

SPSS in Windows: ANOVA

Part I: One-way ANOVA (Between-Subjects):

Example:

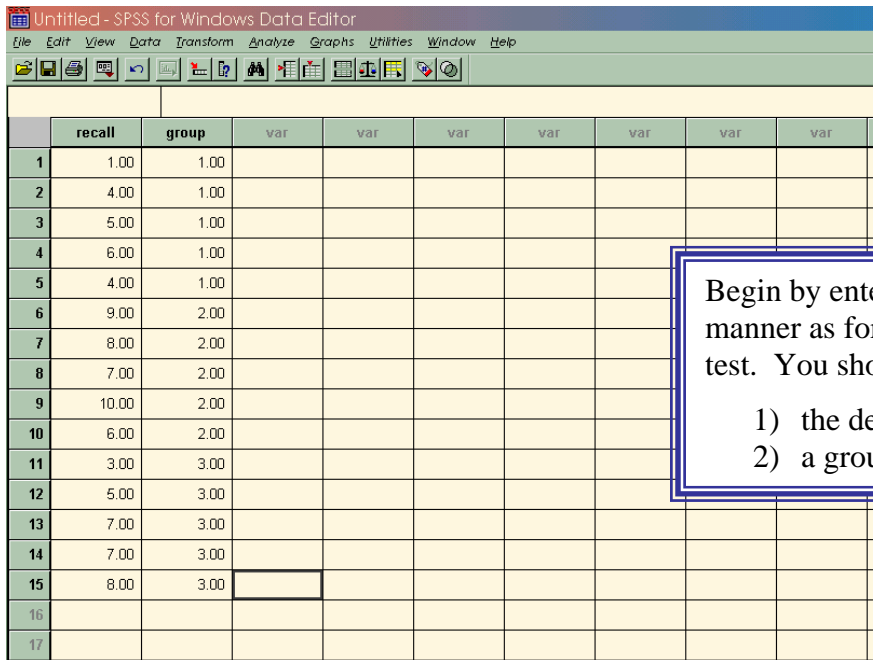
In a verbal learning task, nonsense syllables are presented for later recall. Three different groups of subjects see the nonsense syllables at a 1-, 5-, or 10-second presentation rate. The data (number of errors) for the three groups are as follows:

	1-second group	5-second group	10-second group
Number of errors	1	9	3
	4	8	5
	5	7	7
	6	10	7
	4	6	8

The research question is whether the three groups have the same error rates.

Following the steps to perform one-way ANOVA analysis in SPSS:

Step 1: Enter your data.



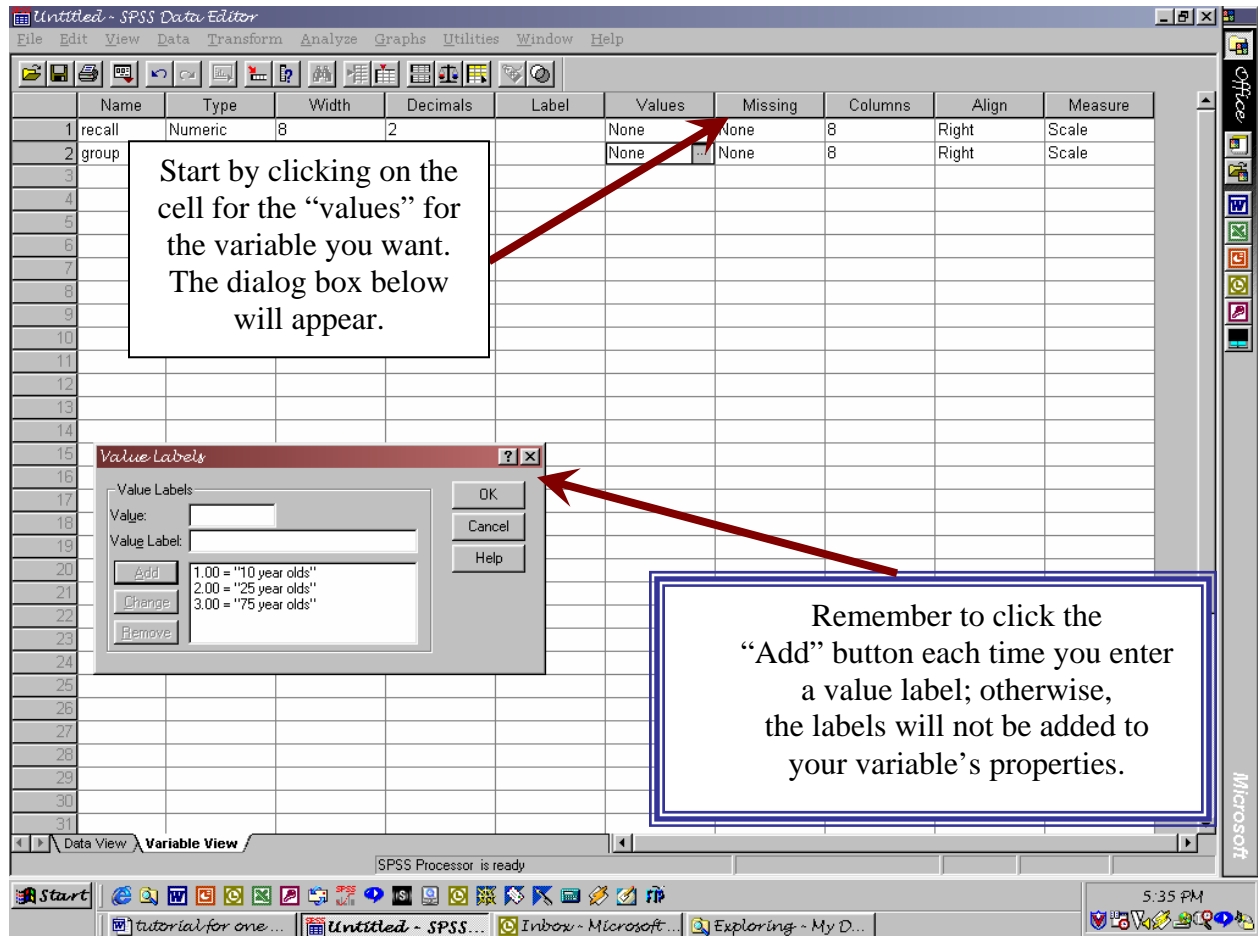
	recall	group	var	var	var	var	var	var	var
1	1.00	1.00							
2	4.00	1.00							
3	5.00	1.00							
4	6.00	1.00							
5	4.00	1.00							
6	9.00	2.00							
7	8.00	2.00							
8	7.00	2.00							
9	10.00	2.00							
10	6.00	2.00							
11	3.00	3.00							
12	5.00	3.00							
13	7.00	3.00							
14	7.00	3.00							
15	8.00	3.00							
16									
17									

Begin by entering your data in the same manner as for an independent groups t-test. You should have two columns:

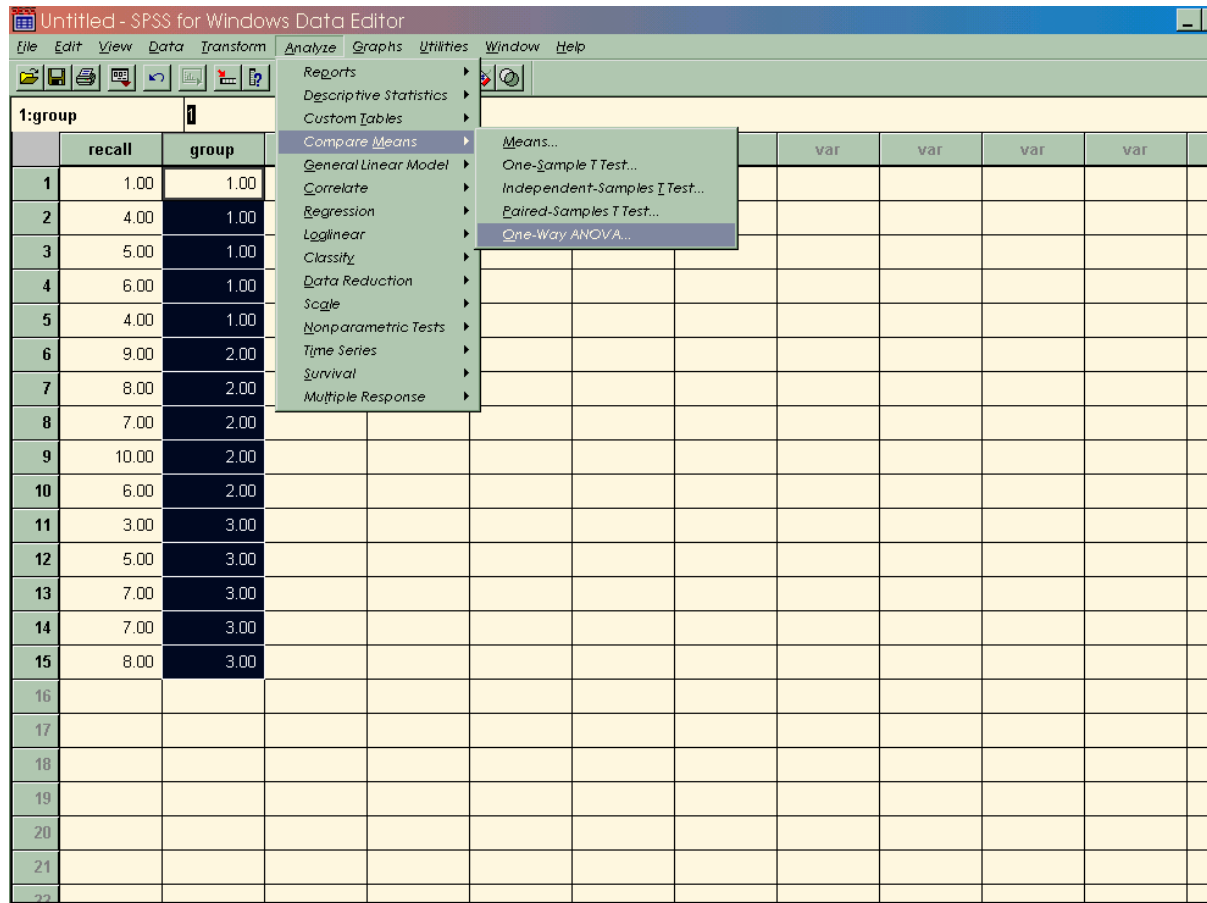
- 1) the dependent variable
- 2) a grouping variable

Step 2: Define your variables.

Remember that to do this, you can simply double-click at the top of the variable's column, and the screen will change from "data view" to "variable view," prompting you to enter properties of the variable. For your dependent variable, giving the variable a name and a label is sufficient. For your independent variable (the grouping variable), you will also want to have **value labels** identifying what numbers correspond with which groups. See the following figure for how to do this.



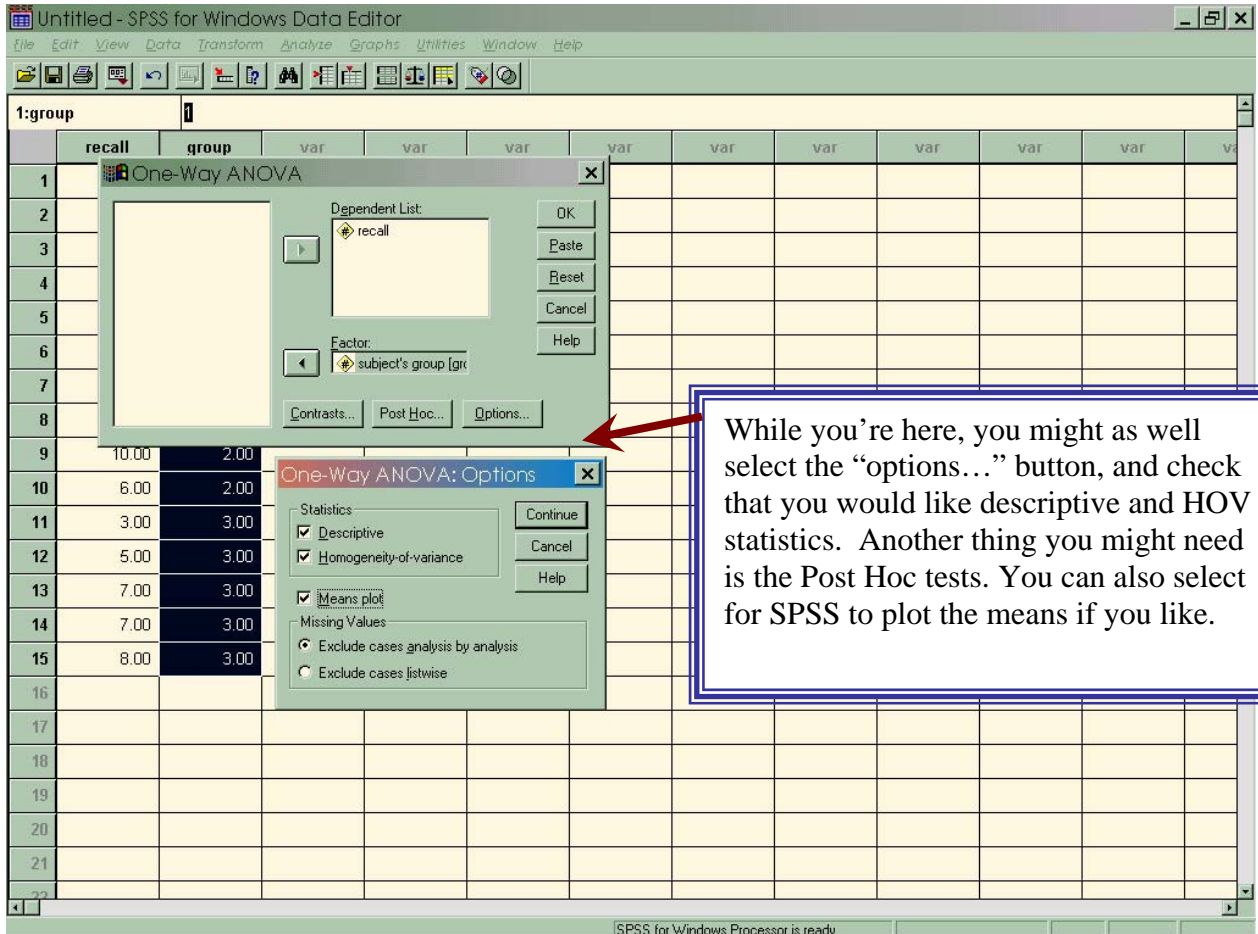
Step 3: Select Oneway ANOVA from the command list in the menu as follows:



Note: There is more than one way to run ANOVA analysis in SPSS. For now, the easiest way to do it is to go through the “compare means” option. However, since the analysis of variance procedure is based on the [general linear model](#), you could also use the analyze/general linear model option to run the ANOVA. This command allows for the analysis of much, much more sophisticated experimental designs than the one we have here, but using it on these data would yield the same result as the One-way ANOVA command.

Step 4: Run your analysis in SPSS.

Once you've selected the One-way ANOVA, you will get a dialog box like the one at the top. Select your dependent and grouping variables (notice that unlike in the independent samples t-test, you do not need to define your groups—SPSS assumes that you will include all groups in the analysis).



Step 5: View and interpret your output.

The screenshot shows the SPSS Output1 window. The left sidebar lists the output hierarchy: Output > Oneway > Descriptives. The main area displays three tables for the variable RECALL.

Descriptives

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 year olds	5	4.0000	1.8708	.8367	1.6771	6.3229	1.00	6.00
21 year olds	5	8.0000	1.5811	.7071	6.0368	9.9632	6.00	10.00
75 year olds	5	6.0000	2.0000	.8944	3.5167	8.4833	3.00	8.00
Total	15	6.0000	2.3905	.6172	4.6762	7.3238	1.00	10.00

Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
.250	2	12	.783

ANOVA

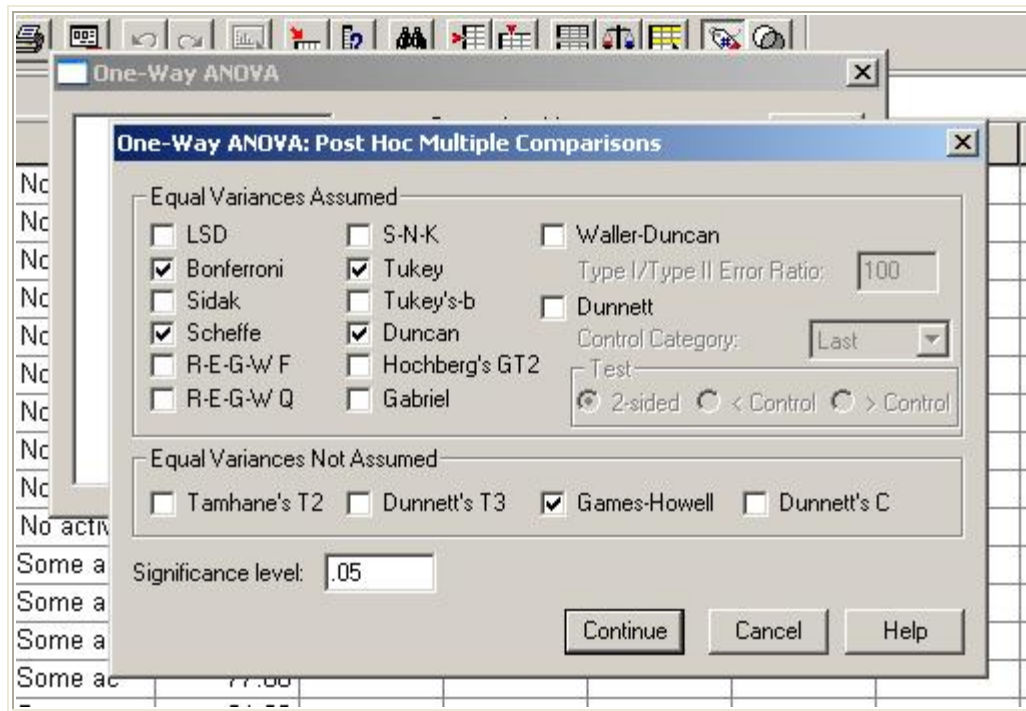
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	40.000	2	20.000	6.000	.016
Within Groups	40.000	12	3.333		
Total	80.000	14			

Note that the descriptive statistics include Confidence Intervals, your test of homogeneity of variance is in a separate table from your descriptive, and your ANOVA partitions your sum of squares.

If you wish to do this with [syntax commands](#), you can see what the syntax looks like by selecting “[paste](#)” when you are in the One-way ANOVA dialog box.

Step 6: Post-hoc tests

Once you have determined that differences exist among the group means, post hoc pairwise and multiple comparisons can determine which means differ. SPSS presents several choices, but different post hoc tests vary in their level by which they control Type I error. Furthermore, some tests are more appropriate than other based on the organization of one's data. The following information focuses on choosing an appropriate test by comparing the tests.



A summary leading up to using a Post Hoc (multiple comparisons):

- Step 1. Test homogeneity of variance using the Levene statistic in SPSS.
 - a. If the test statistic's significance is greater than 0.05, one may assume equal variances.
 - b. Otherwise, one may not assume equal variances.
- Step 2. If you can assume equal variances, the F statistic is used to test the hypothesis. If the test statistic's significance is below the desired alpha (typically, $\alpha = 0.05$), then at least one group is significantly different from another group.
- Step 3. Once you have determined that differences exist among the means, post hoc pairwise and multiple comparisons can be used to determine which means differ. Pairwise multiple comparisons test the difference between each pair of means, and yield a matrix where asterisks indicate significantly different group means at an alpha level of 0.05.
- Step 4. Choose an appropriate post hoc test:
 - a. Unequal Group Sizes: Whenever you violate the equal n assumption for groups, select any of the following post hoc procedures in SPSS: LSD, Games-Howell, Dunnett's T3, Scheffé, and Dunnett's C.
 - b. Unequal Variances: Whenever you violate the equal variance assumption for groups (i.e., the homogeneity of variance assumption), check any of the following post hoc procedures in SPSS: Tamhane's T2, Games-Howell, Dunnett's T3, and Dunnett's C.

c. Selecting from some of the more popular post hoc tests:

- Fisher's LSD (Least Significant Different): This test is the most liberal of all Post Hoc tests and its critical t for significance is not affected by the number of groups. **This test is appropriate when you have 3 means to compare.** It is not appropriate for additional means.
- Bonferroni (AKA, Dunn's Bonferroni): This test does not require the overall ANOVA to be significant. **It is appropriate when the number of comparisons ($c = \text{number of comparisons} = k(k-1)/2$) exceeds the number of degrees of freedom (df) between groups ($df = k-1$).** This test is very conservative and its power quickly declines as the c increases. A good rule of thumb is that the number of comparisons (c) be no larger than the degrees of freedom (df).
- Newman-Keuls: If there is more than one true null hypothesis in a set of means, this test will overestimate the familywise error rate. **It is appropriate to use this test when the number of comparisons exceeds the number of degrees of freedom (df) between groups ($df = k-1$)** and one does not wish to be as conservative as the Bonferroni.
- Tukey's HSD (Honestly Significant Difference): This test is perhaps the most popular post hoc. It reduces Type I error at the expense of Power. **It is appropriate to use this test when one desires all the possible comparisons between a large set of means (6 or more means).**
- Tukey's b (AKA, Tukey's WSD (Wholly Significant Difference)): This test strikes a balance between the Newman-Keuls and Tukey's more conservative HSD regarding Type I error and Power. **Tukey's b is appropriate to use when one is making more than k-1 comparisons, yet fewer than $(k(k-1))/2$ comparisons, and needs more control of Type I error than Newman-Keuls.**
- Scheffé: This test is the most conservative of all post hoc tests. Compared to Tukey's HSD, Scheffé has less Power when making pairwise (simple) comparisons, but more Power when making complex comparisons. **It is appropriate to use Scheffé's test only when making many post hoc complex comparisons (e.g. more than k-1).**

End note:

Try to understand every piece of information presented in the output. Button-clicks in SPSS are not hard, but as an expert, you are expected to explain the tables and figures using the knowledge you have learned in class.

Part II: Two-way ANOVA (Between-Subjects):

Example:

A researcher is interested in investigating the hypotheses that college achievement is affected by (1) home-schooling vs. public schooling, (2) growing up in a dual-parent family vs. a single-parent family, and (3) the interaction of schooling and family type. She locates 5 people that match the requirements of each cell in the 2×2 (schooling \times family type) factorial design, like this:

		Schooling	
		Home	Public
Family type	Dual Parent		
	Single Parent		

Again, we'll do the 5 steps of hypothesis testing for each F -test. Because step 5 can be addressed for all three hypotheses in one fell swoop using SPSS, that will come last. Here are the first 4 steps for each hypothesis:

A. The main effect of schooling type

1. $H_0 : \mu_{home} = \mu_{public} ; H_1 : \text{not } H_0$
2. F
3. $N = 20; F(1,16)$
4. $\alpha = .05 , F_{critical} = 4.49$

B. The main effect of family type

1. $H_0 : \mu_{dual} = \mu_{single} ; H_1 : \text{not } H_0$
2. F
3. $N = 20; F(1,16)$
4. $\alpha = .05 , F_{critical} = 4.49$

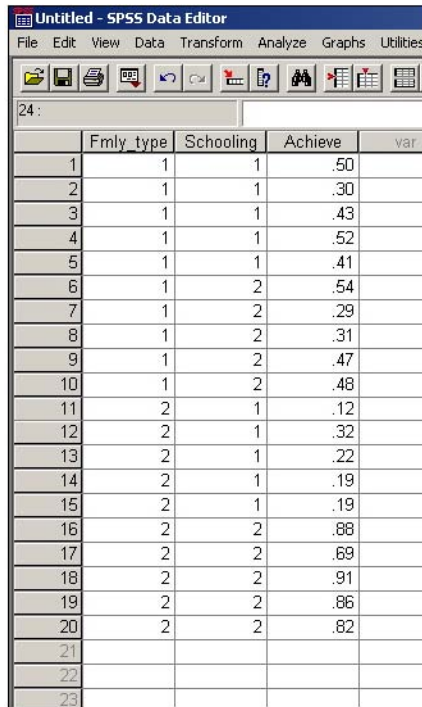
C. The interaction effect

1. $H_0 : (\mu_{11} - \mu_{12}) = (\mu_{21} - \mu_{22}) ; H_1 : \text{not } H_0$;
2. F
3. $N = 20; F(1,16)$
4. $\alpha = .05 , F_{critical} = 4.49$

Step 5, using SPSS

Following the steps to perform two-way ANOVA analysis in SPSS:

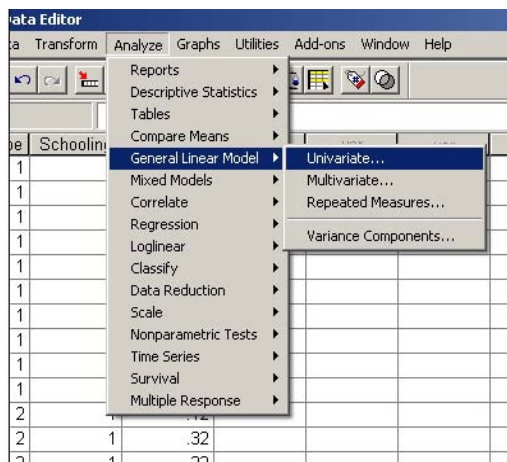
Step 1: Enter your data.



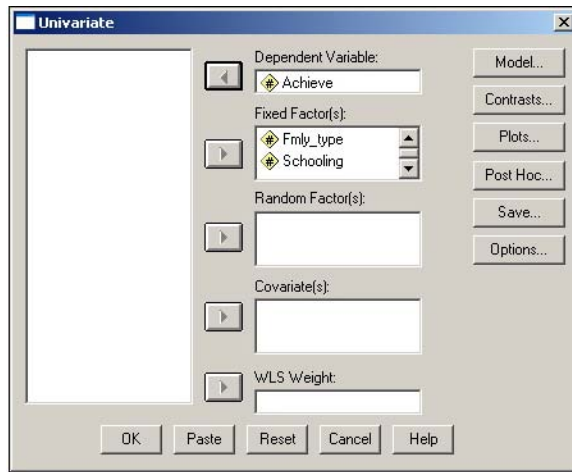
	Fmly_type	Schooling	Achieve	var
1	1	1	.50	
2	1	1	.30	
3	1	1	.43	
4	1	1	.52	
5	1	1	.41	
6	1	2	.54	
7	1	2	.29	
8	1	2	.31	
9	1	2	.47	
10	1	2	.48	
11	2	1	.12	
12	2	1	.32	
13	2	1	.22	
14	2	1	.19	
15	2	1	.19	
16	2	2	.88	
17	2	2	.69	
18	2	2	.91	
19	2	2	.86	
20	2	2	.82	
21				
22				
23				

Because there are two factors, there are now two columns for "group": one for family type (1: dual-parent; 2: single-parent) and one for schooling type (1: home; 2: public). Achievement is placed in the third column. *Note:* if we had more than two factors, we would have more than two group columns. See how that works? Also, if we had more than 2 levels in a given factor, we would use 1, 2, 3 (etc.) to denote level.

Step 2. Choose Analyze -> General Linear Model -> Univariate...



Step 3. When you see a pop-up window like this one below, plop Fmly_type and Schooling into the "Fixed Factors" window and Achieve into the "Dependent Variable" window...



In this window, you might as well select the "options..." button, and check that you would like descriptive and HOV statistics. Another thing you might need is the Post Hoc tests. You can also select for SPSS to plot the means if you like.

...and click on "OK," yielding:

Tests of Between-Subjects Effects

Dependent Variable: Achieve

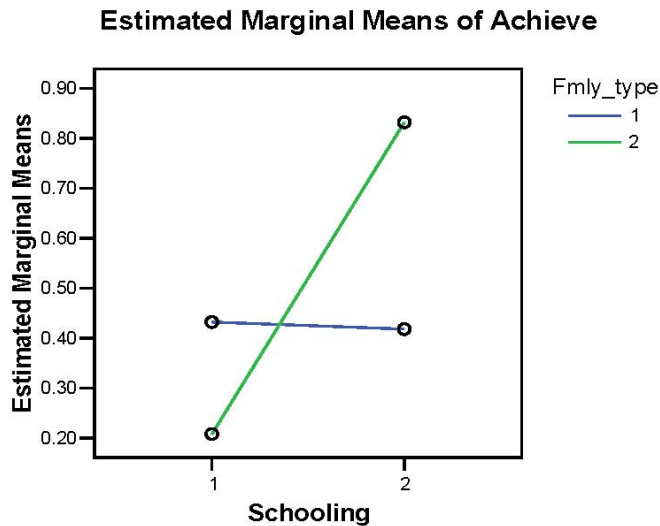
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.019(a)	3	.340	41.705	.000
Intercept	4.465	1	4.465	548.204	.000
Fmly_type	.045	1	.045	5.540	.032
Schooling	.465	1	.465	57.106	.000
Fmly_type * Schooling	.509	1	.509	62.468	.000
Error	.130	16	.008		
Total	5.614	20			
Corrected Total	1.149	19			

a R Squared = .887 (Adjusted R Squared = .865)

I have highlighted the important parts of the summary table. As with the one-way ANOVA, $MS = SS/df$ and $F = MS_{effect} / MS_{error}$ for each effect of interest. Also, values add up to the numbers in the "Corrected Total" row.

An effect is significant if $p < \alpha$ or, equivalently, if F_{obs} / F_{crit} . The beauty of SPSS is that we don't have to look up a F_{crit} if we know p . Because $p < \alpha$ for each of the three effects (two main effects and one interaction), all three are statistically significant.

One way to plot the means (I used SPSS for this – the "Plots" option in the ANOVA dialog window) is:



The two main effects and interaction effect are very clear in this plot. It would be very good practice to conduct this factorial ANOVA by hand and see that the results match what you get from SPSS.

Here is the hand calculation. First, degrees of freedom...

$$df_F = (f - 1) = 1$$

$$df_S = (S - 1) = 1$$

$$df_{FS} = df_F \times df_S = 1$$

$$df_{error} = df_{denominator} = (20 - 1) - df_F - df_S - df_{FS} = 19 - 1 - 1 - 1 = 16$$

Note that these df match those in the ANOVA summary table.

Next, the means...

$$\bar{x} = \frac{\begin{pmatrix} .50 + .30 + .43 + .52 + .41 \\ + .54 + .29 + .31 + .47 + .48 \\ + .12 + .32 + .22 + .19 + .19 \\ + .88 + .69 + .91 + .86 + .82 \end{pmatrix}}{20} = .4725$$

$$\bar{x}_{11} = \frac{.50 + .30 + .43 + .52 + .41}{5} = .432$$

$$\bar{x}_{21} = \frac{.12 + .32 + .22 + .19 + .19}{5} = .218$$

$$\bar{x}_{12} = \frac{.54 + .29 + .31 + .47 + .48}{5} = .408$$

$$\bar{x}_{22} = \frac{.88 + .69 + .91 + .86 + .82}{5} = .832$$

$$\begin{aligned}\bar{x}_{dual} &= \frac{\left(\begin{array}{c} .50 + .30 + .43 + .52 + .41 \\ +.54 + .29 + .31 + .47 + .48 \end{array} \right)}{10} = .425 \\ \bar{x}_{single} &= \frac{\left(\begin{array}{c} .12 + .32 + .22 + .19 + .19 \\ +.88 + .69 + .91 + .86 + .82 \end{array} \right)}{10} = .52 \\ \bar{x}_{home} &= \frac{\left(\begin{array}{c} .50 + .30 + .43 + .52 + .41 \\ +.12 + .32 + .22 + .19 + .19 \end{array} \right)}{10} = .32 \\ \bar{x}_{public} &= \frac{\left(\begin{array}{c} .54 + .29 + .31 + .47 + .48 \\ +.88 + .69 + .91 + .86 + .82 \end{array} \right)}{10} = .625\end{aligned}$$

Then, sums of squares...

$$\begin{aligned}SS_{total} &= \sum (x_{ijk} - \bar{x}_{..})^2 = (.50 - .4725)^2 + (.30 - .4725)^2 + \dots + (.82 - .4725)^2 = 1.1494 \\ SS_F &= ns \sum (\bar{x}_F - \bar{x}_{..})^2 = (5)(2) \left[(.425 - .4725)^2 + (.52 - .4725)^2 \right] = .0451 \\ SS_S &= nf \sum (\bar{x}_S - \bar{x}_{..})^2 = (5)(2) \left[(.32 - .4725)^2 + (.625 - .4725)^2 \right] = .4651 \\ SS_{cells} &= n \sum (\bar{x}_{FS} - \bar{x}_{..})^2 = (5) \left[\begin{array}{l} (.432 - .4725)^2 + (.418 - .4725)^2 \\ + (.208 - .4725)^2 + (.832 - .4725)^2 \end{array} \right] = 1.0191\end{aligned}$$

...and by subtraction for the remaining ones:

$$SS_{FS} = SS_{cells} - SS_F - SS_S = 1.0191 - .0451 - .4651 = .5089$$

$$SS_{error} = SS_{total} - SS_{cells} = 1.1494 - 1.0191 = .1303$$

Note that these sums of squares match those in the ANOVA summary table. So the F -values are:

$$F_F = \frac{MS_F}{MS_{error}} = \frac{\left(\frac{SS_F}{df_F} \right)}{\left(\frac{SS_{error}}{df_{error}} \right)} = \frac{\left(\frac{.0451}{1} \right)}{\left(\frac{.1303}{16} \right)} = 5.538$$

$$F_S = \frac{MS_S}{MS_{error}} = \frac{\left(\frac{SS_S}{df_S} \right)}{\left(\frac{SS_{error}}{df_{error}} \right)} = \frac{\left(\frac{.4651}{1} \right)}{\left(\frac{.1303}{16} \right)} = 57.111$$

$$F_{FS} = \frac{MS_{FS}}{MS_{error}} = \frac{\left(\frac{SS_{FS}}{df_{FS}} \right)}{\left(\frac{SS_{error}}{df_{error}} \right)} = \frac{\left(\frac{.5089}{1} \right)}{\left(\frac{.1303}{16} \right)} = 62.490$$

Note that these F values are within rounding error of those in the ANOVA summary table.

According to Table C.3 (because $\alpha = .05$), the critical value for all three F -tests is 4.49. All three F s exceed this critical value, so we have evidence for a main effect of family type, a main effect of schooling type, and the interaction of family type and schooling type. This agrees with our intuition based on the mean plots.

In the current example, a good way to organize the data is :

		Schooling	
	Home	Public	Mean(i)
Dual Parent	0.50	0.54	
	0.30	0.29	
	0.43	0.31	
	0.52	0.47	
	0.41	0.48	
Mean(1j)	0.432	0.418	0.425
Single Parent	0.12	0.88	
	0.32	0.69	
	0.22	0.91	
	0.19	0.86	
	0.19	0.82	
Mean(2j)	0.208	0.832	0.520
Mean(j)	0.320	0.625	0.4725

Note: Post-hoc tests

Once you have determined that differences exist among the group means, post hoc multiple comparisons can determine which means differ.

Part III: One-way Repeated Measures ANOVA (Within-Subjects):

The Logic

Just as there is a repeated measures or dependent samples version of the Student t test, there is a repeated measures version of ANOVA. Repeated measures ANOVA follows the logic of univariate ANOVA to a large extent. As the same participants appear in all conditions of the experiment, however, we are able to allocate more of the variance. In univariate ANOVA we partition the variance into that caused by differences within groups and that caused by differences between groups, and then compare their ratio. In repeated measure ANOVA we can calculate the individual variability of participants as the same people take part in each condition. Thus we can partition more of the error (or within condition) variance. The variance caused by differences between individuals is not helpful when deciding whether there is a difference between occasions. If we can calculate it we can subtract it from the error variance and then compare the ratio of error variance to that caused by changes in the independent variable between occasions. So repeated measures allows us to compare the variance caused by the independent variable to a more accurate error term which has had the variance caused by differences in individuals removed from it. This increases the power of the analysis and means that fewer participants are needed to have adequate power.

The Model

For the sake of simplicity, I will demonstrate the analysis by using the following three participants that were measured in four occasions.

Participant	Occasion 1	Occasion 2	Occasion 3	Occasion 4	
1	7	7	5	5	$\Sigma = 24$
2	6	6	5	3	$\Sigma = 20$
3	5	4	4	3	$\Sigma = 16$
	$\Sigma = 18$	$\Sigma = 17$	$\Sigma = 14$	$\Sigma = 11$	

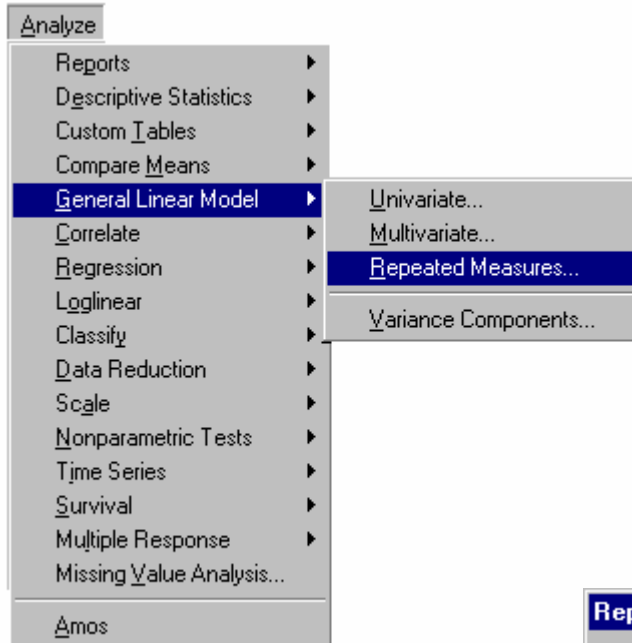
SPSS Analysis

Step 1: Enter the data

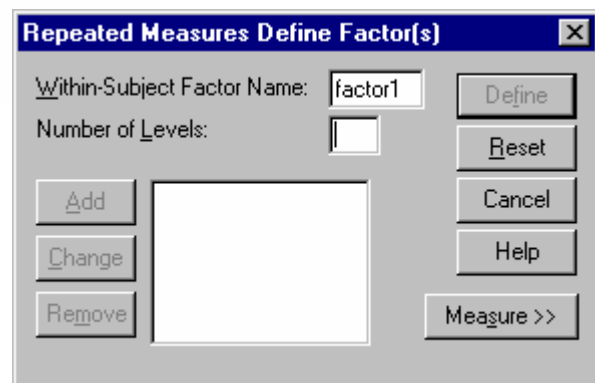
	occas1	occas2	occas3	occas4
1	7.00	7.00	5.00	5.00
2	6.00	6.00	5.00	3.00
3	5.00	4.00	4.00	3.00

When you enter the data remember that it consists of three participants measured on four occasions and each row is for a separate participant. Thus, for this data you have three rows and four variables, one for each occasion.

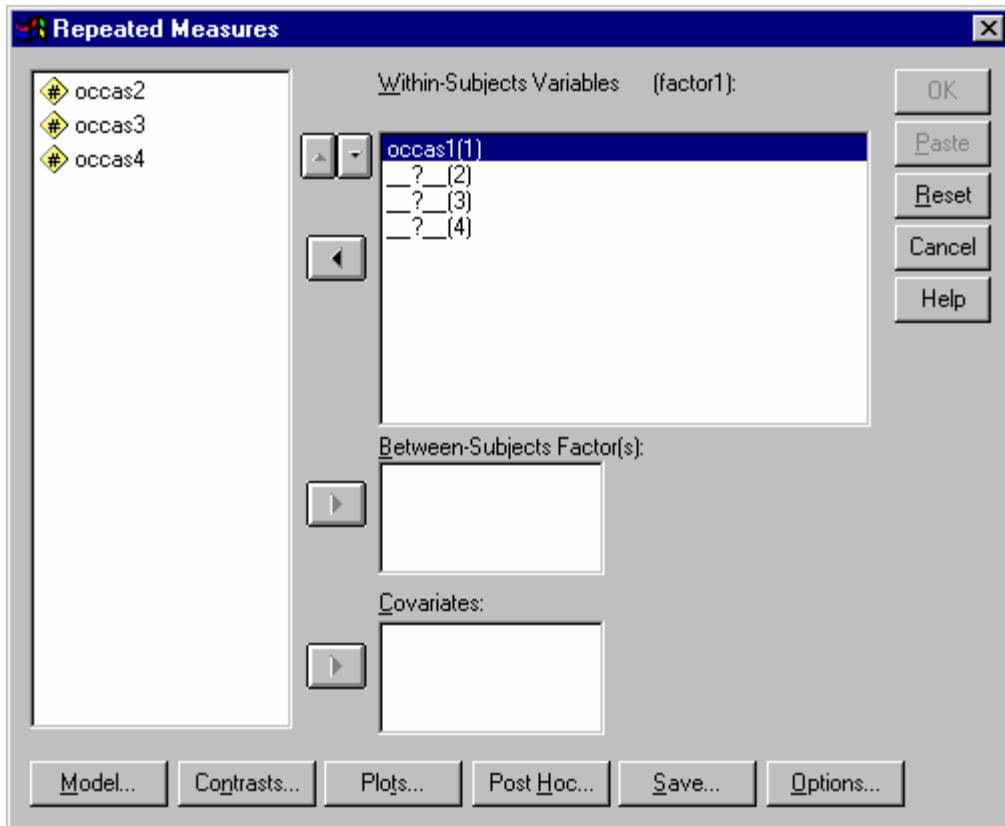
Step 2. To perform a repeated measures ANOVA you need to go through **Analyze** to **General Linear Model**, which is where you found one of the ways to perform Univariate ANOVA. This time, however, you click on **Repeated Measures**.



After this the following dialogue box should appear.



The dialogue box refers to the occasions as a within subjects factor and it automatically labels it factor 1. You can if you want give it a different name one which has meaning for the particular data set you are looking at. Although SPSS knows that there is a within subjects factor, it does not know how many levels of it there are, in other words it does not know how many occasions you tested you subjects. Here you need to type in 4 then click on the Add button and then the Define button, which will let you tell SPSS which occasions you want to compare. If you do this the following dialogue box will appear.



Next we need to put the variables into the within subjects box; as you can see we have already put occasion 1 in slot (1) and occasion 2 in slot (2). We could also ask for some descriptive statistics by going to Options and selecting Descriptives, once this is done press OK and the following output should appear.

General Linear Model

Within-Subjects Factors

Measure: MEASURE_1

FACTOR1	Dependent Variable
1	OCCAS1
2	OCCAS2
3	OCCAS3
4	OCCAS4

This first box just tells us what the variables are

Descriptive Statistics

	Mean	Std. Deviation	N
occasion 1	6.0000	1.0000	3
occasion 2	5.6667	1.5275	3
occasion 3	4.6667	.5774	3
occasion 4	3.6667	1.1547	3

From the descriptives, it is clear that the means get smaller over occasions. The box below should be ignored.

Multivariate Tests^b

Effect	Value	F	Hypothesis df	Error df	Sig.
FACTOR1 Pillai's Trace	. ^a	.	.	.	.
Wilks' Lambda	. ^a	.	.	.	.
Hotelling's Trace	. ^a	.	.	.	.
Roy's Largest Root	. ^a	.	.	.	.

a. Cannot produce multivariate test statistics because of insufficient residual degrees of freedom.

b.

Design: Intercept

Within Subjects Design: FACTOR1

Mauchly's Test of Sphericity^b

Measure: MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon ^a		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
FACTOR1	.000	.	5	.	.667	.	.333

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.

Design: Intercept

Within Subjects Design: FACTOR1

This box gives a measure of sphericity. Sphericity is similar to the assumption of homogeneity of variances in Univariate ANOVA. It is a measure of the homogeneity of the variances of the differences between levels. That is in this case that the variance of the difference between occasion 1 and 2 is similar to that between 3 and 4 and so on. Another way to think of it is that it means that participants are performing in similar ways across the occasions. If the Mauchly test statistic is not significant then we use the sphericity assumed F value in the next box. If it is significant then we should use the Greenhouse-Geisser corrected F value. In this case there are insufficient participants to calculate Mauchly. Try adding one more participant who scores four on every occasion and check the sphericity.

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
FACTOR1	Sphericity Assumed	10.000	3	3.333	10.000	.009
	Greenhouse-Geisser	10.000	2.000	5.000	10.000	.028
	Huynh-Feldt	10.000	.	.	.	.
	Lower-bound	10.000	1.000	10.000	10.000	.087
Error(FACTOR1)	Sphericity Assumed	2.000	6	.333		
	Greenhouse-Geisser	2.000	4.000	.500		
	Huynh-Feldt	2.000	.	.		
	Lower-bound	2.000	2.000	1.000		

This is the most important box for repeated measures ANOVA. As you can see the F value is 10.

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	FACTOR1	Type III Sum of Squares	df	Mean Square	F	Sig.
FACTOR1	Linear	9.600	1	9.600	48.000	.020
	Quadratic	.333	1	.333	1.000	.423
	Cubic	6.667E-02	1	6.667E-02	.143	.742
Error(FACTOR1)	Linear	.400	2	.200		
	Quadratic	.667	2	.333		
	Cubic	.933	2	.467		

The Within-Subjects contrast box test for significant trends. In this case there is a significant linear trend, which means in this case there is a tendency for the data to fall on a straight line. In other words the mean for occasion 1 is larger than occasion 2 which is larger than occasion 3 which is larger than occasion 4. If we have a quadratic trend we would have an inverted U or a U shaped pattern. It is important to remember that this box is only of interest if the overall F value is significant and that it is a test of a trend not a specific test of differences between occasions. For that we need to look at post hoc tests.

Hand Calculation:

It would be very good practice to conduct this repeated-measures ANOVA by hand and see that the results match what you get from SPSS. The only formula needed is the formula for the sum of squares that we used for univariate ANOVA; $\sum x^2 - (\sum x)^2/n$.

The first step is to calculate the total variability or the total sum of squares (SS_T). It will not surprise you to learn that this is the same as you were doing a univariate ANOVA. That is, $(49+49+25+25+36+36+25+9+25+16+16+9) - (60)^2/12 = 320 - 300 = 20$.

We now calculate the variability due to occasions. This variability is calculated exactly the same way as the within group variability is calculated for a univariate ANOVA. So for this data the variability due to occasions is the sum of the variability within each occasion.

The variability for occasion 1 is $(49+36+25) - (18)^2/3$; for occasion 2 it is $(49+36+16) - 17^2/3$. See if you can work out the sum for occasions 3 and 4. The answers should come to occasion 3 = 0.66 and occasion 4 = 2.66 and added to occasion 1 and 2, we get a sum of 10. Again this is no surprise as it should be the same for within group variability for a univariate ANOVA. This time, however, this variability is very important as it is not a measure of error but a measure of the effect of the independent variable, as the participants have remained the same but the independent variable has altered with the occasion.

We now need to calculate the variation caused by individual variability, that is the three participants in this study differ in their overall measures here. This calculation is something we have not met in univariate ANOVA but the principles remain the same. Looking at the data you can see that overall participant 1 had the highest score of 24, participant 2 had an overall score of 20 and participant 3 had an overall score of 16.

To calculate individual variability we still use the sum of squares formula $\sum x^2 - (\sum x)^2/n$. In this case we get $(24^2+20^2+16^2) - (60)^2/3 = (576+400+256)-3600/3 = 32$.

Alarm bells may be ringing as you will see that we have more variability than the total. However, we have not adjusted this figure for the number of occasions; to do that we divide in this instance by 4 to get a figure of 8. So the variability that is caused by differences in participants is 8.

Another way to calculate the individual variability is to divide the squared row totals by the number of occasions and then subtract the correction factor. This would give us; $24^2/4+20^2/4+16^2/4 = 308$, and then subtracting the correction factor gives us $308-300 = 8$.

At this stage we have calculated all of the variabilities that we need to perform our analysis; the variability due to occasions that is caused by the differences in the independent variable across occasions is 10, the variability due to differences in individuals is 8 and the residual variability is 2. The residual or error variability is the total variability (20) minus the sum of the variability due to occasions and individuals (18).

The next step is to calculate the degrees of freedom so that we can turn these variabilities into variances or mean squares (MS). The total degrees of freedom is $12 - 1 = 11$, as in the univariate ANOVA. The degrees of freedom for individuals is the number of participants minus 1, in this case $3 - 1 = 2$ and for occasions it is the number of occasions

minus 1, in this case $4-1=3$. The residual degrees of freedom is the total minus the sum of the degrees of freedom from individuals and occasions; $11-5=6$.

The mean squares are then calculated by dividing the variability by the degrees of freedom. The mean square for individuals is $8/2=4$, for occasions $10/3= 3.33$ and for the residual $2/6=0.33$.

To calculate the F statistic it is important to remember that we are not interested in the individual variability of subjects. This is part of the error variance which we cannot control for in a univariate ANOVA, but which we can measure in a repeated measures design and then discard. What we are concerned with is whether our independent variable which changes on different occasions has an effect on subject's performance. The F ratio we are interested in is, therefore, $MS_{occasions} / MS_{residual}$; $3.33/0.33$ which is 10.

If you were calculating statistics by hand you would now need to go to a table of values for F_{crit} to work out whether it is significant or not. We won't do that we will just perform the same calculation by SPSS and check the significance there.

Notes:

1. The information presented in this handout is modified from the following websites:

For one-way between-subjects ANOVA

<http://courses.washington.edu/stat217/218tutorial2.doc>

For two-way between-subjects ANOVA

http://www.unc.edu/~preacher/30/anova_spss.pdf

For post-hoc tests:

http://staff.harrisonburg.k12.va.us/~gcorder/test_post_hocs.html

For repeated-measures ANOVA:

<http://psynts.dur.ac.uk/notes/Year2/reesdat/RepeatedmeasuresANOVA.htm>

2. Other useful web resources include:

<http://employees.csbsju.edu/rwiellk/psy347/spssinst.htm>

<http://www.colby.edu/psychology/SPSS/>

<http://www.oswego.edu/~psychol/spss/spsstoc.html>

<http://webpub.alleg.edu/dept/psych/SPSS/SPSS1wANOVA.html>