Two-Way Repeated Measures ANOVA

A repeated measures test is what you use when the same participants take part in all of the conditions of an experiment.

This kind of analysis is similar to a repeated-measures (or paired samples) t-test, in that they are both tests which are used to analyse data collected from a within participants design study. However, while the t-test limits you to situations where you only have one independent variable with two levels, a repeated measures ANOVA can be done when you have more than two conditions, and/or more than one independent variable.

In this tutorial we will consider an example where we have two independent variables and one dependent variable.

**Worked Example**

Let’s consider a fictional study designed to investigate how we mentally represent concepts. Imagine that we want to explore whether the way we think about specific objects (or concepts) mirrors what we actually experience in real life, or whether these concept representations are independent of reality.

For example, when we think of an object (e.g. a car), do we always think about it in the same way? If concepts had no bearing on the real-world you might expect this to be the case, as the underlying concept would always be the same. In contrast, just as changes in context and perspective can alter how we see an object in the real world, do such changes also affect our mental representations? If so, this would suggest concepts are represented as ‘perceptual simulations’ of the real world.

To investigate this, participants were asked to read sentences (one at a time) that appeared on a computer screen. Each sentence placed them in different positions relative to an object; for example, either inside (‘you are driving a car’) or outside (‘you are fuelling a car’) an object.

Immediately after each sentence, participants saw a probe word that was either part of that object or not. To test the effect of functional perspective on mental representations, parts from two different locations were used: inside parts (e.g. a steering wheel) and outside parts (e.g. a tyre).

Participants had to verify, as quickly as possible, whether or not the part presented belonged to the object by pressing a key on the computer. Correct Response Times (measured in milliseconds) were taken as the Dependent Variable.
In this example, the experiment used a 2 x 2 repeated-measures design.

The two independent variables were Functional Perspective and Part Location:

- **Functional Perspective** related to the position participants took in relation to the object being imagined. It had two levels: **Inside** and **Outside**, depending on where the sentence they read had placed them.

- **Part Type** also had two levels, which were also **Inside** and **Outside**: depending on where the part named in the probe word was located on the target object.

All participants took part in all of the conditions.

This is what the data collected should look like in SPSS (and can be found in the SPSS file ‘Week 4 Concepts Data.sav’):
As a general rule in SPSS, each row in the spreadsheet should contain all of the data provided by one participant.

In a repeated measures design, this means that separate columns are needed to represent each of the conditions of the experiment. Please note that this differs from independent tests where the IVs are coded in separate columns and data for the different experimental conditions is provided by separate individuals.

In this example, we have two IVs, each with two levels. This means that each participant takes part in four (2x2) conditions:

1. Part Inside + Inside Functional Perspective
2. Part Inside + Outside Functional Perspective
3. Part Outside + Inside Functional Perspective
4. Part Outside + Outside Functional Perspective

The different columns in SPSS display the following data:

- **ID_No**: This just refers to the ID number assigned to the participants. We use numbers as identifiers instead of participant names, as this allows us to collect data while keeping the participants anonymous.

- **PI_FPI**: This column displays each participant’s mean reaction time in milliseconds (ms) to the inside part words (PI) when taking an inside functional perspective (FPI).

- **PI_FPO**: This column displays each participant’s mean reaction time to the inside part words (PI) when taking an outside functional perspective (FPO).

- **PO_FPI**: This column displays each participant’s mean reaction time in milliseconds (ms) to the outside part words (PO) when taking an inside functional perspective (FPI).

- **PO_FPO**: This column displays each participant’s mean reaction time to the outside part words (PO) when taking an outside functional perspective (FPO).

The Two-Way Repeated-Measures ANOVA compares the scores in the different conditions across both of the variables, as well as examining the interaction between them.

In this case, we want to compare participant’s part verification time (measured in milliseconds) for the two functional perspectives, the two part locations, and we want to look at the interaction between these variables.
To start the analysis, begin by **CLICKING** on the **Analyze** menu, select the **General Linear Model** option, and then the **Repeated Measures...** sub-option.

The “**Repeated Measures Define Factor(s)**” box should now appear. This is where we tell SPSS what our different IVs are, and how many levels they have. SPSS doesn’t mind what names we give the variables, but it’s probably a good idea to give them sensible names which we can interpret easily when we look at the output. In this case, let’s name our variables **Part_Location** (the underscore is used to separate the words, as SPSS doesn’t like spaces in variable names) and **Perspective**.

We can define our first variable by typing the name (**Part_Location**) into the **Within-Subject Factor Name** box, and entering the number of levels (2) into the **Number of Levels** box:

**CLICK** on **Add** to add this variable to the analysis.
Next, we need to define the second independent variable in the same way.

Again, **CLICK** on **Add** to add this variable to the analysis. And once you have finished defining your IVs, **CLICK** on the **Define** button to continue with the analysis.

This opens up the **Repeated Measures** dialog box. We now have to use this to tell SPSS the way our variable conditions fit into the ANOVA.
At the top of the **Within-Subjects Variables** box SPSS tells you that there are two factors to be analyzed (the ones we have just named): **Part_Location** and **Perspective**.

In the box itself, there are a series of question marks with bracketed numbers. These numbers represent the levels of our IVs. In this example, there are two IVs so there are also two numbers in each of the brackets. The first number refers to the levels of the first variable we defined (**Part_Location**), while the second refers to Perspective.

Our task is to replace the question marks with the names of the conditions that match the variable level codes.

For example, the first line (1,1) means that we have to move across the condition that contains data for the first level of Part_Location (in this case: inside) and the first level of Perspective (which is also 'inside'). So we have to **CLICK** on the condition that matches this and move it across to the Within-Subjects Variables box by **CLICKING** on the arrow button.

We then need to do the same for the following three conditions in the list.

For example, the next position we want to fill is labelled (1,2), which means we want the condition that contains data for the first level of Part_Location (again, this is 'inside') and the second level of Perspective (i.e. outside). So we need to **SELECT** the matching condition and move it across to the **Within-Subjects Variables** box.

Repeat these steps for all of the conditions, until the box looks like the following screenshot.
Now we have told SPSS what it is that we want to analyse, we are almost ready to run the ANOVA. But before we do, we need to ask SPSS to produce some other information for us, to help us understand our data.

First, we want to ask SPSS to produce some descriptive statistics for our different conditions (i.e. means and standard deviations). CLICK on the Options button (highlighted in the image above) to do this.

This options the Repeated Measures: Opens dialog box. To produce means for the different variables and conditions, highlight all of the factor names in the Factor(s) and Factor Interactions box, as is shown here.

When doing this yourself, remember that if you hold down the SHIFT key you can click on and highlight all of the factors in one go. (OVERALL) just gives you the overall mean of the whole data set. As we are looking for group differences, this isn't very informative... so it isn't really worth including in this step (although you can if you like)!

To move the variables across, CLICK the blue arrow highlighted above.
In the bottom half of the dialogue box, there are a number of tick box options that you can select to get more information about the data in your output. In this example we are just going to select two.

First, **CLICK** on Descriptive Statistics, so we can produce our means and standard deviations.

Next, **CLICK** on Estimates of effect size to produce effect size information.

Finally, **CLICK** on Continue to proceed.

Almost there... but before we run our ANOVA, we also want to tell SPSS to create a graph of our data for us. This will help us interpret any interactions that there might be between our two Independent Variables.

**CLICK** on the Plots button to do this

This opens the next dialog box.

Here we are going to tell SPSS what type of graph we want. For this example, let's put **Part_Location** on the horizontal (x) axis and use **separate lines** for the two types of
**Perspective** (inside and outside)... although it wouldn’t matter if you did this the other way round.

This plot will show us whether the effect of Part Location changes depending on the Functional Perspective the participants took. The **vertical (y) axis** will show the **dependent variable** which is **Response Time**.

As **Part_Location** is already highlighted, you just need to **CLICK** the arrow to the left of the Horizontal Axis box to move the variable across. Then, **SELECT** **Perspective** and move it across to the **Separate Lines** box using the appropriate arrow.

**CLICK** on the **Add** button to add it to the **Plots** box, and then **CLICK Continue** to proceed.

We are now ready to run the analysis! **CLICK OK** to continue.
You can now view the results in the output window:

SPSS produces a lot of output for a 2x2 ANOVA, but don't worry - not all of it is relevant. We will now go through the output box by box.

**Within-Subjects Factors**

**Within-Subjects Factors**

<table>
<thead>
<tr>
<th>Measure: MEASURE_1</th>
<th>Dependent Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part_Location</td>
<td>PI_FPI</td>
</tr>
<tr>
<td>Perspective</td>
<td>PI_FPO</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

This box is here to tell you which numbers SPSS has assigned to the levels of your variables (they are the numbers in the brackets of the main ANOVA dialog box). You may find it useful to refer back to this when interpreting your output.

From looking at the box you should be able to see that for the first factor, **Part_Location**, there are two levels, where the number 1 = inside, number 2 = outside.

For **Perspective**, similarly the number 1 = inside, and the number 2 = outside.
Descriptive Statistics

The next table gives you your means and standard deviations. You need to report these statistics when writing up your results, as they tell you what is happening in your data.

From this table we can see that participants were fastest in conditions when the functional perspective and part location matched (mean PIFPI = 941.03ms; mean POFPO = 964.75ms) compared to when they differed (mean PIFPO = 1053.75ms; mean POFPI = 1012.37ms).

While this suggests that there may be interaction between the variables, we need to look at the inferential statistics to confirm this.

Multivariate Tests

This table is not necessary for the interpretation of the ANOVA results, so feel free to ignore it at this point!

Mauchly’s Test of Sphericity

This table tests whether the assumption of homogeneity of variance for independent tests; and like Levene’s test, we do not want Mauchly’s test to reach significance. However, rather than assuming equal levels of variance in the data for the different conditions, in this case we assume that the relationship between the pairs of experimental conditions is similar. This is quite a difficult concept to get your head around...

The good news is, you only need to look at this table when at least one of your repeated measures variables has more than two levels... which is not the case in this example!!
Tests of Within-Subjects Effects

This is the most important table in the output. The key columns you need to interpret your analysis are highlighted here:

- df stands for degrees of freedom. Degrees of freedom are crucial in calculating statistical significance, so you need to report them. Don’t worry too much about the stats involved in this though, as SPSS automatically controls the calculations for you.

- F stands for F-Ratio. This is the test value calculated by the ANOVA, you need to report the F values for all of your variables and interactions. In this case, this would need to know the dfs for Part_Location, Perspective and the interaction Part_Location*Perspective, as well as their related Error dfs.

With Two-Way ANOVA, you need to report the df values for all of your variables and interactions. In this case, you would need to know the dfs for Part_Location, Perspective and the interaction Part_Location*Perspective, as well as their related Error dfs.

- F stands for F-Ratio. This is the test value calculated by the ANOVA, you need to report the F values for all of your variables and interactions, in this case: Part_Location, Perspective and Part_Location*Perspective.

It is calculated by dividing the mean squares for each variable or interaction by the error mean squares. Essentially, this is the systematic variance divided by the unsystematic (error) variance. The larger the impact of your manipulation (i.e. the systematic variance) the larger your F-Ratio and the more likely it is your effect will be significant.
• **Sig** stands for **Significance Level**. This column gives you the probability that the results could have occurred by chance, if the null hypothesis were true.

The convention is that the p-value should be smaller than 0.05 for the F-ratio to be significant. If this is the case (i.e. \( p < 0.05 \)) we reject the null hypothesis, inferring that the results didn’t occur by chance, but are instead due to the effect of your manipulation. However, if the p-value is larger than 0.05, then we have to retain the null hypothesis; that there is no difference between the groups.

• **Partial Eta Squared**. While the p-value can tell you whether the difference between conditions is statistically significant, partial eta squared (\( \eta_p^2 \)) tells you about the magnitude of this difference. As such, we refer to this as a measure of **effect size**.

To determine how much of an effect your IV has had on the DV, you can use the following cut-offs to interpret your results:

- 0.14 or more are large effects
- 0.06 or more are medium effects
- 0.01 or more are small effects

So we know which columns we need to look at, but what numbers do we use?

To make life easier for you, SPSS groups your analysis into blocks: one block for each variable, or interaction. You deal with each block separately.

### Tests of Within Subjects Effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
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<td>Part Location</td>
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<td>2337.301</td>
<td>0.41</td>
<td>.940</td>
<td>.001</td>
</tr>
<tr>
<td></td>
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<td>2337.301</td>
<td>0.41</td>
<td>.940</td>
<td>.001</td>
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<tr>
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<td>2337.301</td>
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<td>.001</td>
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<td>.940</td>
<td>.001</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>56334.860</td>
<td></td>
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<td>56334.860</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>.026</td>
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<tr>
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<td>8.87</td>
<td>.390</td>
<td>.026</td>
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<td>.026</td>
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<td>.390</td>
<td>.026</td>
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<tr>
<td>Error(Perspective)</td>
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<td>29</td>
<td>36672.196</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greenhouse-Geisser 1063469.692</td>
<td>29</td>
<td>36672.196</td>
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</tr>
<tr>
<td></td>
<td>Huynh-Feldt 1063469.692</td>
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<td>36672.196</td>
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<td></td>
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<tr>
<td></td>
<td>Lower-bound 1063469.692</td>
<td>29</td>
<td>36672.196</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part Location* Perspective</td>
<td>Sphericity Assumed 192792.817</td>
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<td>192792.817</td>
<td>4.287</td>
<td>.047</td>
<td>.126</td>
</tr>
<tr>
<td></td>
<td>Greenhouse-Geisser 192792.817</td>
<td>1</td>
<td>192792.817</td>
<td>4.287</td>
<td>.047</td>
<td>.126</td>
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<td>Huynh-Feldt 192792.817</td>
<td>1</td>
<td>192792.817</td>
<td>4.287</td>
<td>.047</td>
<td>.126</td>
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<tr>
<td></td>
<td>Lower-bound 192792.817</td>
<td>1</td>
<td>192792.817</td>
<td>4.287</td>
<td>.047</td>
<td>.126</td>
</tr>
<tr>
<td>Error(Part_Location*Perspective)</td>
<td>Sphericity Assumed 1304025.756</td>
<td>29</td>
<td>44668.406</td>
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<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
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<td>44668.406</td>
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</tr>
<tr>
<td></td>
<td>Lower-bound 1304025.756</td>
<td>29</td>
<td>44668.406</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
First, let’s look at **Part_Location**. We know that we need to read the numbers from the df, F and Sig column... but the question is which numbers do we need?

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphericity Assumed</td>
<td>2337.331</td>
<td>1</td>
<td>2337.331</td>
<td>0.04</td>
<td>.940</td>
<td>.001</td>
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<tr>
<td>Greenhouse-Geisser</td>
<td>2337.331</td>
<td>1</td>
<td>2337.331</td>
<td>0.04</td>
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<td>.001</td>
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<tr>
<td>Huyhn-Feldt</td>
<td>2337.331</td>
<td>1</td>
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<tr>
<td>Lower-bound</td>
<td>2337.331</td>
<td>1</td>
<td>2337.331</td>
<td>0.04</td>
<td>.940</td>
<td>.001</td>
</tr>
</tbody>
</table>

Which row you choose completely depends on whether your assumption of Sphericity has been met. If your Mauchley’s test was **non-significant** (i.e. the assumption had been met), **or** if you have less than 3 levels in your IV (which we do!), then you read across from the **Sphericity Assumed** row. If Mauchley’s **had** been significant, then you would need to use one of the other rows (often Greenhouse-Geisser).

So using the Sphericity Assumed row, you report your results as:

$$F(IV\ df,\ error\ df) = F-Ratio,\ p = Sig, \ \eta^2 = Partial\ Eta\ Squared$$

...along with a sentence, explaining what you have found. In this case you might say something like:

- **There was no significant main effect of part location on participants’ reaction times** ($F(1,29) = .04, p > .05, \eta^2 = .001$).

Using the same method for the **Perspective** block...

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphericity Assumed</td>
<td>31764.424</td>
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<td>31764.424</td>
<td>.67</td>
<td>.360</td>
<td>.025</td>
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<tr>
<td>Greenhouse-Geisser</td>
<td>31764.424</td>
<td>1</td>
<td>31764.424</td>
<td>.67</td>
<td>.360</td>
<td>.025</td>
</tr>
<tr>
<td>Huyhn-Feldt</td>
<td>31764.424</td>
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<td>31764.424</td>
<td>.67</td>
<td>.360</td>
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<tr>
<td>Lower-bound</td>
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<td>1</td>
<td>31764.424</td>
<td>.67</td>
<td>.360</td>
<td>.025</td>
</tr>
</tbody>
</table>

...you might say something like:

- **There was no significant main effect of Functional Perspective on participants' reaction times** ($F(1,29) = .87, p = .36, \eta^2 = .03$)
And finally, you report your interaction term.

In this case, you might want to say something along the lines of:

There was a significant interaction between Part_Location and Perspective

- \( F(1,29) = 4.29, p < .05, \eta^2_p = .13 \)

But the question is, what does this all mean? We know we have a significant interaction between our independent variables... but we need to explain what this actually means in English!! And to do that, we need to look back at our group means, and see exactly what is happening in each of our different conditions.

You really don’t need to worry about the next couple of tables in your output for interpreting your results... so skip over these and go straight to your Estimated Marginal Means.

**Estimated Marginal Means**

These boxes show you the means and standard error for the different levels of your IVs, and all of the conditions.

1. **Part_Location**

<table>
<thead>
<tr>
<th>Part_Location</th>
<th>Mean</th>
<th>Std. Error</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>997.388</td>
<td>30.614</td>
<td>934.776</td>
</tr>
<tr>
<td>2</td>
<td>988.561</td>
<td>32.087</td>
<td>922.936</td>
</tr>
</tbody>
</table>

First, we can look at our overall means for the different levels of **Part_Location** (i.e. regardless of the functional perspective participants were taking). Remember from our first output table that: 1=Inside; 2=Outside

As such, we might say something like:

Participants’ mean response times for verifying inside parts (mean = 997.39ms) were similar to that of outside parts (mean = 988.56ms)
Next, we can look at our overall means for the different levels of Perspective, regardless of the part location participants were verifying. Again: 1=Inside; 2=Outside. Here we could say:

**Participants’ mean response times were slightly faster when taking an inside functional perspective (mean = 976.70ms) compared to an outside functional perspective (mean = 1009.25ms)**

### 3. Part_Location × Perspective

<table>
<thead>
<tr>
<th>Part_Location</th>
<th>Perspective</th>
<th>Mean</th>
<th>Std. Error</th>
<th>95% Confidence Interval</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
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</tbody>
</table>

Finally, we can look at the interaction between the two variables; that is whether the effect of one variable differs according to the level of the other variable. It can be quite tricky to figure this out just by looking at the means, and this is where our graph comes in handy!

But looking at the table it seems that participants were faster at verifying inside parts when taking an inside (mean = 941.03) compared to outside (mean = 1053.75) functional perspective. In contrast, they showed the opposite pattern for outside part verification (outside perspective mean = 964.75; inside perspective mean = 1012.37).

**Profile Plots**

Next, we can examine the final part of our output: the profile plots. Graphs can really help to interpret your interaction. It’s a good idea to include one in your results. When looking at the graph, it helps to think about:

- Are the lines doing the same thing... If not, what are they doing?
- Are some points on the graph closer together than others?
The trick is to put what you see into words - and this will describe your interaction!

Here we can see that the blue line (which represents **Perspective Level 1 = Inside**) slopes up dramatically. This suggests that when an inside perspective was taken, reaction times were much slower for **Part Location 2 (Outside parts)** than parts that were located inside an object.

In contrast, the green line (which represents **Perspective Level 2 = Outside**) slopes in the opposite direction. This means that reaction times were faster for **Outside parts** than **Inside** parts.

In addition, the difference between response times for **Inside** and **Outside** functional perspectives was more pronounced for inside part verification than for outside part verification.

The trick now is to put all of the information from your output together to make a results section that is sensible and meaningful!!
How do we write it up?

When writing up the findings from your analysis in APA format, you need to include all of the relevant information covered by the previous pages.

- What were the inferential statistics for the two IVs (i.e. what was the ANOVA results)?
- What did this mean in terms of your pattern of results (i.e. what were the means and descriptive statistics for each of your IVs)?
- Was the interaction term significant?
- If so, what does it mean in English (i.e. describe what is going on in the different conditions)?

It is helpful to both you and the reader of your results if you include a table of the means and standard deviations for all of the conditions in your results. It also helps to include a graph of your interaction. To make the graph labels more informative, you can edit your graph by double clicking on it in the output of SPSS.

For this example, you might write a results section that looks like this:

The results of the two-way repeated measures ANOVA revealed that there was no significant main effect of part location on participants' reaction times (F(1,29) = .04, p > .05, \( \eta^2_p \) = .001). Participants' performed similarly when verifying inside (mean = 997.39ms) and outside parts (mean = 988.56ms).

And while descriptive statistics revealed that participants' mean response times were slightly faster when taking an inside functional perspective (mean = 976.70ms) compared to an outside functional perspective (mean = 1009.25ms), the ANOVA revealed that this difference was not significant (F(1,29) = .87, p = .36, \( \eta^2_p \) = .03).

In contrast, there was a significant interaction between Part_Location and Perspective (F(1,29) = 4.29, p < .05, \( \eta^2_p \) = .13) such that participants were fastest in conditions when the functional perspective and part location matched compared to when they differed (see Table 1 below).

<table>
<thead>
<tr>
<th>Table 1: Descriptive Statistics</th>
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<tbody>
<tr>
<td>Part Inside, Functional Perspective Inside</td>
</tr>
<tr>
<td>Part Inside, Functional Perspective Outside</td>
</tr>
<tr>
<td>Part Outside, Functional Perspective Inside</td>
</tr>
<tr>
<td>Part Outside, Functional Perspective Outside</td>
</tr>
</tbody>
</table>

This brings us to the end of this tutorial. Why not download the data file used in this tutorial and see if you can run the analysis yourself?