Chapter 12: Analysis of covariance, ANCOVA

Smart Alex's Solutions

Task 1

*A few years back I was stalked. You'd think they could have found someone a bit more interesting to stalk, but apparently times were hard. It could have been a lot worse than it was, but it wasn't particularly pleasant. I imagined a world in which a psychologist tried two different therapies on different groups of stalkers (25 stalkers in each group – this variable is called **Group**). To the first group of stalkers he gave what he termed cruel-to-be-kind therapy (every time the stalkers followed him around, or sent him a letter, the psychologist attacked them with a cattle prod). The second therapy was psychodyshamic therapy, in which stalkers were hypnotized and regressed into their childhood to discuss their penis (or lack of penis), their father's penis, their dog's penis and any other penis that sprang to mind. The psychologist measured the number of hours in the week that the stalker spent stalking their prey both before (**stalk1**) and after (**stalk2**) treatment. The data are in the file **Stalker.sav**. Analyse the effect of therapy on stalking behaviour after therapy, covarying for the amount of stalking behaviour before therapy.*

First let's conduct an ANOVA to test whether the number of hours spent stalking before therapy (our covariate) is independent of the type of therapy (our independent variable). Your completed dialog box should look like Figure .

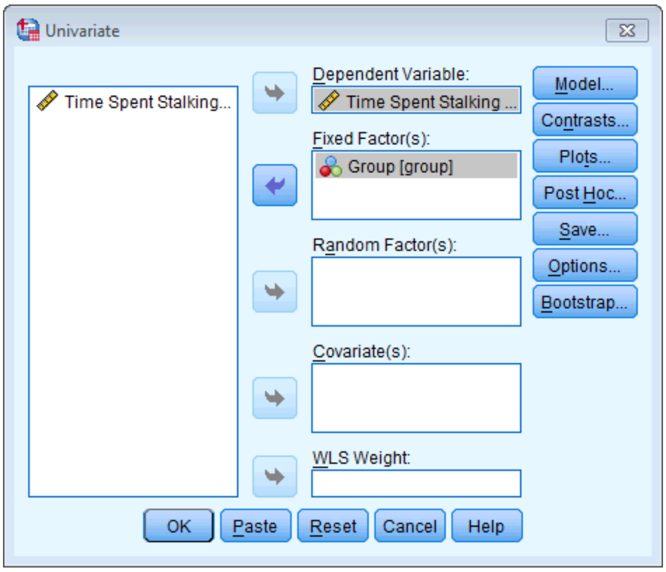


Figure 1

Tests of Between-Subjects Effects

Dependent Variable: Time Spent Stalking Before Therapy (hours per week)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.220[a]	1	7.220	.062	.804
Intercept	212682.420	1	212682.420	1837.641	.000
group	7.220	1	7.220	.062	.804
Error	5555.360	48	115.737		
Total	218245.000	50			
Corrected Total	5562.580	49			

a. R Squared = .001 (Adjusted R Squared = -.020)

Output 1

Error! Reference source not found. shows the results of the one way ANOVA. The main effect of group is not significant, *F*(1, 48) = .06, *p* = .804, which shows that the average level of stalking behaviour before therapy was roughly the same in the two therapy groups. In other words, the mean number of hours spent stalking before therapy is not significantly different in the cruel-to-be-kind and psychodyshamic therapy groups. This result is good news for using stalking behaviour before therapy as a covariate in the analysis.

We could also conduct a one-way ANOVA to see whether the two therapy groups differ in their levels of stalking behaviour after therapy (Figure).

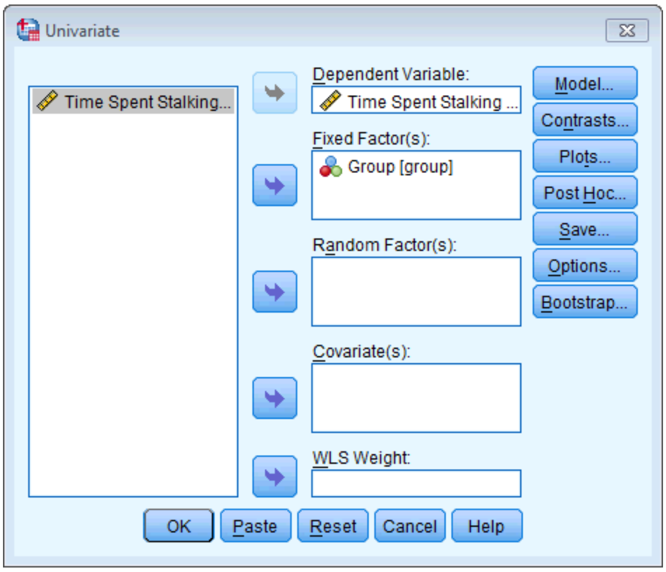


Figure 2

Tests of Between-Subjects Effects

Dependent Variable: Time Spent Stalking After Therapy (hours per week)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	591.680[a]	1	591.680	3.331	.074
Intercept	170528.000	1	170528.000	960.009	.000
group	591.680	1	591.680	3.331	.074
Error	8526.320	48	177.632		
Total	179646.000	50			
Corrected Total	9118.000	49			

a. R Squared = .065 (Adjusted R Squared = .045)

Output 2

Output shows the ANOVA table when the covariate is not included. It is clear from the significance value that there is no difference in the hours spent stalking after therapy for the two therapy groups (*p* is .074, which is greater than .05). You should note that the total amount of variation to be explained (SS_T) was 9118, of which the experimental manipulation accounted for 591.68 units (SS_M), while 8526.32 were unexplained (SS_R).

To conduct the ANCOVA, access the main dialog box by selecting Analyze General Linear Model ▸ Univariate... . The main dialog box is similar to that for one-way ANOVA, except that there is a space to specify covariates. Select **stalk2** and drag this variable to the box labelled *Dependent Variable* or click on . Select **group** and drag it to the box labelled *Fixed Factor(s)*, and then select **stalk1** and drag it to the box labelled *Covariate(s)*. Your completed dialog box should look like Figure .

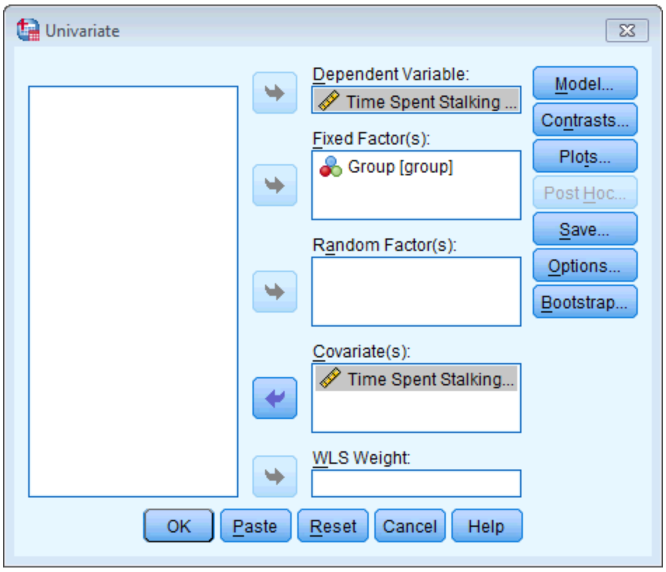


Figure 3

Because our independent variable (**group**) has only two levels (cruel-to-be-kind therapy and psychodyshamic therapy), we do not need to worry about contrasts. To access the *options* dialog box click on Options... . Your completed dialog box should look like Figure .

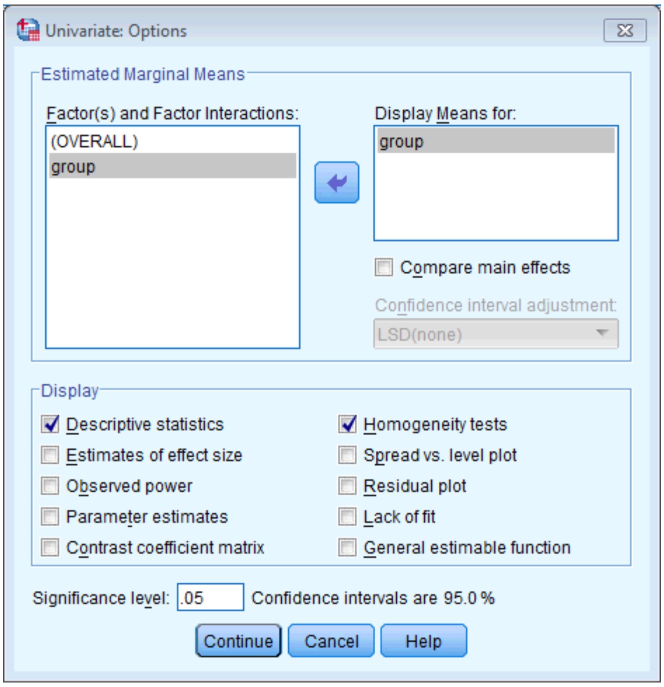


Figure 4

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Time Spent Stalking After Therapy (hours per week)

F	df1	df2	Sig.
7.890	1	48	.007

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + group + stalk1 + group * stalk1

Error! Reference source not found.

Output 3 shows the results of Levene's test, which is significant because the significance value is .01 (less than .05). This finding tells us that the variances across groups are different and the assumption has been broken.

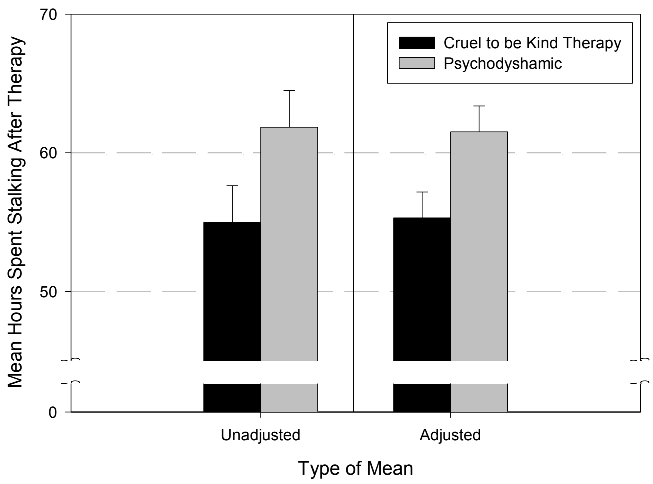


Figure 5

Figure is a bar chart (that I created for illustrative purposes using SigmaPlot, not SPSS) displaying the mean number of hours spent stalking after therapy. The normal means are shown on the left-hand side of the graph (these means can also be found in Output 1) and on the right-hand side of the graph are the same means when the data are adjusted for the effect of the covariate (these means can also be found in Output 3). In this case the adjusted and unadjusted means are relatively similar.

Descriptive Statistics

Dependent Variable: Time Spent Stalking After Therapy (hours per week)

Group	Mean	Std. Deviation	N
Cruel to be Kind Therapy	54.9600	16.33116	25
Psychodyshamic Therapy	61.8400	9.41046	25
Total	58.4000	13.64117	50

Output 1

Output 1 shows the unadjusted means (i.e. the normal means if we ignore the effect of the covariate, (left-hand side of Figure)). These means are displayed on the results show that the time spent stalking after therapy was less after cruel-to-be-kind therapy. However, we know from our initial ANOVA that this difference is non-significant. So, what now happens when we consider the effect of the covariate (in this case the extent of the stalker's problem before therapy)?

Tests of Between-Subjects Effects

Dependent Variable: Time Spent Stalking After Therapy (hours per week)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	5006.278[a]	2	2503.139	28.613	.000	.549
Intercept	.086	1	.086	.001	.975	.000
stalk1	4414.598	1	4414.598	50.462	.000	.518
group	480.265	1	480.265	5.490	.023	.105
Error	4111.722	47	87.483			
Total	179646.000	50				
Corrected Total	9118.000	49				

a. R Squared = .549 (Adjusted R Squared = .530)

Output 2

Output 2 shows the ANCOVA. Looking first at the significance values, it is clear that the covariate significantly predicts the dependent variable, so the hours spent stalking after therapy depend on the extent of the initial problem (i.e. the hours spent stalking before therapy). More interesting is that when the effect of initial stalking behaviour is removed, the effect of therapy becomes significant (*p* has gone down from .074 to .023, which is less than .05).

Group

Dependent Variable: Time Spent Stalking After Therapy (hours per week)

Group	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Cruel to be Kind Therapy	55.344[a]	1.874	51.572	59.117
Psychodyshamic Therapy	61.545[a]	1.874	57.773	65.318

a. Covariates appearing in the model are evaluated at the following values: Time Spent Stalking Before Therapy (hours per week) = 65.22.

Output 3

To interpret the results of the main effect of therapy we need to look at adjusted means. These adjusted means are shown in Output 3 (and displayed on the right-hand side of Figure 5). There are only two groups being compared in this example, so we can conclude that the therapies had a significantly different effect on stalking behaviour; specifically, stalking behaviour was lower after the therapy involving the cattle prod than after psychodyshamic therapy.

Finally, we need to interpret the covariate. To do this we can create a graph of the time spent stalking after therapy (dependent variable) and the initial level of stalking (covariate) using the chart builder (see Chapter 4). Your completed dialog box should look like Figure .

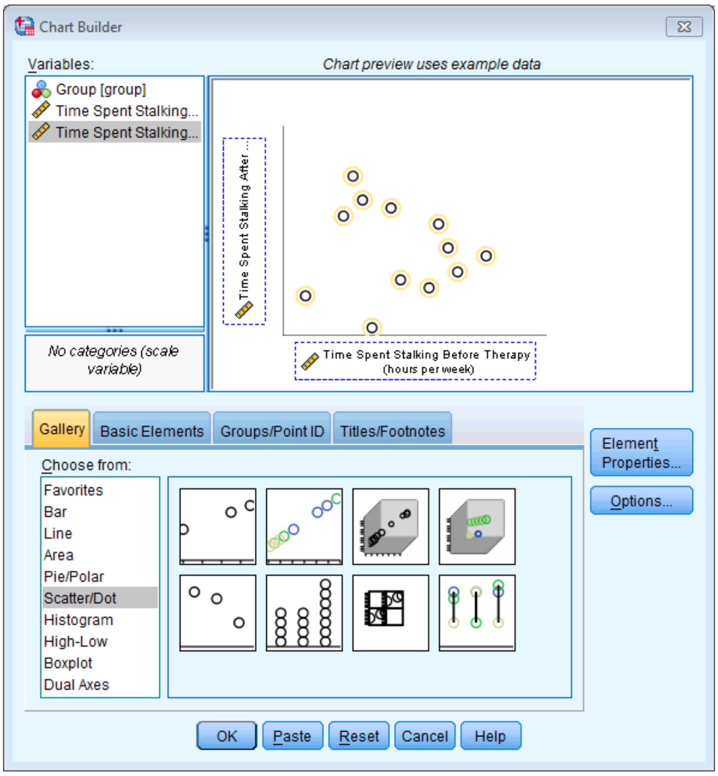


Figure 6

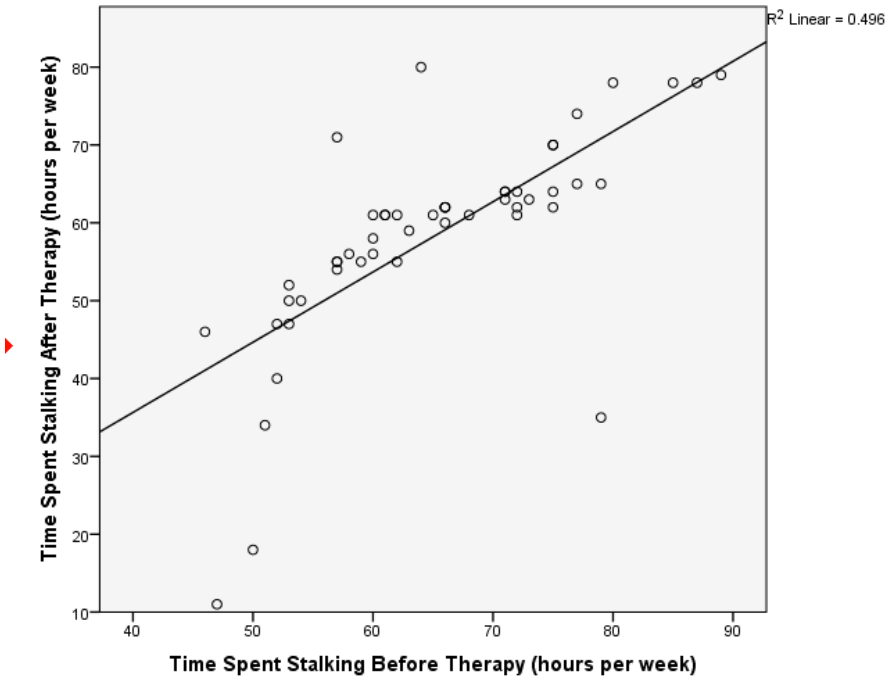


Figure 7

The resulting graph is shown in Figure and shows that there is a positive relationship between the two variables: that is, high scores on one variable correspond to high scores on the other, whereas low scores on one variable correspond to low scores on the other.

Task 2

Compute effect sizes and report the results from Task 1.

Calculating the effect size

We need to use the sums of squares in Output 2 to calculate partial eta squared for the effect of therapy (480.265), the covariate (4414.598) and the error (4111.722) (or you could just get SPSS you calculate them for you by selecting *Estimates of effect size* in the *options* dialog box; see Figure):

$$\text{partial } \eta^2_{\text{group}} = \frac{\text{SS}_{\text{group}}}{\text{SS}_{\text{group}} + \text{SS}_{\text{Residual}}} = \frac{480.27}{480.27 + 4111.722} = \frac{480.27}{4591.992} = .10$$

$$\text{partial } \eta^2_{\text{stalk1}} = \frac{\text{SS}_{\text{stalk1}}}{\text{SS}_{\text{stalk1}} + \text{SS}_{\text{Residual}}} = \frac{4414.598}{4414.598 + 4111.722} = \frac{4414.598}{8526.32} = .52$$

These values show that **stalk1** explained a bigger proportion of the variance not attributable to other variables than **group** (therapy). Therefore, the relationship between initial stalking behaviour and the stalking behaviour after therapy is very strong indeed.

Interpreting and writing the result

The correct way to report the main finding would be:

- ✓ Levene's test was significant, $F(1, 48) = 7.89$, $p = .01$, indicating that the assumption of homogeneity of variance had been broken. The main effect of therapy was significant, $F(1, 47) = 5.49$, $p = .02$, partial $\eta^2 = .10$, indicating that the time spent stalking was lower after using a cattle prod ($M = 55.30$, $SE = 1.87$) than after psychodyshamic therapy ($M = 61.50$, $SE = 1.87$).
- ✓ The covariate was also significant, $F(1, 47) = 50.46$, $p < .001$, partial $\eta^2 = .52$, indicating that level of stalking before therapy had a significant effect on level of stalking after therapy (there was a positive relationship between these two variables). All significant values are reported at $p < .05$.

Task 3

A marketing manager was interested in the therapeutic benefit of certain soft drinks for curing hangovers. He took 15 people out on the town one night and got them drunk. The next morning as they awoke, dehydrated and feeling as though they'd licked a camel's *sandy feet clean with their tongue, he gave five of them water to drink, five of them Lucozade (a very nice glucose-based UK drink) and the remaining five a leading brand of cola (this variable is called* ***drink****). He measured how well they felt (on a scale from 0 = I feel like death to 10 = I feel really full of beans and healthy) two hours later (this variable is called* ***well****). He measured how* ***drunk*** *the person got the night before on a scale of 0 = as sober as a nun to 10 = flapping about like a haddock out of water on the floor in a puddle of their own vomit. The data are in the file* ***HangoverCure.sav****. Conduct an ANCOVA to see whether people felt better after different drinks when covarying for how drunk they were the night before.*

First let's run an ANOVA without the covariate. Your completed dialog box should look like Figure .

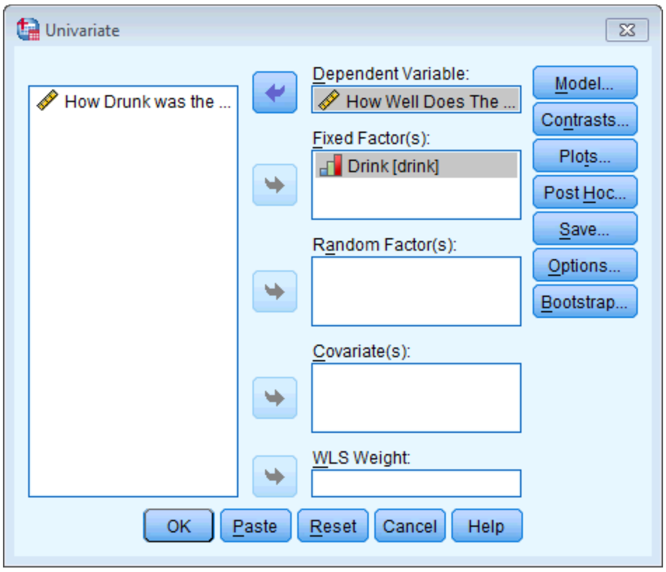


Figure 8

Tests of Between-Subjects Effects

Dependent Variable: How Well Does The Person Feel?

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.133[a]	2	1.067	.821	.463
Intercept	459.267	1	459.267	353.282	.000
DRINK	2.133	2	1.067	.821	.463
Error	15.600	12	1.300		
Total	477.000	15			
Corrected Total	17.733	14			

a. R Squared = .120 (Adjusted R Squared = -.026)

Output 4

Output 4 shows the ANOVA table for these data when the covariate is not included. It is clear from the significance value that there are no differences in how well people feel when they have different drinks.

The next thing that we should do is check that the independent variable (**drink**) and the covariate (**drunk**) are independent. To do this we can run a one-way ANOVA (see Figure).

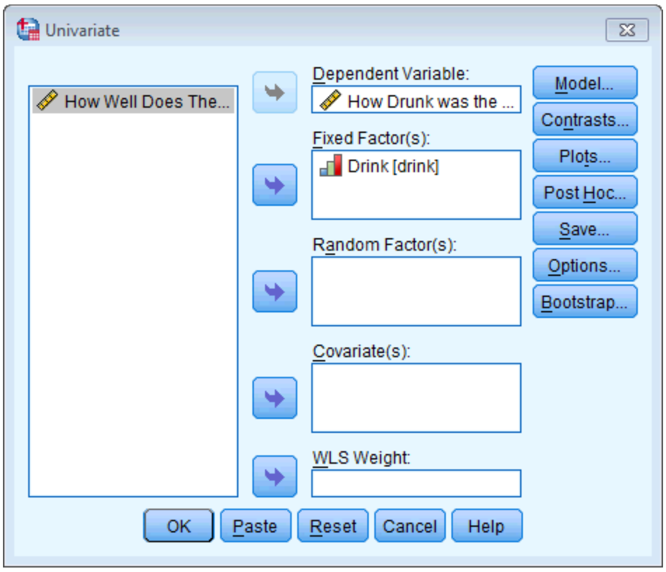


Figure 9

Tests of Between-Subjects Effects

Dependent Variable: How Drunk was the Person the Night Before

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8.400[a]	2	4.200	1.355	.295
Intercept	173.400	1	173.400	55.935	.000
drink	8.400	2	4.200	1.355	.295
Error	37.200	12	3.100		
Total	219.000	15			
Corrected Total	45.600	14			

a. R Squared = .184 (Adjusted R Squared = .048)

Output 5

Output 5 shows the results of the one-way ANOVA. The main effect of **drink** is not significant, $F(2, 12) = 1.36$, $p = .30$, which shows that the average level of drunkenness the night before was roughly the same in the three drink groups. This result is good news for using the variable **drunk** as a covariate in the analysis.

Next we can conduct the ANCOVA. To do this, access the main dialog box by selecting Analyze General Linear Model ▸ Univariate... . The main dialog box is similar to that for one-way ANOVA, except that there is a space to specify covariates. Select **well** and drag this variable to the box labelled *Dependent Variable* or click on . Select **drink** and drag it to the box labelled *Fixed Factor(s)*, and then select **drunk** and drag it to the box labelled *Covariate(s)*. Your completed dialog box should look like Figure .

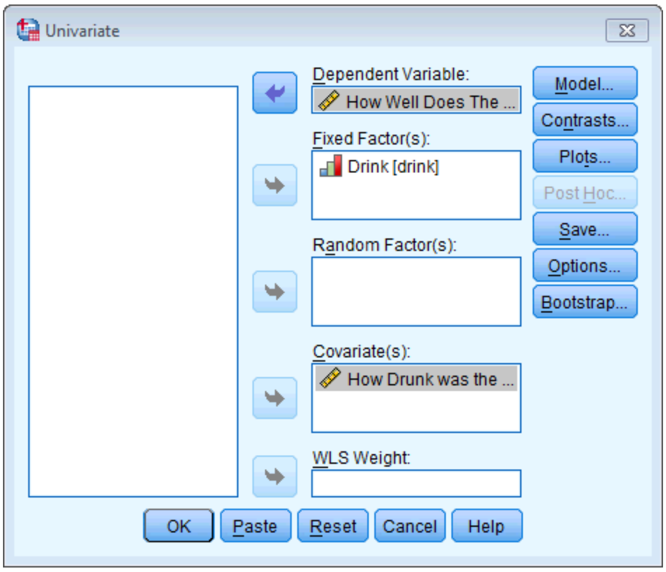


Figure 1

To access the *options* dialog box click on Options... . Your completed dialog box should look like Figure .

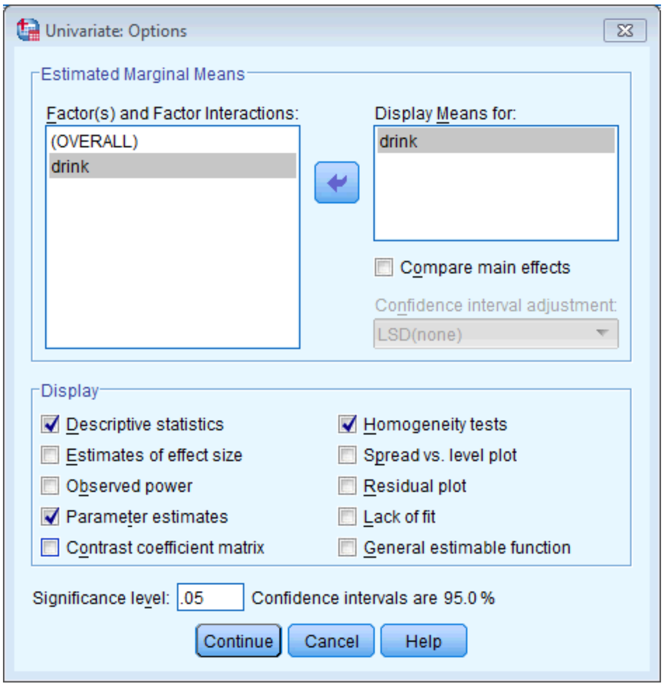


Figure 2

Next, click on Contrasts... to access the *contrasts* dialog box. In this example, a sensible set of contrasts would be simple contrasts comparing each experimental group with the control group, water. To select a type of contrast click on None to access a drop-down list of possible contrasts. Select a type of contrast (in this case *Simple*) from this list and the list will automatically disappear. For simple contrasts you have the option of specifying a reference category (which is the category against which all other groups are compared). By default the reference category is the last category, but because for our data the control group was the first category (assuming that you coded water as 1) we need to change this option by selecting ◉ First. When you have selected a new contrast option, you must click on Change to register this change. The final dialog box should look like Figure . Click on Continue to return to the main dialog box.

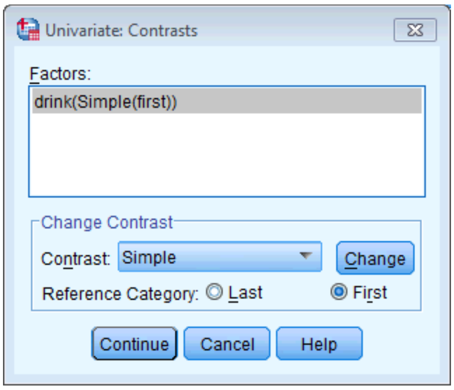


Figure 3

Click on OK in the main dialog box to run the analysis.

Output

Levene's Test of Equality of Error Variances[a]

Dependent Variable: How Well Does The Person Feel?

F	df1	df2	Sig.
.220	2	12	.806

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a. Design: Intercept+DRUNK+DRINK

Output 6

Tests of Between-Subjects Effects

Dependent Variable: How Well Does The Person Feel?

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13.320[a]	3	4.440	11.068	.001
Intercept	145.006	1	145.006	361.456	.000
drunk	11.187	1	11.187	27.886	.000
drink	3.464	2	1.732	4.318	.041
Error	4.413	11	.401		
Total	477.000	15			
Corrected Total	17.733	14			

a. R Squared = .751 (Adjusted R Squared = .683)

Output 7

Output 6 shows the results of Levene's test and Output 7 shows the ANOVA table when drunkenness the previous night is included in the model as a covariate. Levene's test is non-significant, indicating that the group variances are roughly equal (hence the assumption of homogeneity of variance has been met). It is clear that the covariate significantly predicts the dependent variable, so the drunkenness of the person influenced how well they felt the next day. What's more interesting is that when the effect of drunkenness is removed, the effect of drink becomes significant (*p* is .041, which is less than .05).

Parameter Estimates

Dependent Variable: How Well Does The Person Feel?

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	7.116	.377	18.861	.000	6.286	7.947
DRUNK	-.548	.104	-5.281	.000	-.777	-.320
[DRINK=1.00]	-.142	.420	-.338	.741	-1.065	.781
[DRINK=2.00]	.987	.442	2.233	.047	.014	1.960
[DRINK=3.00]	0[a]	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

Output 8

Output 8 shows the parameter estimates selected in the *options* dialog box. These estimates are calculated using a regression analysis with **drink** split into two dummy coding variables. SPSS codes the two dummy variables such that the last category (the category coded with the highest value in the data editor, in this case the cola group) is the reference category. This reference category (labelled *dose=3* in the output) is coded with a 0 for both dummy variables; *dose=2*, therefore, represents the difference between the group coded as 2 (Lucozade) and the reference category (cola); and *dose=1* represents the difference between the group coded as 1 (water) and the reference category (cola). The beta values literally represent the differences between the means of these groups and so the significances of the *t*-tests tell us whether the group means differ significantly. Therefore, from these estimates we could conclude that the cola and water groups have similar means whereas the cola and Lucozade groups have significantly different means.

Contrast Results (K Matrix)

Drink Simple Contrast[a]			Dependent Variable: How Well Does The Person Feel?
Level 2 vs. Level 1	Contrast Estimate		1.129
	Hypothesized Value		0
	Difference (Estimate - Hypothesized)		1.129
	Std. Error		.405
	Sig.		.018
	95% Confidence Interval for Difference	Lower Bound	.237
		Upper Bound	2.021
Level 3 vs. Level 1	Contrast Estimate		.142
	Hypothesized Value		0
	Difference (Estimate - Hypothesized)		.142
	Std. Error		.420
	Sig.		.741
	95% Confidence Interval for Difference	Lower Bound	-.781
		Upper Bound	1.065

a. Reference category = 1

Output 9

Output 9 shows the result of a contrast analysis that compares level 2 (Lucozade) against level 1 (water) as a first comparison, and level 3 (cola) against level 1 (water) as a second comparison. These results show that the Lucozade group felt significantly better than the water group (contrast 1), but that the cola group did not differ significantly from the water group (p = 0.741). These results are consistent with the regression parameter estimates (in fact, note that contrast 2 is identical to the regression parameters for *dose=1* in the previous section).

Drink

Dependent Variable: How Well Does The Person Feel?

Drink	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Water	5.110[a]	.284	4.485	5.735
Lucozade	6.239[a]	.295	5.589	6.888
Cola	5.252[a]	.302	4.588	5.916

a. Covariates appearing in the model are evaluated at the following values: How Drunk was the Person the Night Before = 4.6000.

Output 10

Output 10 gives the adjusted values of the group means, and it is these values that should be used for interpretation. The adjusted means show that the significant ANCOVA reflects a difference between the water and the Lucozade groups. The cola and water groups appear to have fairly similar adjusted means, indicating that cola is no better than water at helping your hangover. These conclusions support what we know from the contrasts and regression parameters.

To look at the effect of the covariate, we can examine a scatterplot by using the chart builder. Your completed dialog box should look like Figure . The resulting scatterplot (Figure) shows that the more drunk a person was the night before, the less well they felt the next day.

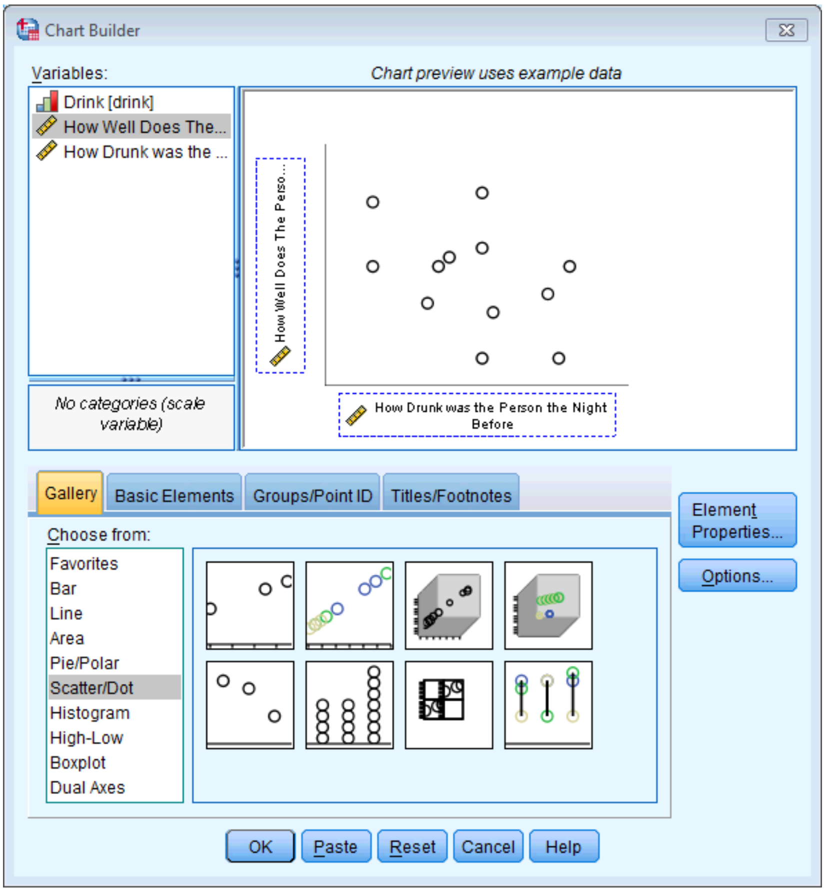


Figure 4

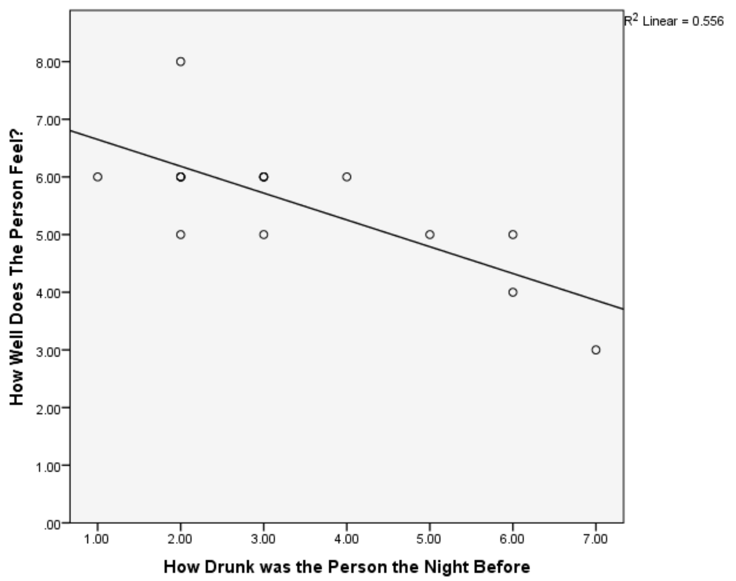


Figure 5

Task 4

Compute effect sizes and report the results from Task 3.

Calculating the effect size

We need to use the sums of squares in Output 7 to calculate partial eta squared for the effect of drink (3.464), the covariate (11.187) and the error (4.413) (or you could just get SPSS you calculate them for you by selecting *Estimates of effect size* in the *options* dialog box; see Figure):

$$\text{partial } \eta^2_{\text{drink}} = \frac{\text{SS}_{\text{drink}}}{\text{SS}_{\text{drink}} + \text{SS}_{\text{Residual}}} = \frac{3.464}{3.464 + 4.413} = \frac{3.464}{7.877} = .44$$

$$\text{partial } \eta^2_{\text{drunk}} = \frac{\text{SS}_{\text{drunk}}}{\text{SS}_{\text{drunk}} + \text{SS}_{\text{Residual}}} = \frac{11.187}{11.187 + 4.413} = \frac{11.187}{15.6} = .72$$

These values show that **drunk** explained a bigger proportion of the variance not attributable to other variables than **drink.** Therefore, the relationship between drunkenness the night before and how well they felt the next day is very strong indeed – not surprisingly!

We've got *t*-statistics for the comparisons between the cola and water groups and the cola and Lucozade groups. These *t*-statistics have *N* − 2 degrees of freedom, where *N* is the total sample size (in this case 15). Therefore we get:

$$r_{\text{Cola vs.Water}} = \sqrt{\frac{(-0.338)^2}{(-0.338)^2 + 13}}$$

$$= .09$$

$$r_{\text{Cola vs.Lucozade}} = \sqrt{\frac{2.233^2}{2.233^2 + 13}}$$

$$= .53$$

Interpreting and writing the result

We could report the main finding as follows:

- ✓ The covariate, drunkenness, was significantly related to the how ill the person felt the next day, $F(1, 11) = 27.89$, $p < .001$, partial $\eta^2 = .72$. There was also a significant effect of the type of drink on how well the person felt after controlling for how drunk they were the night before, $F(2, 11) = 4.32$, $p = .041$, partial $\eta^2 = .44$.

We can also report some contrasts:

- ✓ Planned contrasts revealed that having Lucozade significantly improved how well you felt compared to having cola, $t(13) = 2.23$, $p = .018$, $r = .53$, but having cola was no better than having water, $t(13) = -0.34$, $p = .741$, $r = .09$. We can conclude that cola and water have the same effect on hangovers but that Lucozade seems significantly better at curing hangovers than cola.

Task 5

*The highlight of the elephant calendar is the annual elephant soccer event in Nepal (http://news.bbc.co.uk/1/hi/8435112.stm). A heated argument burns between the African and Asian elephants. In 2010, the president of the Asian Elephant Football Association, an elephant named Boji, claimed that Asian elephants were more talented than their African counterparts. The head of the African Elephant Soccer Association, an elephant called Tunc, issued a press statement that read 'I make it a matter of personal pride never to take seriously any remark made by something that looks like an enormous scrotum'. I was called in to settle things. I collected data from the two types of elephants (**elephant**) over a season. For each elephant, I measured how many goals they scored in the season (**goals**) and how many years of experience the elephant had (**experience**). The data are in **Elephant Football.sav**. Analyse the effect of the type of elephant on goal scoring, covarying for the amount of football experience the elephant has.*

First let's run an ANOVA without the covariate. Your completed dialog box should look like Figure .

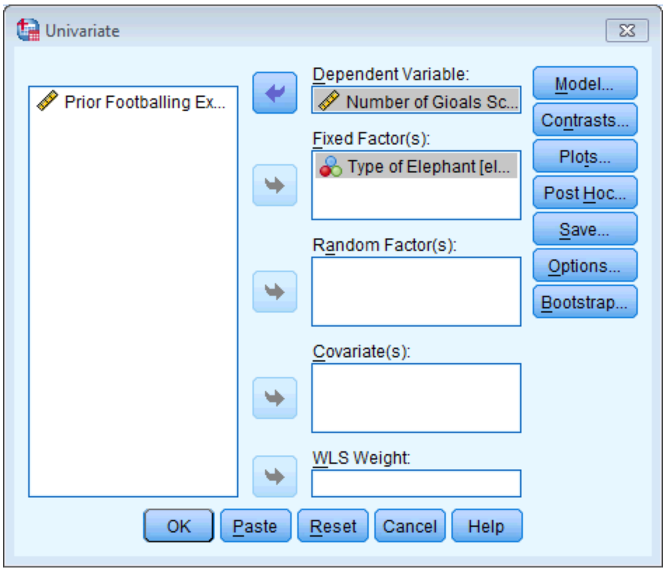


Figure 15

Tests of Between-Subjects Effects

Dependent Variable: Number of Gioals Scored in Season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	35.208[a]	1	35.208	10.057	.002
Intercept	1992.675	1	1992.675	569.175	.000
elephant	35.208	1	35.208	10.057	.002
Error	413.117	118	3.501		
Total	2441.000	120			
Corrected Total	448.325	119			

a. R Squared = .079 (Adjusted R Squared = .071)

Output 11

Output 11 shows the ANOVA table for these data when the covariate is not included. It is clear from the significance value that there was a significant difference between type of elephant and the number of goals scored.

The next thing that we should do is check that the independent variable (**elephant**) and the covariate (**experience**) are independent. To do this we can run a one-way ANOVA (see Figure).

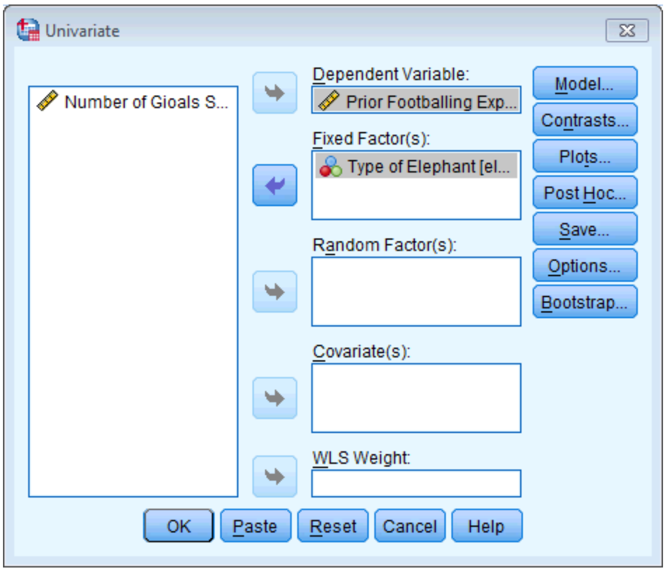


Figure 16

Tests of Between-Subjects Effects

Dependent Variable: Prior Footballing Experience (Years)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.033[a]	1	4.033	1.384	.242
Intercept	2100.033	1	2100.033	720.500	.000
elephant	4.033	1	4.033	1.384	.242
Error	343.933	118	2.915		
Total	2448.000	120			
Corrected Total	347.967	119			

a. R Squared = .012 (Adjusted R Squared = .003)

Output 12

Output 12 shows the results of the one-way ANOVA. The main effect of **elephant** is not significant, $F(1, 118) = 1.38$, $p = .24$, which shows that the average level of prior football experience was roughly the same in the two elephant groups. This result is good news for using the variable **experience** as a covariate in the analysis.

Next we can conduct the ANCOVA. To do this, access the main dialog box by selecting Analyze General Linear Model ▸ Univariate... . The main dialog box is similar to that for one-way ANOVA, except that there is a space to specify covariates. Select **goals** and drag this variable to the box labelled *Dependent Variable* or click on . Select **elephant** and drag it to the box labelled *Fixed Factor(s)*, and then select **experience** and drag it to the box labelled *Covariate(s)*. Your completed dialog box should look like Figure .

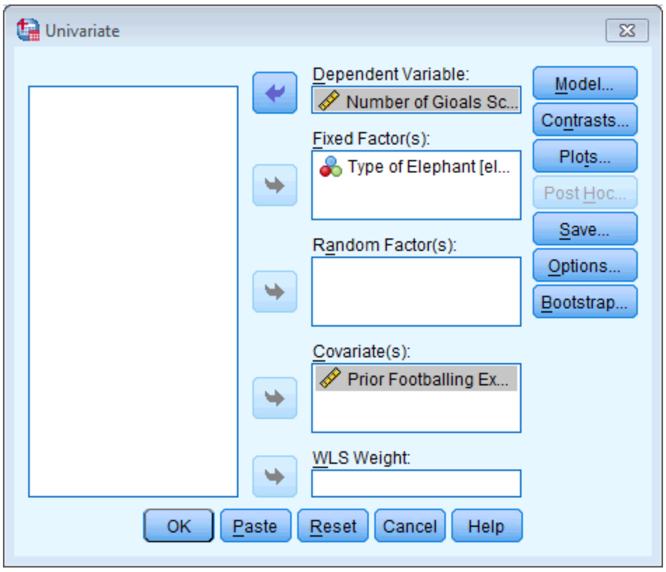


Figure 17

To access the *options* dialog box click on Options... . Your completed dialog box should look like Figure .

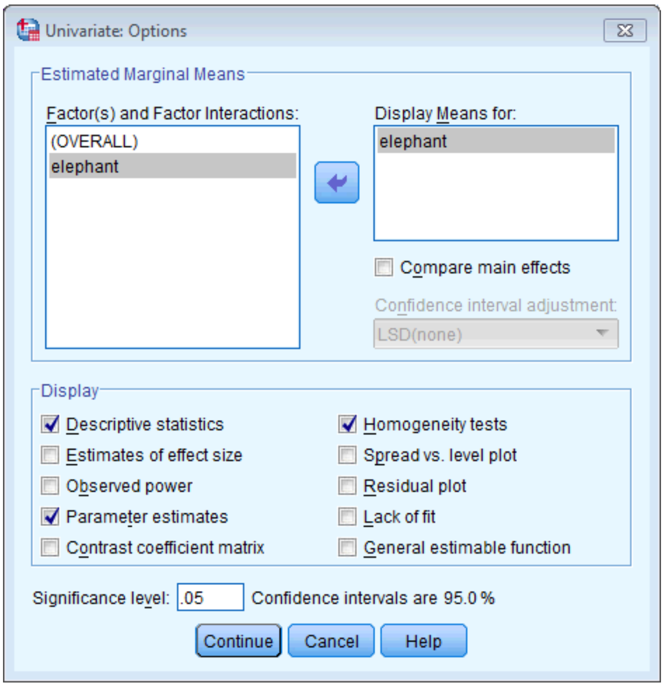
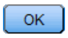


Figure 18

Because our independent variable **elephant** only has two levels (Asian and African) we do not need to worry about contrasts. Click on 

in the main dialog box to run the analysis.

Output

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Number of Gioals Scored in Season

F	df1	df2	Sig.
.422	1	118	.517

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + experience + elephant

Output 13

Tests of Between-Subjects Effects

Dependent Variable: Number of Gioals Scored in Season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	67.529[a]	2	33.765	10.374	.000
Intercept	131.697	1	131.697	40.464	.000
experience	32.321	1	32.321	9.931	.002
elephant	27.953	1	27.953	8.589	.004
Error	380.796	117	3.255		
Total	2441.000	120			
Corrected Total	448.325	119			

a. R Squared = .151 (Adjusted R Squared = .136)

Output 14

Output 13 shows the results of Levene's test and Output 14 shows the ANOVA table when prior experience is included in the model as a covariate. Levene's test is non-significant, indicating that the group variances are roughly equal (hence the assumption of homogeneity of variance has been met). It is clear that the covariate significantly predicts the dependent variable, so prior football experience influenced how many goals the elephants scored.

Type of Elephant

Dependent Variable: Number of Gioals Scored in Season

Type of Elephant	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Asian	3.590[a]	.234	3.127	4.052
African	4.560[a]	.234	4.098	5.023

a. Covariates appearing in the model are evaluated at the following values: Prior Footballing Experience (Years) = 4.18.

Output 15

Output gives the adjusted values of the group means, and it is these values that should be used for interpretation. There are only two groups being compared in this example, so we can conclude that the two types of elephants had significantly different goal scoring abilities; specifically, African elephants scored significantly more goals than Asian elephants even after taking prior football experience into account.

Finally, we need to interpret the covariate. To do this we can create a graph of the number of goals scored (dependent variable) and prior football experience (covariate) using the chart builder (see Chapter 4). Your completed dialog box should look like Figure . The resulting scatterplot (Figure) shows that the more prior football experience the elephant had, the more goals they scored in the season.

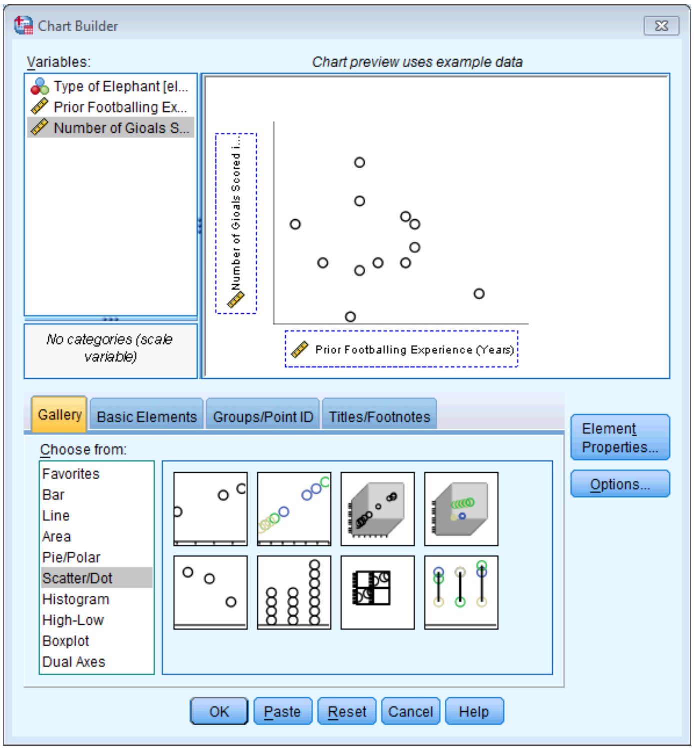


Figure 19

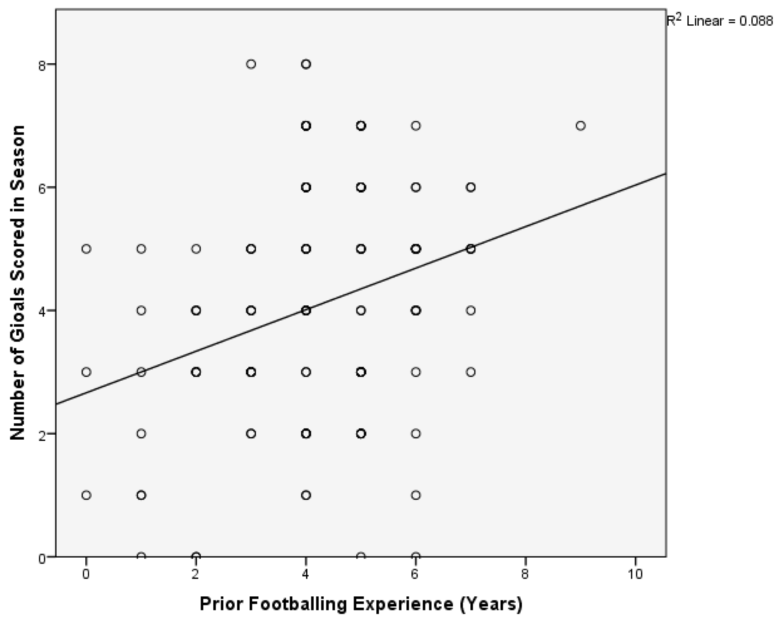


Figure 6

Task 6

*In Chapter 3 (Task 5) we looked at data from people who had been forced to marry goats and dogs and measured their life satisfaction and, also, how much they like animals (**Goat or Dog.sav**). Run an ANCOVA predicting life satisfaction from the type of animal to which a person was married and their animal liking score (covariate).*

First let's run an ANOVA without the covariate. Your completed dialog box should look like Figure .

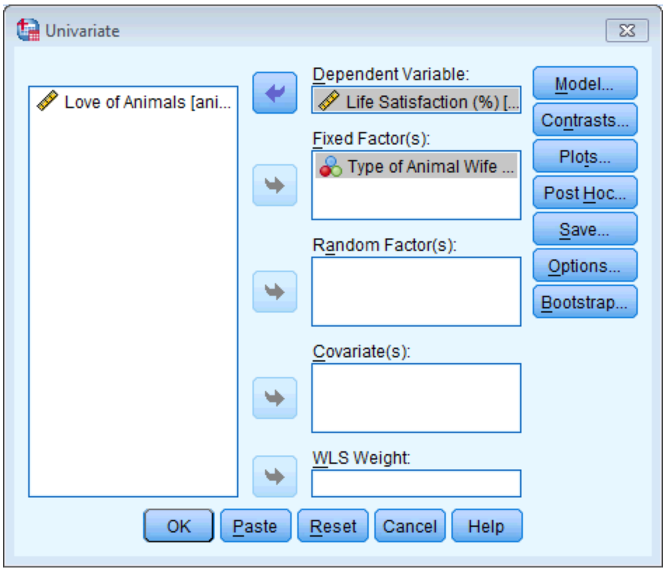


Figure 7

Tests of Between-Subjects Effects

Dependent Variable: Life Satisfaction (%)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2314.408[a]	1	2314.408	11.874	.003
Intercept	46374.008	1	46374.008	237.914	.000
wife	2314.408	1	2314.408	11.874	.003
Error	3508.542	18	194.919		
Total	49909.000	20			
Corrected Total	5822.950	19			

a. R Squared = .397 (Adjusted R Squared = .364)

Output 16

Output 16 shows the ANOVA table for these data when the covariate is not included. It is clear from the significance value that there was a significant difference between type of animal wife and life satisfaction.

The next thing that we should do is check that the independent variable (**wife**) and the covariate (**love of animals**) are independent. To do this we can run a one-way ANOVA (see Figure).

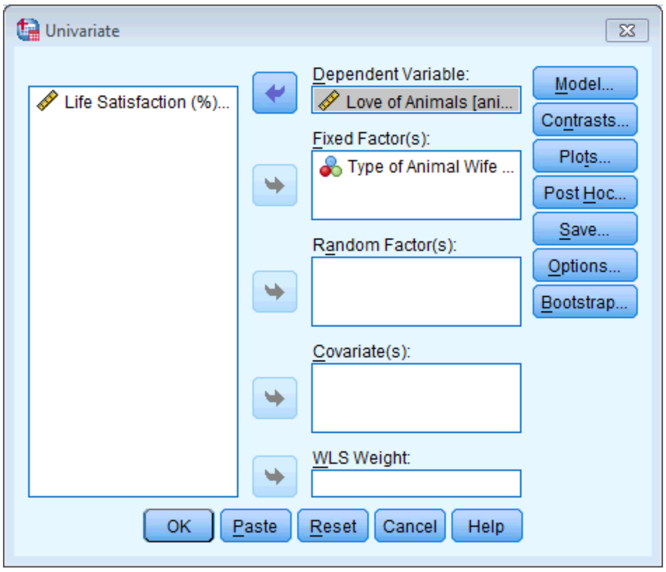


Figure 8

Tests of Between-Subjects Effects

Dependent Variable: Love of Animals

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	14.700[a]	1	14.700	.059	.812
Intercept	25404.300	1	25404.300	101.156	.000
wife	14.700	1	14.700	.059	.812
Error	4520.500	18	251.139		
Total	30744.000	20			
Corrected Total	4535.200	19			

a. R Squared = .003 (Adjusted R Squared = -.052)

Output 17

Output 17 shows the results of the one-way ANOVA. The main effect of **wife** is not significant, $F(1, 18) = 0.06$, $p = .81$, which shows that the average level of love of animals was roughly the same in the two type of animal wife groups. This result is good news for using the variable **love of animals** as a covariate in the analysis.

Next we can conduct the ANCOVA. To do this, access the main dialog box by selecting Analyze General Linear Model ▸ Univariate... . The main dialog box is similar to that for one-way ANOVA, except that there is a space to specify covariates. Select **life satisfaction** and drag this variable to the box labelled *Dependent Variable* or click on . Select **wife** and drag it to the box labelled *Fixed Factor(s)*, and then select **love of animals** and drag it to the box labelled *Covariate(s)*. Your completed dialog box should look like Figure .

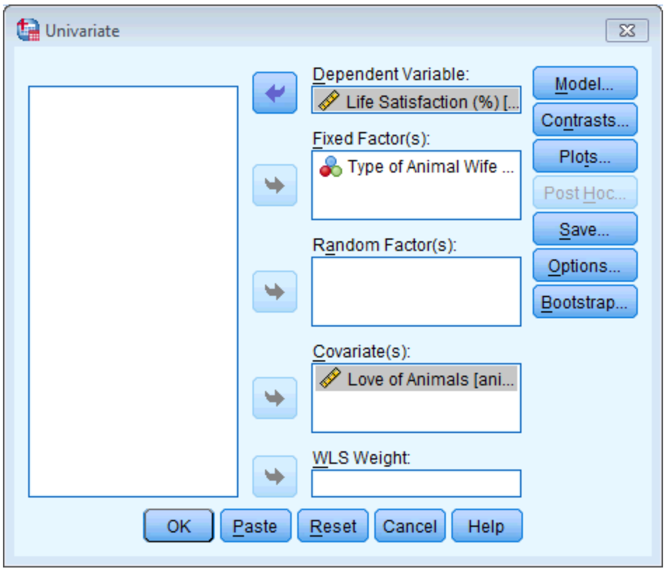


Figure 9

To access the *options* dialog box click on Options... . Your completed dialog box should look like Figure .

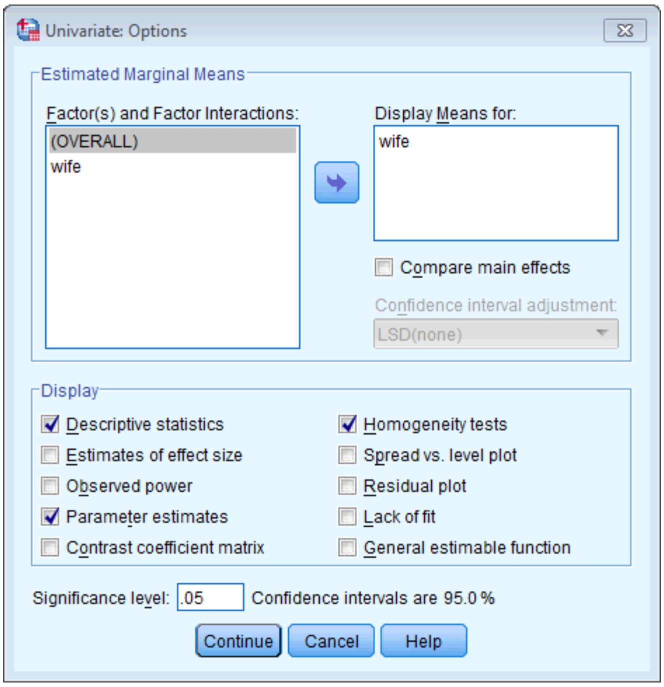


Figure 10

Because our independent variable **wife** only has two levels (goat and dog) we do not need to worry about contrasts. Click on OK in the main dialog box to run the analysis.

Output

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Life Satisfaction (%)

F	df1	df2	Sig.
1.157	1	18	.296

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + animal + wife

Output 18

Tests of Between-Subjects Effects

Dependent Variable: Life Satisfaction (%)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3639.810[a]	2	1819.905	14.172	.000
Intercept	2515.444	1	2515.444	19.588	.000
animal	1325.402	1	1325.402	10.321	.005
wife	2112.099	1	2112.099	16.447	.001
Error	2183.140	17	128.420		
Total	49909.000	20			
Corrected Total	5822.950	19			

a. R Squared = .625 (Adjusted R Squared = .581)

Output 19

Output 18 shows the results of Levene's test and Output 19 shows the ANOVA table when love of animals is included in the model as a covariate. Levene's test is non-significant, indicating that the group variances are roughly equal (hence the assumption of homogeneity of variance has been met). It is clear that the covariate significantly predicts the dependent variable, so love of animals influenced life experience.

Parameter Estimates

Dependent Variable: Life Satisfaction (%)

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared
					Lower Bound	Upper Bound	
Intercept	39.955	7.448	5.365	.000	24.241	55.669	.629
animal	.541	.169	3.213	.005	.186	.897	.378
[wife=1]	-21.011	5.181	-4.055	.001	-31.941	-10.080	.492
[wife=2]	0[a]	.	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

Output 20

Output 20 shows the parameter estimates. These confirm the results in the main ANCOVA table (Output 19). We can see that both love of animals and type of animal wife significantly predict life satisfaction.

Type of Animal Wife

Dependent Variable: Life Satisfaction (%)

Type of Animal Wife	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Goat	38.546[a]	3.273	31.639	45.452
Dog	59.556[a]	4.010	51.095	68.018

a. Covariates appearing in the model are evaluated at the following values: Love of Animals = 36.20.

Output 21

Output 21 gives the adjusted values of the group means, and it is these values that should be used for interpretation. There are only two groups being compared in this example, so we can conclude that the type of animal wife had a significant effect on life satisfaction; specifically, life satisfaction was significantly higher in men who were married to dogs than in men who were married to goats.

Finally, we need to interpret the covariate. To do this we can create a graph of life satisfaction (dependent variable) and love of animals (covariate) using the chart builder (see Chapter 4). Your completed dialog box should look like Figure . The resulting scatterplot (Figure) shows a positive relationship between love of animals and life satisfaction. Specifically, the greater the love of animals, the higher the life satisfaction.

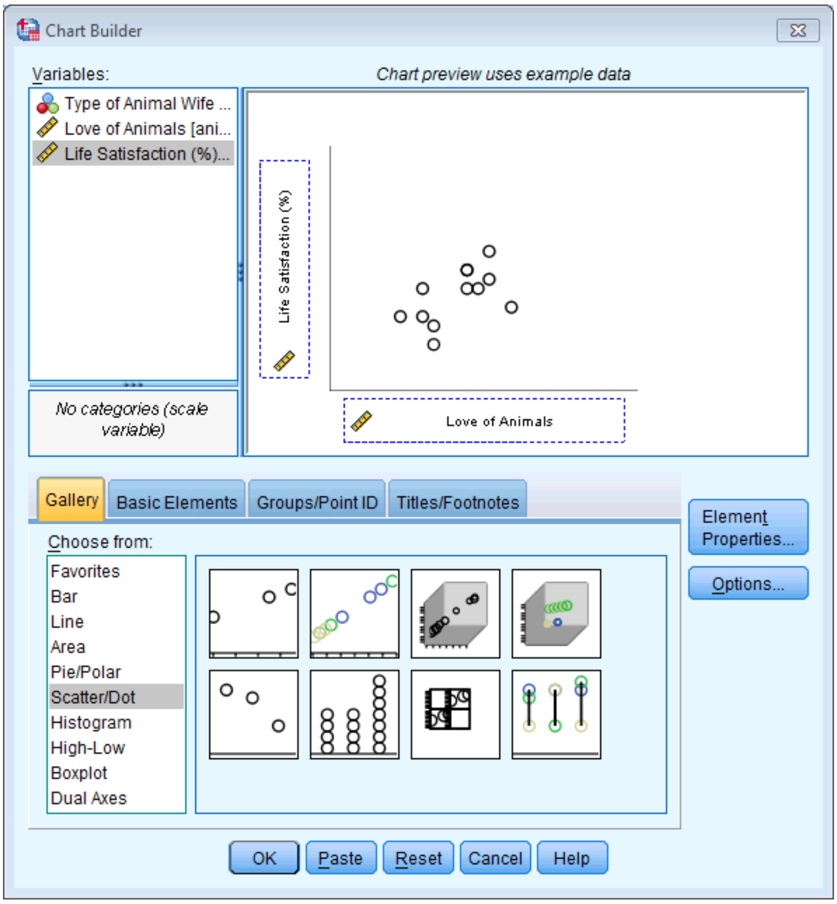


Figure 25

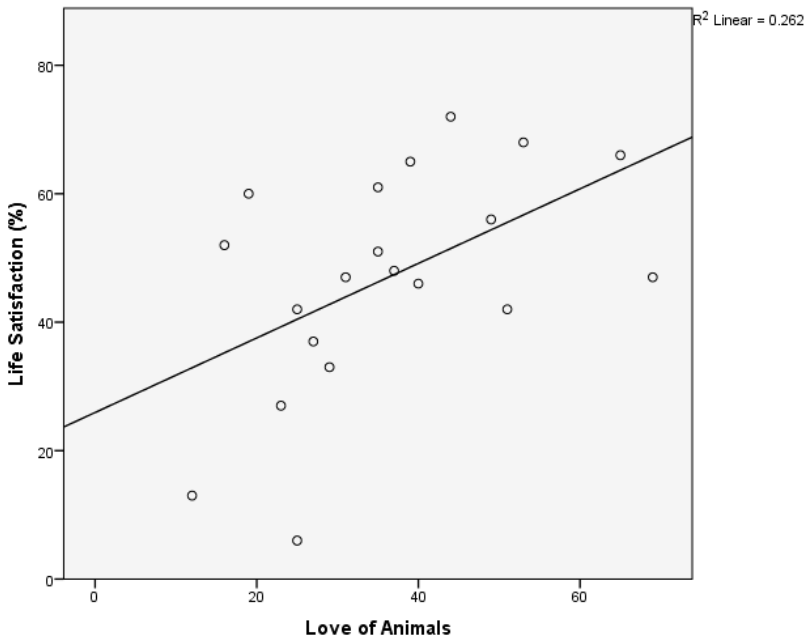


Figure 26

Calculating the effect size

We need to use the sums of squares in Output 19 to calculate partial eta squared for the effect of wife (2112.099), the covariate (1325.402) and the error (2183.140) (or you could just get SPSS you calculate them for you by selecting *Estimates of effect size* in the *options* dialog box; see Figure 24):

$$\text{partial } \eta^2_{\text{wife}} = \frac{\text{SS}_{\text{wife}}}{\text{SS}_{\text{wife}} + \text{SS}_{\text{Residual}}} = \frac{2112.099}{2112.099 + 2183.140} = \frac{2112.099}{4295.239} = .49$$

$$\text{partial } \eta^2_{\text{animal}} = \frac{\text{SS}_{\text{animal}}}{\text{SS}_{\text{animal}} + \text{SS}_{\text{Residual}}} = \frac{1325.402}{1325.402 + 2183.140} = \frac{1325.402}{3508.54} = .38$$

These values show that **wife** explained a bigger proportion of the variance not attributable to other variables than **love of animals.**

Interpreting and writing the result

We could report the main finding as follows:

- ✓ The covariate, love of animals, was significantly related to life satisfaction, $F(1, 17) = 10.32$, $p = .01$, partial $\eta^2 = .38$. There was also a significant effect of the type of animal wife after controlling for love of animals, $F(1, 17) = 16.45$, $p = .001$, partial $\eta^2 = .49$, indicating that life satisfaction was higher for men who were married to dogs (M = 59.56, SE = 4.01) than for men who were married to goats (M = 38.55, SE = 3.27).

Task 7

Compare your results to Task 6 to those for the corresponding task in Chapter 10. What differences do you notice, and why?

Output 22 is from Smart Alex Task 6, Chapter 10, in which we conducted a hierarchical regression predicting life satisfaction from the type of animal wife, controlling for the effect of love of animals. Animal liking was entered in the first block, and type of animal wife in the second block.

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	25.940	8.993		2.884	.010
	Love of Animals	.580	.229	.512	2.530	.021
2	(Constant)	-2.067	9.551		-.216	.831
	Love of Animals	.541	.169	.478	3.213	.005
	Type of Animal Wife	21.011	5.181	.603	4.055	.001

a. Dependent Variable: Life Satisfaction (%)

Output 22

Looking at the coefficients from model 2, we can see that both love of animals, $t(17) = 3.21$, $p < .01$, and type of animal wife, $t(17) = 4.06$, $p < .01$, significantly predicted life satisfaction. This means that type of animal wife predicted life satisfaction over and above the effect of love of animals. In other words, even after controlling for the effect of love of animals, type of animal wife still significantly predicted life satisfaction.

Output 23 displays the results from Task 6 in the present chapter, in which we conducted an ANCOVA predicting life satisfaction from the type of animal to which a person was married and their animal liking score (covariate).

Parameter Estimates

Dependent Variable: Life Satisfaction (%)

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	39.955	7.448	5.365	.000	24.241	55.669	.629
animal	.541	.169	3.213	.005	.186	.897	.378
[wife=1]	-21.011	5.181	-4.055	.001	-31.941	-10.080	.492
[wife=2]	0[a]	.	.	.	.	.	.

a. This parameter is set to zero because it is redundant.

Output 23

The covariate, love of animals, was significantly related to life satisfaction, $F(1, 17) = 10.32$, $p = .01$, partial $\eta^2 = .38$. There was also a significant effect of the type of animal wife after controlling for love of animals, $F(1, 17) = 16.45$, $p = .001$, partial $\eta^2 = .49$, indicating that life satisfaction was higher for men who were married to dogs ($M = 59.56$, $SE = 4.01$) than for men who were married to goats ($M = 38.55$, $SE = 3.27$).

If we compare the results in Output 22 (hierarchical regression output) with the results in Output 23 (ANCOVA output) we can see that they are the same! Basically, what I wanted to show you is that it doesn't matter whether you conduct a regression or an ANCOVA because they are the same.

Task 8

*In Chaopter 9 we compared the number of mischievous acts (**mischief2**) in people who had invisibility cloaks compared to those without (**cloak**). Imagine we also had information about the baseline number of mischievous acts in these participants (**mischief1**). Conduct an ANCOVA to see whether people with invisibility cloaks get up to more mischief than those without, when controlling for their baseline level of mischief (**Cloakofinvisibility.sav**).*

If you are using a PC then my screenshots might look weird to you because I have done them all on a Mac ☺. However, apart from being a different colour they are basically the same, so don't panic.

Let's begin by running a one-way ANOVA without the covariate (**mischief1**). So, we just want to include the independent variable (**cloak**) and the outcome (**mischief2**). Your completed dialog box should look like Figure .

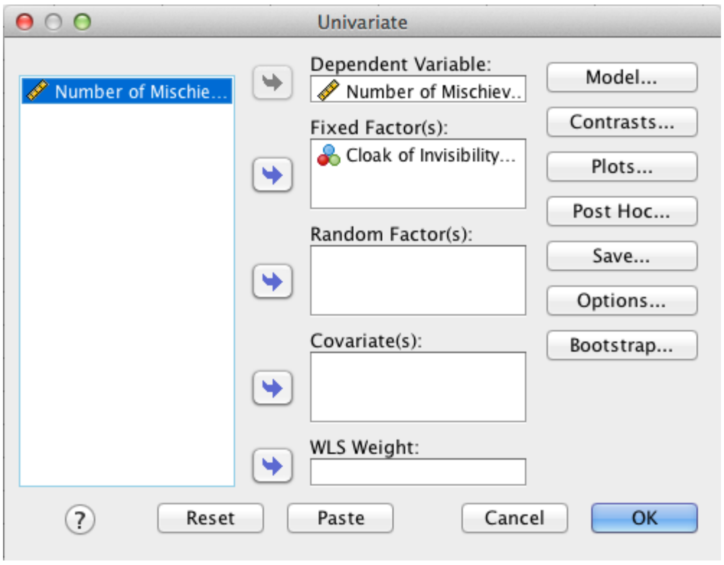


Figure 27

Tests of Between-Subjects Effects

Dependent Variable:Number of Mischievous Acts (Post)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	37.635[a]	1	37.635	11.202	.001
Intercept	6995.935	1	6995.935	2082.343	.000
cloak	37.635	1	37.635	11.202	.001
Error	262.052	78	3.360		
Total	7615.000	80			
Corrected Total	299.687	79			

a. R Squared = .126 (Adjusted R Squared = .114)

Output 24

Output 24 shows the ANOVA table for these data when the covariate is not included. It is clear from the significance value that there was a significant difference between whether or not the person had a cloak of invisibility and the number of mischievous acts they committed.

The next thing that we should do is check that the independent variable (**cloak**) and the covariate (**mischief1**) are independent. To do this we can run another one-way ANOVA, this time including the independent variable (**cloak**) and the covariate (**mischief1**). The dialog box is shown in Figure .

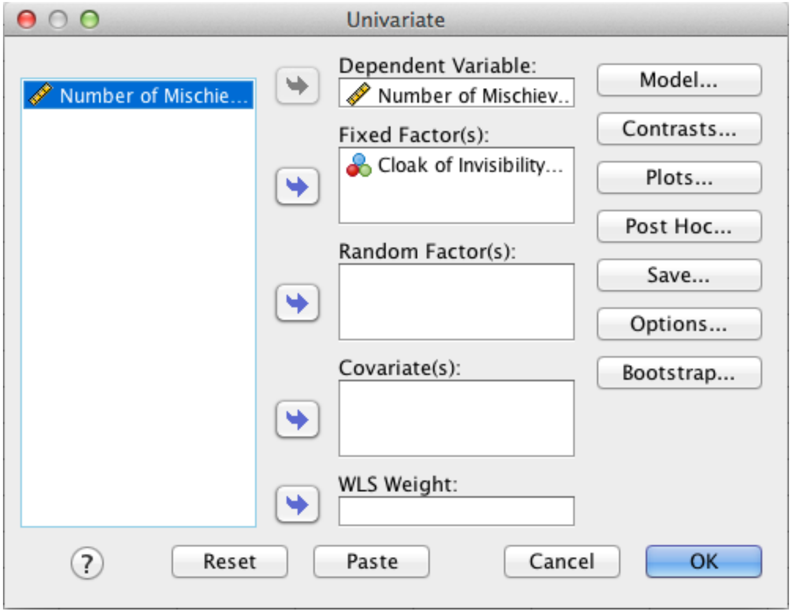


Figure 28

Tests of Between-Subjects Effects

Dependent Variable:Number of Mischievous Acts (Baseline)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.654[a]	1	.654	.135	.714
Intercept	1565.154	1	1565.154	323.538	.000
cloak	.654	1	.654	.135	.714
Error	377.334	78	4.838		
Total	1989.000	80			
Corrected Total	377.988	79			

a. R Squared = .002 (Adjusted R Squared = -.011)

Output 25

Output shows the results of the one-way ANOVA. The main effect of **cloak** is not significant, $F(1, 78) = 0.14$, $p = .71$, which shows that the average number of mischievous acts at baseline was roughly the same in the cloak and no cloak groups. This result is good news for using the variable **mischief1** as a covariate in the analysis.

Next we can conduct the ANCOVA. To do this, access the main dialog box by selecting Analyze General Linear Model ▸ Univariate... . The main dialog box is similar to that for one-way

ANOVA, except that there is a space to specify covariates. Select **mischief2** and drag this variable to the box labelled *Dependent Variable* or click on . Select **cloak** and drag it to the box labelled *Fixed Factor(s)*, and then select **mischief1** and drag it to the box labelled *Covariate(s)*. Your completed dialog box should look like Figure .

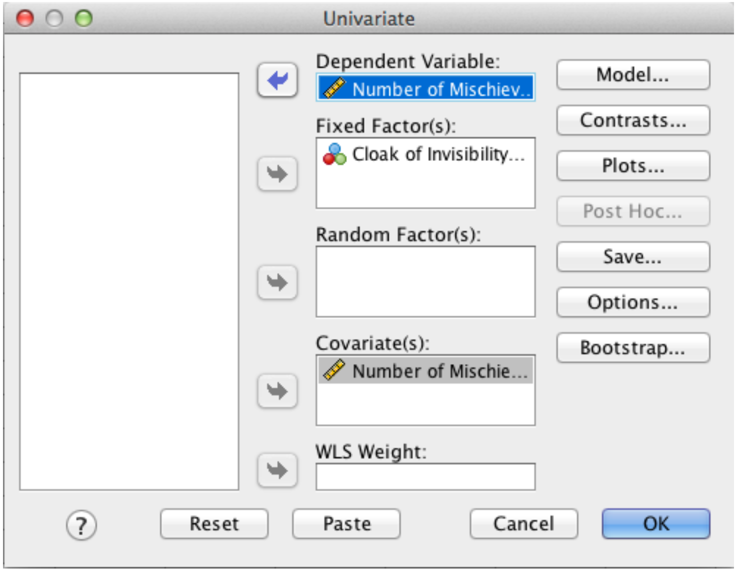


Figure 29

To access the *options* dialog box, click on Options... . Your completed dialog box should look like Figure . (Note that I have not ticked the box for *Parameter estimates*. This is because our independent variable **cloak** has only two levels (cloak and no cloak) and, as such, the parameter estimates would not tell us anything different than the between-subjects effects box. However, for this example I have ticked the box for *Estimates of effect size*, so that SPSS will calculate the partial eta squared for us.)

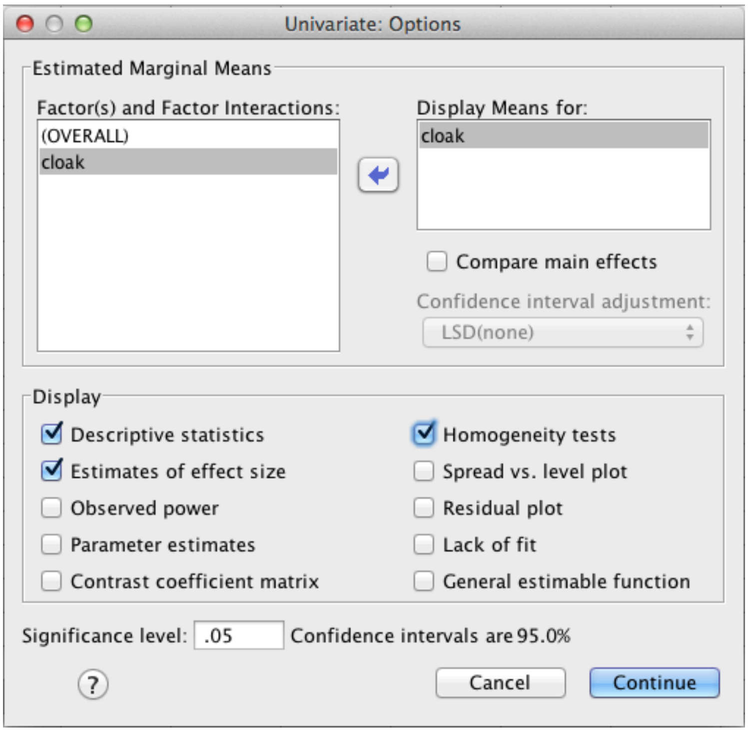


Figure 11

Because our independent variable **cloak** only has two levels (cloak and no cloak) we do not need to worry about contrasts or post hoc tests. Click on OK in the main dialog box to run the analysis.

Output

Levene's Test of Equality of Error Variances[a]

Dependent Variable:Number of Mischievous Acts (Post)

F	df1	df2	Sig.
.247	1	78	.620

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + mischief1 + cloak

Output 29

Tests of Between-Subjects Effects

Dependent Variable:Number of Mischievous Acts (Post)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	60.607[a]	2	30.303	9.760	.000	.202
Intercept	1060.290	1	1060.290	341.484	.000	.816
mischief1	22.972	1	22.972	7.398	.008	.088
cloak	35.166	1	35.166	11.326	.001	.128
Error	239.081	77	3.105			
Total	7615.000	80				
Corrected Total	299.687	79				

a. R Squared = .202 (Adjusted R Squared = .182)

Output 26

Output shows the results of Levene's test and Output shows the ANCOVA table when baseline number of mischievous acts is included in the model as a covariate. Levene's test is non-significant, indicating that the group variances are roughly equal (hence the assumption of homogeneity of variance has been met). We can see that the covariate (**mischief1**) significantly predicts the dependent variable (**mischief2**), so baseline number of mischievous acts significantly influenced the number of mischievous acts committed when wearing a cloak of invisibility.

Cloak of Invisibility

Dependent Variable:Number of Mischievous Acts (Post)

Cloak of Invisibility	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
No Cloak	8.791[a]	.302	8.189	9.393
Cloak	10.133[a]	.260	9.615	10.651

a. Covariates appearing in the model are evaluated at the following values: Number of Mischievous Acts (Baseline) = 4.49.

Output 27

Output gives the adjusted values of the group means, and it is these values that should be used for interpretation. There are only two groups being compared in this example, so we can conclude that wearing a cloak of invisibility had a significant effect on the number of mischievous acts; specifically, the number of mischievous acts was significantly higher in people who wore a cloak of invisibility than in people who did not wear a cloak of invisibility.

Finally, we need to interpret the covariate. To do this we can create a graph of mischievous acts post experiment (dependent variable) and baseline number of mischievous acts (covariate). Your completed dialog box in the chart builder should look like Figure . The resulting scatterplot (Figure) shows a positive relationship between baseline number of mischievous acts and number of mischievous acts post manipulation; specifically, the greater the baseline number of mischievous acts, the greater the number of mischievous acts after the experimental manipulation.

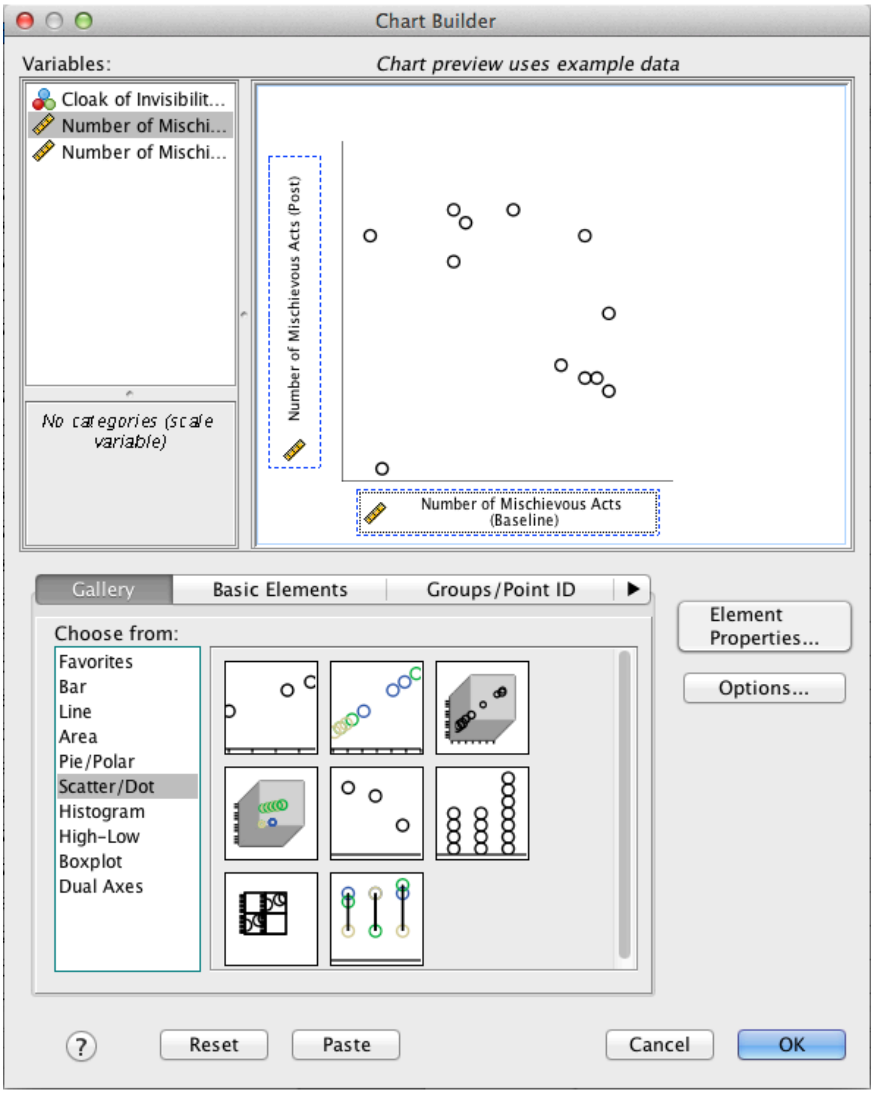


Chart Builder
Variables:
Chart preview uses example data
Cloak of Invisibilit...
Number of Mischi...
Number of Mischi...
No categories (scale variable)
Number of Mischievous Acts (Post)
Number of Mischievous Acts (Baseline)
Gallery
Basic Elements
Groups/Point ID
Element Properties...
Options...
Choose from:
Favorites
Bar
Line
Area
Pie/Polar
Scatter/Dot
Histogram
High-Low
Boxplot
Dual Axes
Reset
Paste
Cancel
OK

Figure 12

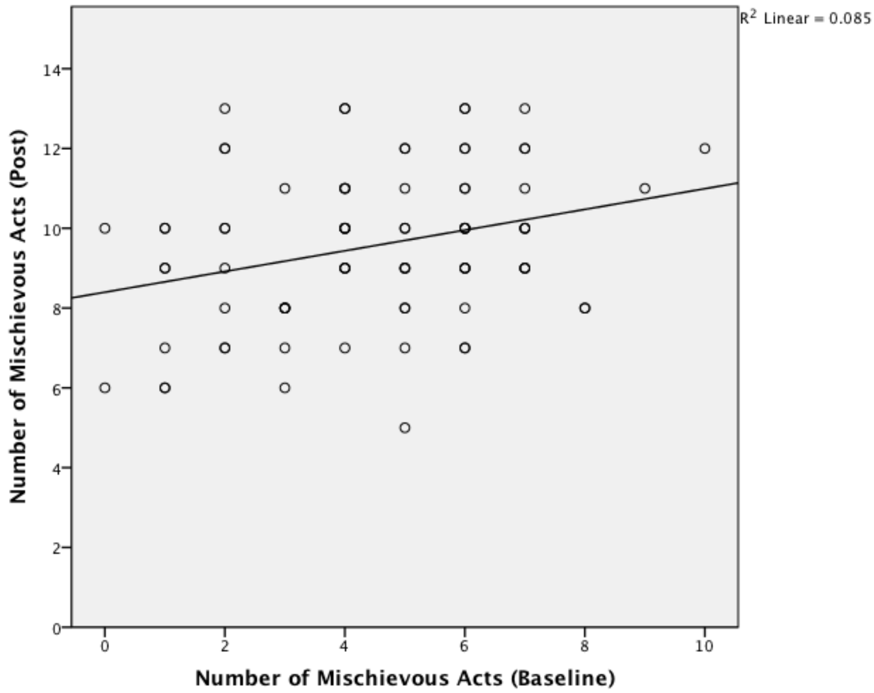


Figure 13

Calculating the effect size

We need to use the sums of squares in Output to calculate partial eta squared for the effect of **cloak** (35.166), the covariate **mischief1** (22.972) and the error (239.081):

$$\text{partial } \eta^2_{\text{cloak}} = \frac{SS_{\text{cloak}}}{SS_{\text{cloak}} + SS_{\text{Residual}}} = \frac{35.166}{35.166 + 239.081} = \frac{35.166}{274.247} = .13$$

$$\text{partial } \eta^2_{\text{mischief1}} = \frac{SS_{\text{mischief1}}}{SS_{\text{mischief1}} + SS_{\text{Residual}}} = \frac{22.972}{22.972 + 239.081} = \frac{22.972}{262.053} = .09$$

These values are the same as the values in the column labelled *Partial Eta Squared* in Output ; they tell us that the independent variable **cloak** explained a bigger proportion of the variance not attributable to other variables than the covariate **mischief1**.

Interpreting and writing the result

We could report the main finding as follows:

✓ The covariate, baseline number of mischievous acts, was significantly related to the number of mischievous acts after the cloak of invisibility manipulation, $F(1, 77) = 7.40$, $p = .01$, partial $\eta^2 = .09$. There was also a significant effect of wearing a cloak of invisibility after controlling for baseline number of mischievous acts, $F(1, 77) = 11.33$, $p = .001$, partial $\eta^2 = .13$, indicating that the number of mischievous acts was higher in those who were given a cloak of invisibility ($M = 10.13$, $SE = .26$) than in those who were not ($M = 8.79$, $SE = .30$).