Power

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Definition of power

To get straight to the point: **power** of a hypothesis test is the probability of rejecting the null hypothesis when it’s false. In this tutorial we’ll define what this means in the context of a specific example: a z-test on the mean of a sample of IQ scores. This first part should be a review for you.

Z-test example

Suppose you want to test the hypothesis that the mean IQ of students at UW have a higher IQ than the population IQ of 100 points. We know that the standard deviation of the IQ’s in the population is 15.

You go and sample 9 UW students and obtain a mean IQ of 106. Is this mean significantly greater than 100? Use a value of \( \alpha = 0.05 \).

To answer this we need to calculate the standard error of the mean and then convert our observed mean into a z-score:

\[
\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{n}} = \frac{15}{\sqrt{9}} = 5
\]

and

\[
z = \frac{\bar{x} - \mu_{\text{hyp}}}{\sigma_{\bar{x}}} = \frac{106 - 100}{5} = 1.2
\]

With a one-tailed test and \( \alpha = 0.05 \), the critical value if \( z \) is \( z_{crit} = 1.64 \). Since our observed value of \( z=1.2 \) is less than the critical value of 1.64 we fail to reject \( H_0 \) and conclude that the mean IQ of UW students is not significantly greater than 100.

Here’s our usual figure describing this outcome, with the rejection region shown in red:
If $H_0$ is true

If we happen to reject $H_0$ it could be that $H_0$ is true and we just happened to grab a sample with a high mean IQ. This kind of mistake, when we accidentally reject $H_0$ is called a **Type I Error**.

In the figure above, type I errors happen when the null hypothesis is true, and our observed value of $z$ falls in the red rejection region. It should be clear that the probability of a Type I error is $\alpha$, which is 0.05 in our example.

We also know the probability of correctly failing to reject the null hypothesis since it’s just the opposite of a type I error: $1 - \alpha = 1 - 0.05 = 0.95$.

If $H_0$ is false

Remember, the power of a test is the probability of correctly rejecting $H_0$.

To calculate power we have to assume $H_0$ is false, so we need to know the true mean of the population. You probably appreciate that this is weird. If we knew the true mean then we wouldn’t have to run an experiment in the first place.

Since we don’t know the true mean of the distribution we play a ‘what if’ game and calculate power for some hypothetical value for the true mean. For our example, let’s say that the true mean is equal to the observed mean of $\bar{x} = 106$.

We just calculated that our observed mean of $\bar{x} = 106$ converted to a $z$-score of $z = 1.2$. So if we assume that the true mean IQ score is $\mu_{true} = 106$, then our $z$-scores will be drawn from a ‘true’ population with mean that I’ll call $z_{true}$:

$$z_{true} = \frac{(\mu_{true} - \mu_{hyp})}{\sigma_{\bar{x}}} = \frac{(\mu_{true} - \mu_{hyp})}{\frac{\sigma_{\bar{x}}}{\sqrt{n}}} = \frac{(106 - 100)}{\frac{15}{\sqrt{9}}} = \frac{6}{5} = 1.2$$

Here’s the true distribution drawn on top of the null hypothesis distribution:
Importantly, even though we’re now drawing z-scores from the ‘true’ distribution our decision rule remains the same: if our observed value of z is greater than the critical value (z = 1.64 in this example), then we reject $H_0$. I’ve colored this region above z = 1.64 under the ‘true’ distribution in green.

It should be clear that this green area is the power of our hypothesis test. It’s the probability of rejecting $H_0$ when $H_0$ is false. You can see that the green area (power) is greater than the red area ($\alpha$).

The green area is the area above the normal distribution with $z_{true} = 1.2$ and $\sigma = 1$ above a value of $z_{crit} = 1.64$. If we subtract 1.2 from both the $z_{true}$ and $z_{crit}$, power is equivalent to the area under the standard normal distribution ($\mu = 0$, $\sigma = 1$) above $z = 1.64 - 1.2 = 0.44$. If you look this up in the z-table (or z-calculator) you’ll find that this area is 0.3282.

If the power of a test is 0.3282, it means that if the true mean of the population had an IQ of 106, then with our sample size of 9 and $\alpha = 0.05$, the probability that we’d draw a mean that is significantly greater than 100 is 0.3282. You can think of the power as the probability of successfully detecting an effect that is different from the null hypothesis.

**The 2x2 matrix of All Things That Can Happen**

Out there in the world, the null hypothesis is either true or it is not true. To make a decision about the state of the world we
run a hypothesis test and decide either to reject or to fail to reject the null hypothesis. Therefore, when we run a hypothesis test, there are four possible things that can happen. This can be described as a 2x2 matrix:

Of the four things, two are correct outcomes (green) and two are errors (red). Consider the case where the null hypothesis is \( H_0 \) is true. We’ve made an error if we reject \( H_0 \). Rejecting \( H_0 \) when it’s actually true is called a **Type I error**.

\[
\text{Pr(Type I error)} = \alpha
\]

Type I errors happen when we accidentally reject \( H_0 \). This happens when we happen to grab a mean that falls in the rejection region of the null hypothesis distribution. We know the probability of this happening because we’ve deliberately chosen it - it’s \( \alpha \).

It follows that the probability of correctly rejecting \( H_0 \) is \( 1 - \alpha \).

\[
\text{Pr(Type II error)} = \beta
\]

Type II errors happen when we accidentally fail to reject \( H_0 \). This happens when we grab a mean from the 'true' distribution that happens to fall outside the rejection region of the null hypothesis distribution. We have a special greek letter for this probability, \( \beta \) ('beta').

\[
\text{power} = 1 - \beta
\]

Remember, power is the probability of correctly rejecting \( H_0 \). This is the opposite of a Type II error, which is when we accidentally fail to reject \( H_0 \). Therefore, power = 1-Pr(\text{Type II error}) which is the same as power = 1 - \( \beta \).

We can summarize all of these probabilities in our 2x2 table of All Things that Can Happen:

<table>
<thead>
<tr>
<th>Decision</th>
<th>( H_0 ) is true</th>
<th>( H_0 ) is false</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fail to reject ( H_0 )</td>
<td>1-( \alpha )</td>
<td>Type II error: ( \beta )</td>
</tr>
<tr>
<td>Reject ( H_0 )</td>
<td>Type I error: ( \alpha )</td>
<td>power: 1-( \beta )</td>
</tr>
</tbody>
</table>

For our example, we can fill in the probabilities for all four types of events:

<table>
<thead>
<tr>
<th>Decision</th>
<th>( H_0 ) is true</th>
<th>( H_0 ) is false</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fail to reject ( H_0 )</td>
<td>0.95</td>
<td>0.67179</td>
</tr>
<tr>
<td>Reject ( H_0 )</td>
<td>0.05</td>
<td>0.32821</td>
</tr>
</tbody>
</table>

**Things that affect power**

Figures like the one above with overlapping null and true distributions show up in all textbook discussion of power. Google 'statistical power' and check out the associated images. It’s an ubiquitous image because it’s very useful for visualizing how power is affected by various factors in your experimental design and your data.

Looking at the figure, you should see that power will increase if we separate the two distributions. There are a variety of ways this can happen.

**Increasing effect size increases power**

The most obvious way is for us to choose a larger value for the mean of the true distribution. In other words, if we have a larger effect size, we’ll get a larger value for power.

The effect size in our current example on IQ’s is

\[
\frac{|\mu_{\text{true}} - \mu_{\text{hyp}}|}{\sigma} = \frac{|106 - 100|}{15} = 0.4.
\]

This is a medium effect size.
What if we think that the true distribution has a mean of $\mu_{true} = 112$ IQ points? This will increase the effect size to:

$$\frac{|\mu_{true} - \mu_{hyp}|}{\sigma} = \frac{|112-100|}{15} = 0.8.$$ 

which is a large effect size.

Means drawn from this new true distribution will have z-scores that are normally distributed with a mean of

$$z_{true} = \frac{(\mu_{true} - \mu_{hyp})}{\sigma_x} = \frac{(112-100)}{5} = 2.4$$

Here’s that standard diagram for this new true distribution:

Notice what has and has not changed. The true distribution is now shifted rightward to have a mean of $z_{true} = 2.4$. However, the critical region is unchanged - we still reject $H_0$ if our observed value of $z$ is greater than 1.64.

Remember, power is the green area - the area under the true distribution above the critical value of $z$. You can now see how shifting the true distribution rightward increases power. For our numbers, increasing the effect size from 0.4 to 0.8 increased the power from 0.32821 to 0.7749.

**Increasing sample size increases power**

Another way to shift the true distribution away from the null distribution is to increase the sample size. For example, let’s go back and assume that our true mean IQ is 106 points, but we increase our sample size from 9 to 36. The z-score for the mean of the true distribution is now:

$$z_{true} = \frac{(\mu_{true} - \mu_{hyp})}{\sigma_x} = \frac{(106-100)}{\frac{15}{\sqrt{36}}} = \frac{6}{2.5} = 2.4$$

This shift in $z_{true}$ from 1.2 to 2.4 is the same as for the last example where $\mu_{true}$ was 112 IQ points and a sample size of 9. Thus, the power will also be 0.7764.

Note that increasing sample size increased the power without affecting the effect size (which doesn’t depend on sample size).
Increasing $\alpha$ increases power

A third thing that affects power is your choice of $\alpha$. Recall that back in our original example of IQ scores with $\mu_{true} = 106$ points, the power for $\alpha = 0.05$ was 0.32821.

What if we keep the sample size at 9 so that effect size the same, but decrease our value of $\alpha$ to our second-favorite value, 0.01?

Decreasing $\alpha$ from 0.05 to 0.01 increases the critical value of $z$ from 1.64 to 2.33.

Here’s the new picture:

Notice that the true distribution still has a mean of $z_{true} = 1.2$. But shifting the critical value of $z$ cuts into the green area, decreasing the power from 0.32821 to 0.13.

This illustrates a classic trade-off of Type I and Type II errors in decision making. Decreasing $\alpha$ by definition decreases the probability of making a Type I error. That is, decreasing $\alpha$ makes it harder to accidentally reject $H_0$. But that comes with the cost decreasing $\alpha$ also makes it harder to correctly reject $H_0$ if it was true. That’s the same as a decrease in power, and a corresponding increase the probability of a Type II error ($\beta$), since power $= 1 - \beta$.

Get it? If you’re still following things, when $\alpha$ goes down, $z_{crit}$ goes up, power goes down and Pr(Type II error) goes up. *whew*

Power goes down with two-tailed tests

Let’s look at our power calculation as we shift our original example from a one-tailed to a two-tailed test. Power calculations with two-tailed tests are a little more complicated because we have two rejection regions, but the concept is the same. We’ll keep the true mean at 106 IQ points, the sample size $n = 9$ and $\alpha = 0.05$.

Recall that the critical value of $z$ for a two-tailed test increases because we need to split the area in rejection region in half. You can therefore think of shifting to a two-tailed test as sort of like decreasing $\alpha$, which as we know decreases power.

Here’s the new picture:
We have two rejection regions now, one for $z < -1.64$ and one for $z > 1.64$. Power is, as always, the area under the true distribution that falls in the rejection region. For a two-tailed test we need to add up two areas. For this example, the area in the negative region is so far below the true distribution that the area below $z = -1.96$ is effectively zero. This leaves the green area above $z = 1.96$. Our power is therefore 0.22. This is lower than the power for the one-tailed test calculated above (0.32821).

Here’s a summary of how things affect power:

<table>
<thead>
<tr>
<th>Things that affect power</th>
<th>Pr(Type I error)</th>
<th>effect size</th>
<th>power</th>
</tr>
</thead>
<tbody>
<tr>
<td>increasing effect size</td>
<td>same</td>
<td>increases</td>
<td>increases</td>
</tr>
<tr>
<td>increasing sample Size</td>
<td>same</td>
<td>same</td>
<td>increases</td>
</tr>
<tr>
<td>increasing alpha</td>
<td>increases</td>
<td>same</td>
<td>increases</td>
</tr>
<tr>
<td>two-tailed test</td>
<td>same</td>
<td>same</td>
<td>decreases</td>
</tr>
</tbody>
</table>

Go through the table and be sure to understand not only what happens with each thing, but also why.

**Power Calculator**

Calculating power by hand by drawing curves and finding areas is great for intuition, but not so useful if you want to calculate power on a daily basis (as one does). Fortunately there is a power calculator in the Excel spreadsheet - it’s the last tab called ‘Power’. It takes in an effect size, a sample size and $\alpha$, since these three things are all you need to calculate power.

For our original example of a one-tailed test with an effect size of 0.4, a sample size of $n = 9$ and $\alpha = 0.05$, the calculator gives:

<table>
<thead>
<tr>
<th>effect size (g)</th>
<th>n</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>9</td>
<td>0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>One tailed test one mean</th>
<th>$z_{crit}$</th>
<th>$z_{crit} - z_{obs}$</th>
<th>area</th>
<th>power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.6449</td>
<td>0.4449</td>
<td>0.3282</td>
<td>0.3282</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two tailed test one mean</th>
<th>$z_{crit}$</th>
<th>$z_{crit} - z_{obs}$</th>
<th>area</th>
<th>power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.96</td>
<td>0.76</td>
<td>0.2236</td>
<td>0.2244</td>
</tr>
<tr>
<td></td>
<td>-1.96</td>
<td>-3.16</td>
<td>0.0008</td>
<td></td>
</tr>
</tbody>
</table>

You can see the power we calculated for a one-tailed test, 0.32821, and for the two-tailed test, 0.22.
See if you can get the power values we calculated above by opening up the spreadsheet and plugging in the an effect size of 0.8, a sample size of 36 or changing $\alpha$ to 0.01.

**Power Curves**

If your computer explodes on the way to work (or you’re not allowed to use a computer for some reason) I’ve provided ‘power curves’ that allow you to estimate power based on effect size, the sample size, $\alpha$ and the number of tails.

You can download the pdf file containing the power curves at: [http://courses.washington.edu/psy315/pdf/PowerCurves.pdf](http://courses.washington.edu/psy315/pdf/PowerCurves.pdf)

For our original example of a one-tailed test with $\alpha = 0.5$, the curves look like this:

The x-axis is effect size, and each of the lines corresponds to a different sample size. See if you can estimate the power of our original example that had an effect size of 0.4 and a sample size of 9.

Most of the things that affect power can be seen in the power curves. What happens when effect size increases? What happens when the sample size increases? If you open up the power curve document you can also see what happens when alpha and the number of tails change by flipping through the pages.

**What is a good amount of power?**

In some sense, you can’t have to much power in your experiment. It’d be great to be 100% sure that you’d make the right decision and reject $H_0$ if $H_0$ is false. But the nature of variability will never allow that. Instead we have to settle for a reasonable probability that we will detect a difference from the null hypothesis.

A 'desirable' level of power is around 0.8. Like $\alpha = .05$, this is an arbitrary number but it is pervasive in the social and behavioral sciences.
The power curves are useful for estimating how to design an experiment to have a desirable level of power. For our example, we’ll use the power curves and see what sample size we’d need to get a power of 0.8 given our effect size is 0.4.

It looks like we’d need a sample size of around 39 to get this desired power of 0.8. If you go to the power calculator and plug in \( n = 39 \) you’ll find that this is about right:

<table>
<thead>
<tr>
<th>effect size (g)</th>
<th>n</th>
<th>( \alpha )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>39</td>
<td>0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>One tailed test one mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>( z_{crit} )</td>
</tr>
<tr>
<td>1.6449</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two tailed test one mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>( z_{crit} )</td>
</tr>
<tr>
<td>1.96</td>
</tr>
<tr>
<td>-1.96</td>
</tr>
</tbody>
</table>

**When do we use power?**

Power is most commonly used to determine what sample size you might need when designing an experiment. Often we’ll take some estimate of the effect size based either on previous studies or on some pilot data for our calculation of power. For our example, you might imagine that or original study was just a pilot study, which why it had only 9 subjects. We could then use the measured effect size of 0.4 as a guess of the true effect size. Using this, we’d then estimate that we’d need 39 subjects in a real study to achieve a desired power of 0.8.

In cases like this when we assume the true distribution based on an effect size from an experiment the resulting power is called 'observed power' or sometimes 'post-hoc power'.
Example from the survey

Suppose you want to test the hypothesis of women at the University of Washington differs from the average height of women in the US, which is 64.6 inches. We’ll use the women in our class as a sample from the UW population. According to the survey that you filled out, the average height of the 78 women in our class is 63.86 inches with a standard deviation of 2.6469. Using an \( \alpha \) value of 0.01, is this height significantly different than the US population?

To answer this we need to conduct a t-test for a single mean, since we don’t know the standard deviation of the population. We first calculate the standard error of the mean:

\[
s_x = \frac{s x}{\sqrt{n}} = \frac{2.6469}{\sqrt{78}} = 0.2997
\]

and use it to calculate our observed value of t:

\[
t = \frac{\bar{x} - \mu_{hyp}}{s_x} = \frac{63.86 - 64.6}{0.2997} = -2.47
\]

This will be a two tailed test. Using table D we find that the critical value of t is:

\[
t_{crit} = \pm 2.64 (df = 77)
\]

We fail to reject \( H_0 \). The height of UW women (M = 63.86, SD = 2.65) is not significantly different than 64.6 \( , t(77) = -2.47 \), \( p=0.0156 \).

Let’s figure out the ‘effective power’ of this test. That is, if we assume that our observed mean is the actual true population mean, let’s calculate the probability that we’d correctly detect this difference from the null hypothesis mean.

First, we calculate effect size, and then we’ll look up the power using either the power calculator or the power curve. The effect size is:

\[
g = \frac{|\bar{x} - \mu_{hyp}|}{s_x} = \frac{|63.86 - 64.6|}{2.6469} = 0.28
\]

This is a small effect size.

If you plug in 0.28 for the effect size, our sample size of \( n = 78 \) and \( \alpha = 0.01 \) into the power calculator, you’ll get:

<table>
<thead>
<tr>
<th>effect size (g)</th>
<th>n</th>
<th>( \alpha )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.28</td>
<td>78</td>
<td>0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>One tailed test one mean</th>
<th>z_{crit}</th>
<th>( z_{crit} - z_{obs} )</th>
<th>area</th>
<th>power</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3263</td>
<td>-0.1465</td>
<td>0.5583</td>
<td>0.5583</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two tailed test one mean</th>
<th>z_{crit}</th>
<th>( z_{crit} - z_{obs} )</th>
<th>area</th>
<th>power</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5758</td>
<td>0.1029</td>
<td>0.459</td>
<td>0.459</td>
<td></td>
</tr>
<tr>
<td>-2.5758</td>
<td>-5.0487</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

So the observed power for this two-tailed test is 0.459.

If you’re stuck on a desert island without electricity (but you brought your power curves) you can find power by using the appropriate page:
Finally, if we were to determine the number of subjects needed to obtain a power of 0.8, we can find use the power curve again and estimate the sample size:
So it looks like for an effect size of 0.28 and a two-tailed test with $\alpha = 0.01$, we’d need to have about 149 students to get a power of 0.8.
Questions

Here are 10 practice questions followed by their answers.

1) Your advisor asks you to sample the volume of 40 ubiquitous musical groups from a population and obtain a mean volume of 18.38 and a standard deviation of 1.5877.
Using an alpha value of $\alpha = 0.01$, is this observed mean significantly less than an expected volume of 19?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

2) We decide to sample the IQ of 91 psych 315 students from a population and obtain a mean IQ of 85.38 and a standard deviation of 5.6851.
Using an alpha value of $\alpha = 0.05$, is this observed mean significantly less than an expected IQ of 86?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

3) You sample the damage of 54 comfortable baby names from a population and obtain a mean damage of 36.32 and a standard deviation of 5.4503.
Using an alpha value of $\alpha = 0.01$, is this observed mean significantly different than an expected damage of 38?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

4) Let’s pretend that you sample the determination of 37 politicians from a population and obtain a mean determination of 53.46 and a standard deviation of 3.8657.
Using an alpha value of $\alpha = 0.01$, is this observed mean significantly less than an expected determination of 55?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

5) You are walking down the street and sample the laughter of 56 first ice dancers from a population and obtain a mean laughter of 6 and a standard deviation of 8.5164.
Using an alpha value of $\alpha = 0.01$, is this observed mean significantly greater than an expected laughter of 5?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

6) Let’s pretend that you sample the morality of 17 elbows from a population and obtain a mean morality of 45.94 and a standard deviation of 6.1763.
Using an alpha value of $\alpha = 0.05$, is this observed mean significantly less than an expected morality of 46?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

7) For some reason you sample the anger of 39 defective oceans from a population and obtain a mean anger of 16.63 and a standard deviation of 5.3131.
Using an alpha value of $\alpha = 0.01$, is this observed mean significantly less than an expected anger of 19?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?
8) You are walking down the street and sample the grief of 102 UW undergraduates from a population and obtain a mean grief of 44.09 and a standard deviation of 5.3098.
Using an alpha value of $\alpha = 0.01$, is this observed mean significantly different than an expected grief of 45?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

9) I sample the homework of 51 exams from a population and obtain a mean homework of 5.44 and a standard deviation of 1.6811.
Using an alpha value of $\alpha = 0.01$, is this observed mean significantly less than an expected homework of 6?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

10) Let’s sample the baggage of 100 dollars from a population and obtain a mean baggage of 87.24 and a standard deviation of 5.7193.
Using an alpha value of $\alpha = 0.01$, is this observed mean significantly greater than an expected baggage of 87?
What is the effect size?
Is the effect size small, medium or large?
What is the observed power?
What sample size would you need to obtain a power of 0.8?

**Answers**

1) 

$\bar{x} = 18.38$, $s_x = 1.5877$, $n = 40$

$s_x = \frac{s_x}{\sqrt{n}} = \frac{1.5877}{\sqrt{40}} = 0.251$

t = \frac{\bar{x} - \mu_{hyp}}{s_x} = \frac{18.38 - 19}{0.251} = -2.46$

df = (n-1) = (40-1) = 39

t_{crit} = -2.43

We reject $H_0$.
The volume of ubiquitous musical groups ($M = 18.38$, SD = 1.59) is significantly less than 19, $t(39) = -2.46$, $p=0.0092$.

Effect size: $g = \frac{|\bar{x} - \mu_{hyp}|}{s_x} = \frac{|18.38 - 19|}{1.5877} = 0.3894$

This is a medium effect size.

The observed power for one tailed test with an effect size of $0.3894$, $n = 40$ and $\alpha = 0.01$ is 0.5543.
You’d need a sample of 66 musical groups to obtain a power of 0.8.

2) 

$\bar{x} = 85.38$, $s_x = 5.6851$, $n = 91$

$s_x = \frac{s_x}{\sqrt{n}} = \frac{5.6851}{\sqrt{91}} = 0.596$
We fail to reject $H_0$.
The IQ of psych 315 students ($M = 85.38$, $SD = 5.69$) is not significantly less than 86 , $t(90) = -1.05$, $p=0.1492$.

Effect size: $g = \frac{|\bar{x} - \mu_{hyp}|}{s_x} = \frac{|85.38 - 86|}{5.6851} = 0.1097$

This is a small effect size.

The observed power for one tailed test with an effect size of $= 0.1097$, $n = 91$ and $\alpha = 0.05$ is 0.2748.
You’d need a sample of 514 psych 315 students to obtain a power of 0.8.

3)

$\bar{x} = 36.32$, $s_x = 5.4503$, $n = 54$

$s_x = \frac{s_x}{\sqrt{n}} = \frac{5.4503}{\sqrt{54}} = 0.7417$

$t = \frac{\bar{x} - \mu_{hyp}}{s_x} = \frac{36.32 - 38}{0.7417} = -2.26$

df = (n-1) = (54-1) = 53

$t_{crit} = \pm 2.67$

We fail to reject $H_0$.
The damage of comfortable baby names ($M = 36.32$, $SD = 5.45$) is not significantly different than 38 , $t(53) = -2.26$, $p=0.0279$.

Effect size: $g = \frac{|\bar{x} - \mu_{hyp}|}{s_x} = \frac{|36.32 - 38|}{5.4503} = 0.3076$

This is a small effect size.

The observed power for two tailed test with an effect size of $= 0.3076$, $n = 54$ and $\alpha = 0.01$ is 0.3762.
You’d need a sample of 123 baby names to obtain a power of 0.8.

4)

$\bar{x} = 53.46$, $s_x = 3.8657$, $n = 37$

$s_x = \frac{s_x}{\sqrt{n}} = \frac{3.8657}{\sqrt{37}} = 0.6355$

$t = \frac{\bar{x} - \mu_{hyp}}{s_x} = \frac{53.46 - 55}{0.6355} = -2.42$

df = (n-1) = (37-1) = 36

$t_{crit} = -2.43$

We fail to reject $H_0$.
The determination of politicians ($M = 53.46$, $SD = 3.87$) is not significantly less than 55 , $t(36) = -2.42$, $p=0.0104$. 

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Effect size:  \( g = \frac{|\bar{x} - \mu_{hyp}|}{s_{\bar{x}}} = \frac{|53.46 - 55|}{3.8657} = 0.3975 \)

This is a medium effect size.

The observed power for one tailed test with an effect size of 0.3975, \( n = 37 \) and \( \alpha = 0.01 \) is 0.5365. You’d need a sample of 64 politicians to obtain a power of 0.8.

\[ 5) \]
\( \bar{x} = 6, s_{\bar{x}} = 8.5164, n = 56 \)
\( s_{\bar{x}} = \frac{s_x}{\sqrt{n}} = \frac{8.5164}{\sqrt{56}} = 1.138 \)
\( t = \frac{\bar{x} - \mu_{hyp}}{s_{\bar{x}}} = \frac{6 - 5}{1.138} = 0.88 \)
\( df = (n-1) = (56-1) = 55 \)
\( t_{crit} = 2.40 \)

We fail to reject \( H_0 \).

The laughter of first ice dancers (M = 6, SD = 8.52) is not significantly greater than 5 , \( t(55) = 0.88, p=0.192 \).

Effect size:  \( g = \frac{|\bar{x} - \mu_{hyp}|}{s_{\bar{x}}} = \frac{|6-5|}{8.5164} = 0.1173 \)

This is a small effect size.

The observed power for one tailed test with an effect size of 0.1173, \( n = 56 \) and \( \alpha = 0.01 \) is 0.0737. You’d need a sample of 729 ice dancers to obtain a power of 0.8.

\[ 6) \]
\( \bar{x} = 45.94, s_{\bar{x}} = 6.1763, n = 17 \)
\( s_{\bar{x}} = \frac{s_x}{\sqrt{n}} = \frac{6.1763}{\sqrt{17}} = 1.498 \)
\( t = \frac{\bar{x} - \mu_{hyp}}{s_{\bar{x}}} = \frac{45.94 - 46}{1.498} = -0.04 \)
\( df = (n-1) = (17-1) = 16 \)
\( t_{crit} = -1.75 \)

We fail to reject \( H_0 \).

The morality of elbows (M = 45.94, SD = 6.18) is not significantly less than 46 , \( t(16) = -0.04, p=0.4836 \).

Effect size:  \( g = \frac{|\bar{x} - \mu_{hyp}|}{s_{\bar{x}}} = \frac{|45.94-46|}{6.1763} = 0.0102 \)

This is a small effect size.

The observed power for one tailed test with an effect size of 0.0102, \( n = 17 \) and \( \alpha = 0.05 \) is 0.0545. You’d need a sample of 10000 elbows to obtain a power of 0.8.
\( \bar{x} = 16.63, s_x = 5.3131, n = 39 \)

\[ s_x = \frac{s_x}{\sqrt{n}} = \frac{5.3131}{\sqrt{39}} = 0.8508 \]

\[ t = \frac{\bar{x} - \mu_{hyp}}{s_x} = \frac{16.63-19}{.8508} = -2.78 \]

\[ df = (n-1) = (39-1) = 38 \]

\[ t_{crit} = -2.43 \]

We reject \( H_0 \).

The anger of defective oceans (M = 16.63, SD = 5.31) is significantly less than 19 , \( t(38) = -2.78, p=0.0042 \).

Effect size: \( g = \frac{|\bar{x} - \mu_{hyp}|}{s_x} = \frac{|16.63-19|}{5.3131} = 0.4451 \)

This is a medium effect size.

The observed power for one tailed test with an effect size of \( g = 0.4451 \), \( n = 39 \) and \( \alpha = 0.01 \) is 0.6748. You’d need a sample of 51 oceans to obtain a power of 0.8.

8)

\( \bar{x} = 44.09, s_x = 5.3098, n = 102 \)

\[ s_x = \frac{s_x}{\sqrt{n}} = \frac{5.3098}{\sqrt{102}} = 0.5257 \]

\[ t = \frac{\bar{x} - \mu_{hyp}}{s_x} = \frac{44.09-45}{0.5257} = -1.74 \]

\[ df = (n-1) = (102-1) = 101 \]

\[ t_{crit} = \pm 2.63 \]

We fail to reject \( H_0 \).

The grief of UW undergraduates (M = 44.09, SD = 5.31) is not significantly different than 45 , \( t(101) = -1.74, p=0.0853 \).

Effect size: \( g = \frac{|\bar{x} - \mu_{hyp}|}{s_x} = \frac{|44.09-45|}{5.3098} = 0.1721 \)

This is a small effect size.

The observed power for two tailed test with an effect size of \( g = 0.1721 \), \( n = 102 \) and \( \alpha = 0.01 \) is 0.2011. You’d need a sample of 394 UW undergraduates to obtain a power of 0.8.

9)

\( \bar{x} = 5.44, s_x = 1.6811, n = 51 \)

\[ s_x = \frac{s_x}{\sqrt{n}} = \frac{1.6811}{\sqrt{51}} = 0.2354 \]

\[ t = \frac{\bar{x} - \mu_{hyp}}{s_x} = \frac{5.44-6}{0.2354} = -2.4 \]

\[ df = (n-1) = (51-1) = 50 \]

\[ t_{crit} = -2.40 \]
We fail to reject $H_0$.
The homework of exams ($M = 5.44$, $SD = 1.68$) is not significantly less than 6, $t(50) = -2.4$, $p=0.0101$.

Effect size: $g = \frac{|\bar{x} - \mu_{hyp}|}{s_x} = \frac{|5.44-6|}{1.6811} = 0.3357$

This is a small effect size.

The observed power for one tailed test with an effect size of $g = 0.3357$, $n = 51$ and $\alpha = 0.01$ is 0.5283. You’d need a sample of 89 exams to obtain a power of 0.8.

10)

$\bar{x} = 87.24, s_x = 5.7193, n = 100$

$s_{\bar{x}} = \frac{s_x}{\sqrt{n}} = \frac{5.7193}{\sqrt{100}} = 0.5719$

$t = \frac{\bar{x} - \mu_{hyp}}{s_{\bar{x}}} = \frac{87.24-87}{0.5719} = 0.42$

$df = (n-1) = (100-1) = 99$

$t_{crit} = 2.37$

We fail to reject $H_0$.
The baggage of dollars ($M = 87.24$, $SD = 5.72$) is not significantly greater than 87, $t(99) = 0.42$, $p=0.3374$.

Effect size: $g = \frac{|\bar{x} - \mu_{hyp}|}{s_x} = \frac{|87.24-87|}{5.7193} = 0.0421$

This is a small effect size.

The observed power for one tailed test with an effect size of $g = 0.0421$, $n = 100$ and $\alpha = 0.01$ is 0.0284. You’d need a sample of 5662 dollars to obtain a power of 0.8.