \hat{\mu}_Y.$$

- Given the observed difference t, what is the probability to observe a difference this big assuming the null hypothesis is true?

$$P(T \geq t | H_0) \text{ (one-sided) or}$$
$$P(|T| \geq t | H_0) \text{ (two-sided)}$$

Testing a difference of two means

- What we need to determine? $$T = \hat{\mu}_X - \hat{\mu}_Y.$$

- The observed difference t and some other information can be obtained from data:

	smoker	nonsmoker
mean	6.78	7.18
st. dev.	1.43	1.60
samp. size	50	100

Testing a difference of two means

What is the distribution of T?

- Given X_i, Y_k have the same, known variance?
- Given X_i, Y_k have the different but known variances?
- Given X_i, Y_k's variances are unknown but equal?
- Given X_i, Y_k' s variances are unknown and unequal?

Some preliminaries

- Let X_i be i.i.d. RV, what is the mean and variance of $M_n = \frac{1}{n}\sum_{i=1}^{n} X_i$?
- The linear combination of two independent Gaussian RVs. is a Gaussian RV.

Testing a difference of two means: **Different but known variances**

Given two data samples $\mathbf{X} = [X_0, X_1, \cdots, X_{n_X-1}]$ and $\mathbf{Y} = [Y_0, Y_1, \cdots, Y_{n_Y-1}]$, where all data samples are assumed to be independent

Assume the X_i's variance is σ_X^2, Y_k's variance is σ_Y^2

$$T = \hat{\mu}_X - \hat{\mu}_Y.$$

Testing a difference of two means: **same, known variance**

Given two data samples $\mathbf{X} = [X_0, X_1, \cdots, X_{n_X-1}]$ and $\mathbf{Y} = [Y_0, Y_1, \cdots, Y_{n_Y-1}]$, where all data samples are assumed to be independent

Assume X_i, Y_k share the same variance σ^2.

$$T = \hat{\mu}_X - \hat{\mu}_Y .$$

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Testing a difference of two means: **Unknown and unequal variances**

Given two data samples $\mathbf{X} = [X_0, X_1, \cdots, X_{n_X - 1}]$ and $\mathbf{Y} = [Y_0, Y_1, \cdots, Y_{n_Y - 1}]$, where all data samples are assumed to be independent

Assume X_i, Y_k share the same variance σ^2.

- However, we don't know the variance.

Testing a difference of two means: **Unknown and equal variances**

Given two data samples $\mathbf{X} = [X_0, X_1, \cdots, X_{n_X-1}]$ and $\mathbf{Y} = [Y_0, Y_1, \cdots, Y_{n_Y-1}]$, where all data samples are assumed to be independent

Assume the X_i's variance is σ_X^2, Y_k's variance is σ_Y^2

- However, we don't know the variance for either?

Testing a difference of two means: **Unknown and unequal variances**

If we cannot assume that the variances are equal, then the distribution of the following normalized form will be approximately equal to a Student's t distribution:

$$\frac{T}{S_d} \sim t_\nu,$$

where

$$S_d = \sqrt{\frac{S_x^2}{n_x} + \frac{S_y^2}{n_y}}.$$

The standard error of the difference of two sample means

Here, the value of ν must be determined from the sample standard errors of the means, which we denote by

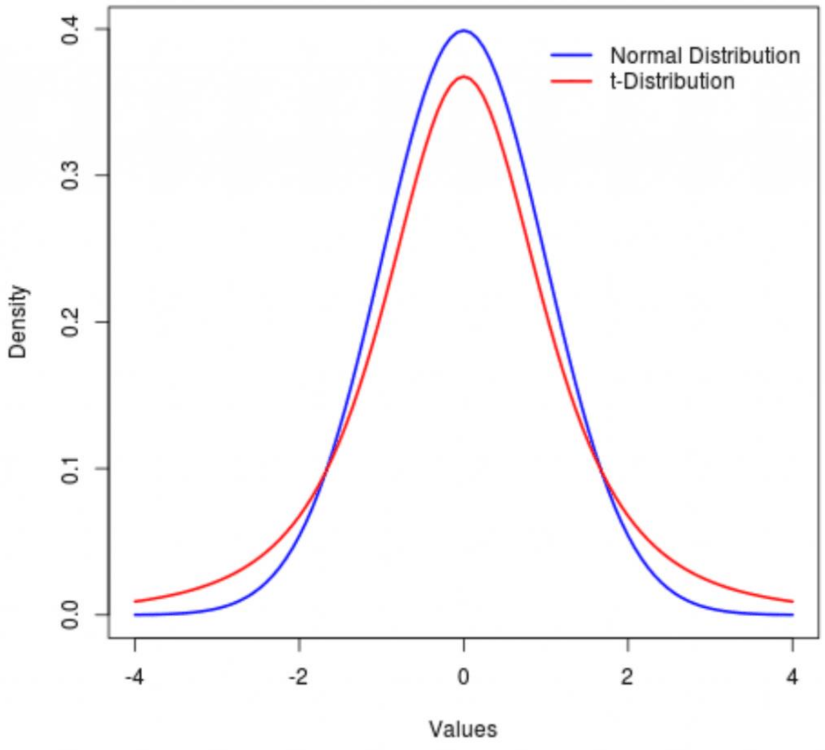
$$s_{\bar{x}}^2 = s_x^2/n_x, \text{ and}$$
$$s_{\bar{y}}^2 = s_y^2/n_x, \text{ and}$$

standard error of a single mean

Then ν is the largest integer that satisfies

$$\nu \leq \frac{\left(s_{\bar{x}}^2 + s_{\bar{y}}^2\right)^2}{s_{\bar{x}}^4/(n_x - 1) + s_{\bar{y}}^4/(n_y - 1)}.$$

Testing a difference of two means: **Unknown and unequal variances**



- For sample sizes greater than 30, the differences between the t distribution and the normal distribution are negligible.

- In other words, we can assume, when the sample size > 30,

$$\frac{T}{S_d} \sim N(0, 1)$$

Example

- Mother smoke related to baby weights.

	smoker	nonsmoker
mean	6.78	7.18
st. dev.	1.43	1.60
samp. size	50	100

- Observation: no knowledge about the underlying distribution: unknown and unequal variance

- The standard error of a single mean is:

- The standard error of the difference of two sample means:

Example (cont.)