Lesson

27

One-Way Analysis of Covariance

A one-way analysis of covariance (ANCOVA) evaluates the null hypothesis that population means on the dependent variable are equal across levels of a factor, adjusting for differences on the covariate, or, more simply stated, the population adjusted means are equal across groups. An assumption underlying ANCOVA is that the slopes relating the covariate to the dependent variable are the same for all groups (i.e., the homogeneity-of-slopes assumption). If this assumption is violated, then between-group differences in adjusted means are not interpretable. In practice, the homogeneity-of-slopes assumption should be empirically evaluated prior to conducting an ANCOVA, and ANCOVA should not be conducted if the results indicate that this assumption has been violated. In place of ANCOVA, analyses should be carried out to assess simple main effects, that is, differences in group means on the dependent variable for particular levels of the covariate.

With a one-way analysis of covariance, each individual or case must have scores on three variables: a factor or independent variable, a covariate, and a dependent variable. The factor divides individuals into two or more groups or levels, while the covariate and the dependent variable differentiate individuals on quantitative dimensions.

APPLICATIONS OF THE ONE-WAY ANCOVA

One-way ANCOVA is used to analyze data from several types of studies.

- Studies with a pretest and random assignment of subjects to factor levels
- Studies with a pretest and assignment to factor levels based on the pretest
- Studies with a pretest, matching based on the pretest, and random assignment to factor levels
- Studies with potential confounding

We will next illustrate each of these four types of studies. Maxwell and Delaney (2000) discuss more extensively the use of ANCOVA with these four applications.

Studies with a Pretest and Random Assignment to Factor Levels

Dana wishes to assess whether vitamin C is effective in the treatment of colds. To evaluate her hypothesis, she decides to conduct a two-year experimental study. She obtains 30 volunteers from undergraduate classes to participate. She randomly assigns an equal number of students to three groups: placebo (group 1), a low dose of vitamin C (group 2), and a high dose of vitamin C (group 3). In the first and second years of the study, students in all three groups are monitored to assess the number of days that they have cold symptoms. During the first year, students do not take any pills. In the second year of the study, students take pills that contain one of the following: no active ingredient (group 1), a low dose of vitamin C (group 2), or a high dose of vitamin C (group 3). Dana's SPSS data file includes 30 cases and three variables: a factor distinguishing among the three medication groups; a covariate, the number of days with cold symptoms in the first year before any treatment; and a dependent variable, the number of days with cold symptoms in the second year when they are taking pills.

Studies with a Pretest and Assignment to Factor Levels Based on the Pretest

Jean wishes to assess whether individuals who are depressed about some event would benefit from intensively writing about their emotions. To evaluate this hypothesis, she obtains a sample of 60 runners who have had

physical injuries that prevent them from running. She administers a measure of depression to these runners. The individuals who have the highest scores on the premeasure of depression (those who are most depressed) are assigned to the writing condition, while those who have lower scores are assigned to the attention placebo group. The runners in both groups meet with Jean's research assistant twice, four hours per occasion. The runners in the writing group are asked to write about how they feel about their injuries, while the runners in the attention placebo group are asked to write a short story involving adventure. Runners in both groups then retake the depression measure. Jean's SPSS data file includes 60 cases and three variables: a factor distinguishing among the two treatment groups, a covariate that assesses depression before treatment, and a dependent variable that assesses depression after treatment.

Studies with a Pretest, Matching Based on the Pretest, and Random Assignment to Factor Levels

Jim decides to conduct a study to learn how much time basketball players need to spend at the foul line preparing themselves to shoot free throws to be effective. Jim asks boys from his physical education classes to volunteer for his free-throw shooting study. Sixty boys consent to participate. These boys initially shoot 50 free throws, and their accuracy is recorded. Next, Jim rank-orders the accuracy scores from lowest to highest and places the boys into 20 groups of three based on these scores. In other words, the three boys who have the three lowest accuracy scores are in one group, the three boys who have the next three lowest accuracy scores are in another group, and so on. Within each of these 20 triads, one boy is randomly assigned to treatment Group 1, another boy to treatment Group 2, and the third boy to treatment Group 3. Over the next two weeks, boys are taught a specific method to shoot free throws. The boys in Group 1 are taught to shoot approximately two seconds after going to the free throw line, the boys in Group 2 are taught to shoot approximately five seconds after going to the free throw line, and the boys in Group 3 are taught to shoot approximately eight seconds after going to the free throw line. Finally, all boys again must shoot 50 free throws, and their scores are recorded. Jim's SPSS data file has 60 cases and three variables: a factor distinguishing among the three treatment groups, a covariate that assesses their accuracy in shooting free throws before treatment, and a dependent variable that assesses their accuracy in shooting free throws after treatment.

Studies with Potential Confounding

Larry worked with 60 boys who had exhibited unruly behavior in their junior high schools. Recently, 20 of these boys participated in a special summer program. The other 40 boys did not participate because they had failed to return the permission slip before the deadline. After the summer program, Larry had the teachers of all 60 boys complete a rating form indicating the degree that they found the boys to be behavioral problems in their classrooms. Larry wanted to compare the two groups of boys on the behavior ratings to assess the effectiveness of the summer program. Because he felt that the boys who participated in the summer program might have come from families with a higher socioeconomic status (SES), he also computed an SES index for each of the 60 boys. Larry's SPSS data file includes 60 cases and three variables: a factor distinguishing between the two groups (boys who participated in the summer program and boys who did not), a covariate SES, and the behavior ratings completed by the teachers.

UNDERSTANDING ONE-WAY ANCOVA

Prior to conducting an ANCOVA, it is necessary to evaluate empirically the homogeneity-of-slopes assumption. The results of this empirical analysis lead researchers to proceed in one of two ways:

- If the results support the homogeneity-of-slopes assumption, researchers may conduct an ANCOVA. The ANCOVA *F* test evaluates whether the population means on the dependent variable, adjusted for differences on the covariate, differ across levels of a factor. If a factor has more than two levels and the *F* is significant, follow-up tests should be conducted to assess differences between adjusted means for the groups. These follow-up tests most often

involve comparisons of pairs of adjusted means. For example, if a factor has three levels, three pairwise comparisons among adjusted means can be conducted: Group 1 adjusted mean versus Group 2 adjusted mean, Group 1 adjusted mean versus Group 3 adjusted mean, and Group 2 adjusted mean versus Group 3 adjusted mean.

- If the results fail to support the homogeneity-of-slopes assumption, researchers should not conduct an ANCOVA. The implication of finding the slopes to be heterogeneous is that the mean differences between groups vary as a function of the covariate score. Accordingly, follow-up tests are required to assess mean differences between groups for particular scores on the covariate. These tests are referred to as simple main effects tests. If mean differences exist for any particular covariate score and the factor has more than two levels, additional analyses may be conducted to assess pairwise differences among groups (i.e., levels of the factor) at that covariate score.

Adequacy of One-Way ANCOVA for Each Application

The adequacy of ANCOVA to adjust the dependent variable scores for covariate differences depends on the type of study.

STUDIES WITH A PRETEST AND RANDOM ASSIGNMENT TO FACTOR LEVELS ANCOVA may be applied to data in which (1) all cases are measured initially on a pretest, (2) cases are randomly assigned to different groups, (3) groups receive different treatments, and (4) all cases subsequently are measured on a posttest. The pretest and the posttest could be the same measure. Alternatively, the pretest and posttest could be different measures and could even assess different constructs. Assuming that the ANCOVA assumptions are met, the one-way ANCOVA should adequately adjust dependent variable scores for initial covariate differences among groups for this design.

STUDIES WITH A PRETEST AND ASSIGNMENT TO FACTOR LEVELS BASED ON THE PRETEST ANCOVA may be applied to data in which (1) all cases are measured on a pretest, (2) cases are assigned to different treatment groups based on their pretest scores, (3) groups receive different treatments, and (4) all cases are measured on a posttest. The pretest and the posttest could be the same measure, or they could be different measures that assess the same or different dimensions. If the ANCOVA assumptions are met, ANCOVA should adequately adjust the dependent variable scores for initial covariate differences among groups for this design.

STUDIES WITH A PRETEST, MATCHING BASED ON THE PRETEST, AND RANDOM ASSIGNMENT TO FACTOR LEVELS ANCOVA may be applied to data in which (1) all cases are measured on a pretest, (2) cases are assigned to different groups based on their pretest scores, (3) cases are randomly assigned to levels of the factor within each of the groups that were formed based on the pretest, (4) cases in different levels of the factor receive different treatments, and (5) all cases are measured on a posttest. Similar to the previous application, the pretest and the posttest could be the same measure or different measures assessing the same or different constructs. Assuming that the ANCOVA assumptions are met, the one-way ANCOVA should adequately adjust dependent variable scores for initial covariate differences among groups.

STUDIES WITH POTENTIAL CONFOUNDING For studies with potential confounding, cases are in different groups, but are neither randomly assigned to groups nor assigned to groups based on their pretest scores. The difficulty with these studies is that the groups may differ due to variables other than the factor and the covariate. Because these studies are potentially confounded, conclusions about the group differences are difficult to reach. The results of an ANCOVA can be misleading for studies with this design.

Assumptions Underlying a One-Way ANCOVA

ASSUMPTION 1: THE DEPENDENT VARIABLE IS NORMALLY DISTRIBUTED IN THE POPULATION FOR ANY SPECIFIC VALUE OF THE COVARIATE AND FOR ANY ONE LEVEL OF A FACTOR This assumption describes multiple conditional distributions of the dependent variable, one for every combination of values of the covariate and levels of the factor, and requires them all to be normally distributed. To the extent that population distributions are

not normal and sample sizes are small, *p* values may be invalid. In addition, the power of ANCOVA tests may be reduced considerably if the population distributions are nonnormal and, more specifically, thick-tailed or heavily skewed. See Wilcox (2001) for an extended discussion of assumptions.

ASSUMPTION 2: THE VARIANCES OF THE DEPENDENT VARIABLE FOR THE CONDITIONAL DISTRIBUTIONS DESCRIBED IN ASSUMPTION 1 ARE EQUAL To the extent that this assumption is violated and the group sample sizes differ, the validity of the results of the one-way ANCOVA analysis should be questioned. Even with equal sample sizes, the results of the standard post hoc tests should be mistrusted if the population variances differ.

ASSUMPTION 3: THE CASES REPRESENT A RANDOM SAMPLE FROM THE POPULATION, AND THE SCORES ON THE DEPENDENT VARIABLE ARE INDEPENDENT OF EACH OTHER The test will yield inaccurate results if the independence assumption is violated.

ASSUMPTION 4: THE COVARIATE IS LINEARLY RELATED TO THE DEPENDENT VARIABLE WITHIN ALL LEVELS OF THE FACTOR, AND THE WEIGHTS OR SLOPES RELATING THE COVARIATE TO THE DEPENDENT VARIABLE ARE EQUAL ACROSS ALL LEVELS OF THE FACTOR The latter part of this assumption is the homogeneity-of-slopes assumption. To the extent that homogeneity of slopes does not hold, the results of ANCOVA are likely to be misinterpreted in that the differences on the dependent variable between groups vary as a function of the covariate. In this lesson, we will discuss a method for evaluating the homogeneity-of-slopes assumption. In addition, we will present simple main effect tests that may be conducted if this assumption does not hold. These tests evaluate differences between groups on the dependent variable for particular values of the covariate.

Effect Size Statistics for One-Way ANCOVA

The General Linear Model procedure computes an effect size index, the partial η^2. Although partial η^2s are computed for the factor and the covariate, via the formula

$$Partial\ \eta^2_{Factor\ or\ Covariate\ Sources} = \frac{Sum\ of\ Squares_{Factor\ or\ Covariate\ Source}}{Sum\ of\ Squares_{Factor\ or\ Covariate\ Source} + Sum\ of\ Squares_{Error}}$$

the partial η^2 of primary interest is the one associated with the factor.

The partial η^2 ranges in value from 0 to 1. The partial η^2 for the factor is interpreted as the proportion of variance of the dependent variable related to the factor, holding constant (partialling out) the covariate. It is unclear what are small, medium, and large values for partial η^2; however, conventional cutoffs are .01, .06, and .14, respectively.

THE DATA SET

The data set used to illustrate this procedure is named *Lesson 27 Data File 1* on the Web at http://www.pearsonhighered.com/greensalkindSPSS and represents data from the vitamin C example described earlier in this lesson. The variables in the data set are shown in Table 24.

Table 24
Variables in Lesson 27 Data File 1

Variable	Definition
group	1 = Placebo
	2 = Low dose of vitamin C
	3 = High dose of vitamin C
predays	Number of days with cold symptoms in the first year
days	Number of days with cold symptoms in the second year

THE RESEARCH QUESTION

The research question can be stated to reflect mean differences or relationships between variables.

1. Mean differences: Does the number of days of cold symptoms differ for those who take a placebo, those who take a low dose of vitamin C, and those who take a high dose of vitamin C, assuming no prior differences in the number of days of cold symptoms among groups?
2. Relationship between variables: Is there a relationship between how much vitamin C is taken and the number of days that an individual shows cold symptoms, holding constant the number of days with cold symptoms in the year prior to treatment?

The research question would have to be modified if the slopes were found to be heterogeneous among groups. For example, the first research question might be rephrased as follows: Does the number of days of cold symptoms differ for students who take a placebo, students who take a low dose of vitamin C, and students who take a high dose of vitamin C if the students had a specific number of days of cold symptoms in the year prior to these treatments (e.g., 9 days of cold symptoms)?

CONDUCTING A ONE-WAY ANCOVA AND RELATED ANALYSES

In this section, we will illustrate a number of analyses:

- ***Test of Homogeneity of Slopes*** We initially demonstrate how to test the hypothesis of the homogeneity of slopes, which is an assumption of ANCOVA. This analysis represents the first step in the testing process when conducting an ANCOVA.
- ***Analysis of Covariance*** Next, we show how to conduct an ANCOVA. ANCOVA evaluates differences in adjusted means. This step presumes that the initial analysis indicated that the slopes appear homogeneous.
- ***Simple Main Effects*** Finally, we describe how to assess group differences on the dependent variable for particular levels of the covariate (i.e., simple main effects). This step assumes that the initial analysis indicated that the slopes appear heterogeneous.

Conducting a Test of the Homogeneity-of-Slopes Assumption

To conduct the test of the homogeneity-of-slopes assumption, follow these steps:

1. Click **Analyze**, click **General Linear Model**, and then click **Univariate**.
2. Click **days**, then click ▶ to move it to the Dependent Variable box.
3. Click **group**, then click ▶ to move it to the Fixed Factor(s) box.
4. Click **predays**, then click ▶ to move it to the Covariate(s) box.
5. Click on **Options**.
6. In the Factor(s) and Factor Interactions box, click **group**.
7. Click ▶ to move it to the Display Means for box.
8. Select **Descriptive statistics**, **Estimates of effect size**, and **Homogeneity tests** in Display box.
9. Click **Continue**.
10. Click **Model**.
11. Click **Custom** under Specify Model.
12. Click **group(F)** under Factors & Covariates, and click ▶ to make it appear in the Model box.
13. Click **predays(C)** under Factors & Covariates, and click ▶ to make it appear in the Model box.
14. Holding down the Ctrl key, click **group(F)** and **predays(C)** in the Factors & Covariates box. Check to see that the default option Interaction is specified in the drop-down menu in the Build Terms box. If it is not, select it.
15. Click ▶ and group*predays should now appear in the Model box.
16. Click **Continue**.
17. Click **OK**.

Selected SPSS Output for Test of the Homogeneity-of-Slopes Assumption

Selected results of the analysis are shown in Figure 163.

Tests of Between-Subjects Effects

Dependent Variable: Days with Colds: Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	351.594[a]	5	70.319	5.917	.001	.552
Intercept	186.218	1	186.218	15.670	.001	.395
group	10.114	2	5.057	.426	.658	.034
predays	156.618	1	156.618	13.179	.001	.354
group * predays	35.039	2	17.519	1.474	.249	.109
Error	285.206	24	11.884			
Total	2960.000	30				
Corrected Total	636.800	29				

a. R Squared = .552 (Adjusted R Squared = .459)

Figure 163. Selected results of the test of homogeneity of slopes.

Before conducting an ANCOVA, the homogeneity-of-slopes assumption should be tested. The null hypothesis for this test is that the population slopes are homogeneous. The null hypothesis can also be conceptualized as the population effect of the interaction between the covariate and the factor in predicting the dependent variable is zero. A significant interaction between the covariate and the factor suggests that population slopes differ or that the mean differences on the dependent variable among groups vary as a function of the covariate. If the interaction is significant, ANCOVA should not be conducted. Instead, the mean differences between groups on the dependent variables should be assessed at particular levels of the covariate (i.e., simple main effects).

The interaction source is labeled group*predays. The interaction is not significant, $F(2, 24) = 1.47$, $p = .25$, although the partial η^2 of .11 is of moderate size. The results of the partial η^2 indicate that in the sample the mean differences in posttreatment days of cold symptoms among the vitamin C groups varied to some extent as a function of the number of pretreatment days of cold symptoms. However, given the interaction test was nonsignificant, the data are not sufficiently convincing that we can reach this conclusion in the population. Under these conditions, researchers may take one of two approaches. Based on the nonsignificant test results, an ANCOVA could be conducted assuming homogeneity of slopes and, if the ANCOVA is significant, follow-up tests could be computed to assess differences in adjusted means. Alternatively, based on the results of the partial η^2, simple main effects tests could be conducted that allow for heterogeneity of slopes. We prefer the second strategy in that the homogeneity-of-slopes assumption is obviated.

We next proceed to the ANCOVA assuming homogeneity of slopes. However, we later consider methods that allow for heterogeneity of slopes for this problem.

Conducting One-Way ANCOVA

To conduct a one-way ANCOVA, follow these steps:

1. Click **Analyze**, click **General Linear Model**, and then click **Univariate**.
2. If you have not exited SPSS, the appropriate options should still be selected. If not, conduct Steps 2 through 9 in the preceding section on conducting the homogeneity-of-slopes test.
3. Click **Model**.
4. Click **Full Factorial**.
5. Click **Continue**.
6. Click on **Options**.
7. Click on the box next to **Compare main effects**.
8. Click **Continue**.
9. Click **OK**.

Selected SPSS Results for the Group Main Effect and the Covariate

The results are shown in Figure 164. The group source (labeled GROUP on the SPSS output) evaluates the null hypothesis that the population adjusted means are equal. The results of the analysis indicate that this hypothesis should be rejected, $F(2, 26) = 6.45$, $p < .01$, and the partial η^2 of .33 suggests a strong relationship between treatment and posttreatment days with cold symptoms, controlling for pretreatment days with cold symptoms. The test assesses the differences among the adjusted means for the three groups, which are reported in the output as the Estimated Marginal Means (i.e., 12.01, 7.71, and 6.67). It should be noted that differences among the adjusted means are not the same as differences among the means on the dependent measure (i.e., 11.60, 8.40, and 6.40) in that the three treatment groups had a differing number of pretreatment days with colds.

The covariate is included in the analysis to control for differences on this variable and is not the focus of the analysis. Consequently, the results for the covariate are frequently not

Dependent Variable: Days with Colds: Post

Vitamin C Treatment	Mean	Std. Deviation	N
Placebo	11.60	5.358	10
Low Vitamin C Dose	8.40	3.836	10
High Vitamin C Dose	6.40	3.471	10
Total	8.80	4.686	30

Tests of Between-Subjects Effects

Dependent Variable: Days with Colds: Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	316.555[a]	3	105.518	8.567	.000	.497
Intercept	172.111	1	172.111	13.973	.001	.350
predays	178.955	1	178.955	14.529	.001	.358
group	158.903	2	79.452	6.450	.005	.332
Error	320.245	26	12.317			
Total	2960.000	30				
Corrected Total	636.800	29				

a. R Squared = .497 (Adjusted R Squared = .439)

Estimates

Dependent Variable: Days with Colds: Post

Vitamin C Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Placebo	12.011[a]	1.115	9.719	14.303
Low Vitamin C Dose	7.715[a]	1.124	5.404	10.026
High Vitamin C Dose	6.674[a]	1.112	4.388	8.960

a. Covariates appearing in the model are evaluated at the following values: Days with Colds: Prior = 9.00.

Pairwise Comparisons

Dependent Variable: Days with Colds: Post

(I) Vitamin C Treatment	(J) Vitamin C Treatment	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Placebo	Low Vitamin C Dose	4.296*	1.596	.012	1.016	7.576
	High Vitamin C Dose	5.337*	1.570	.002	2.110	8.564
Low Vitamin C Dose	Placebo	-4.296*	1.596	.012	-7.576	-1.016
	High Vitamin C Dose	1.041	1.590	.518	-2.227	4.308
High Vitamin C Dose	Placebo	-5.337*	1.570	.002	-8.564	-2.110
	Low Vitamin C Dose	-1.041	1.590	.518	-4.308	2.227

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Figure 164. Results of the one-way ANCOVA.

reported in a Results section. Nevertheless, the results are available as part of the output. The test of the covariate evaluates the relationship between the covariate and the dependent variable within groups (i.e., controlling for the factor). In the current example, this relationship is significant, $F(1, 26) = 14.53$, $p < .01$, with the covariate accounting for about 36% (i.e., the partial η^2 of .36) of variance of the posttreatment days with cold symptoms, controlling for the treatment factor.

The results of the pairwise comparisons are shown in the bottom portion of Figure 164. The differences in adjusted means are 4.30 (12.01 − 7.71) between the placebo and the low-dose vitamin C groups, 5.34 (12.01 − 6.67) between the placebo and high-dose vitamin C groups, and 1.04 (7.71 − 6.67) between the low- and high-dose vitamin C groups. Based on the LSD (Appendix B), the first two pairwise differences were significant, $p = .01$ and $p < .01$, whereas the last pairwise difference was nonsignificant, $p = .52$.

Conducting Tests of Simple Group Main Effects for Particular Values of the Covariate

If the slopes are heterogeneous in the population, ANCOVA is inappropriate. Under these conditions, analyses are required that assess mean differences between groups on the dependent variable for particular levels of the covariate—that is, simple group main effects. To conduct these analyses, researchers must choose levels on the covariate. We recommend selecting at least three levels representing low, medium, and high values. One empirical approach to determine levels would be to choose one standard deviation below the mean, the mean, and one standard deviation above the mean on the covariate. For our data, the mean and standard deviation on predays, ignoring groups, are 9.00 and 5.55, respectively. Accordingly, low, medium, and high values are 3.45, 9.00, and 14.55. To assess differences between groups at these levels of the covariate, follow these steps:

1. Click **Analyze**, click **General Linear Model**, and then click **Univariate**.
2. Conduct Steps 2 through 16 as described in Conducting a Test of the Homogeneity-of-Slopes Assumption.
3. Click on **Options**.
4. Click on the box next to **Compare main effects.**
5. Click **Continue**.
6. Click on **Paste**.
7. Copy the /EMMEANS statement so that it appears three times in the syntax:
   /EMMEANS = TABLES(group) WITH(predays=MEAN) COMPARE ADJ(LSD)
   /EMMEANS = TABLES(group) WITH(predays=MEAN) COMPARE ADJ(LSD)
   /EMMEANS = TABLES(group) WITH(predays=MEAN) COMPARE ADJ(LSD)
8. Substitute 3.45 for MEAN in the first /EMMEANS statement and 14.55 for MEAN in the third /EMMEANS statement. The syntax should appear as it does in Figure 165.
9. Highlight the syntax, click **Run**, and then click **Selection**.

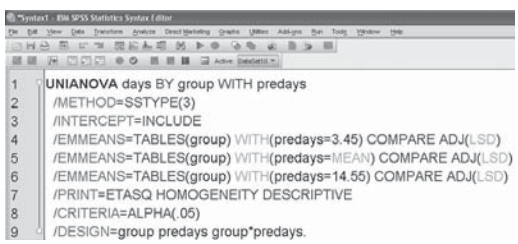

Figure 165. Syntax for conducting tests of simple group main effects.

Selected SPSS Output for Simple Group Main Effects

Simple main effect tests were conducted at low, medium, and high values on the covariate. Accordingly, we required a p value of .017 (.05/3) for significance. If any one simple main effect was significant, pairwise comparisons were evaluated using the LSD procedure at the same level (i.e., .017) as the simple main effects test.

The results of the tests for the simple group main effects when the pretreatment days of cold symptoms is equal to 3.45 are shown in Figure 166. For individuals with a pretreatment score of 3.45, the means for the posttreatment days of cold symptoms are estimated to be 8.51, 5.06, and 5.63 for the placebo, low-dose, and high-dose groups, respectively. As indicated in the table labeled Univariate Tests, we cannot conclude that the corresponding population means differ, $F(2, 24) = 1.48$, $p = .25$, partial η^2 of .11. Given nonsignificance among means, we did not examine the pairwise differences among groups.

Estimates

Dependent Variable: Days with Colds: Post

Vitamin C Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Placebo	8.508[a]	1.416	5.586	11.430
Low Vitamin C Dose	5.064[a]	1.762	1.428	8.699
High Vitamin C Dose	5.631[a]	1.559	2.414	8.849

a. Covariates appearing in the model are evaluated at the following values: Days with Colds: Prior = 3.

Pairwise Comparisons

Dependent Variable: Days with Colds: Post

(I) Vitamin C Treatment	(J) Vitamin C Treatment	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Placebo	Low Vitamin C Dose	3.444	2.260	.141	-1.220	8.109
	High Vitamin C Dose	2.877	2.106	.185	-1.470	7.223
Low Vitamin C Dose	Placebo	-3.444	2.260	.141	-8.109	1.220
	High Vitamin C Dose	-.568	2.352	.811	-5.423	4.287
High Vitamin C Dose	Placebo	-2.877	2.106	.185	-7.223	1.470
	Low Vitamin C Dose	.568	2.352	.811	-4.287	5.423

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: Days with Colds: Post

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	35.178	2	17.589	1.480	.248	.110
Error	285.206	24	11.884			

The F tests the effect of Vitamin C Treatment. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Figure 166. Results of tests of simple group main effects when the covariate is equal to 3.45.

The results of the tests of simple main effects are not shown for medium and high values on the covariate. For individuals with a pretreatment score of 9.00, the means for posttreatment days of cold symptoms are estimated to be 12.20, 7.69, and 6.49 for the placebo, low-dose, and high-dose groups, respectively. As indicated in the Univariate Tests table, the differences among the means on posttreatment measure when the pretreatment measure is 9.00 differ significantly, $F(2, 24) = 7.43$, $p < .01$, partial η^2 of .38. Pairwise comparisons indicate differences in the population between the placebo and low-dose vitamin C groups, $p < .01$, between the placebo and high-dose vitamin C groups, $p < .01$, but not between the low- and high-dose vitamin C groups, $p = .45$.

For individuals with high scores on the covariate (i.e., 14.55), the means for posttreatment days of cold symptoms are estimated to be 15.89, 10.32, and 7.36 for the placebo, low-dose, and high-dose groups, respectively. As indicated in the Univariate Tests table, the differences among the means on days when the pretest is 9.00 differ significantly, $F(2, 24) = 6.58$, $p < .01$, partial η^2 of .35. Pairwise comparisons indicate differences in the population between the placebo and

low-dose vitamin C group, $p = .016$, between the placebo and high-dose vitamin C group, $p < .01$, but not between the low- and high-dose vitamin C groups, $p = .19$.

USING SPSS GRAPHS TO DISPLAY THE RESULTS

A scatterplot may help in the interpretation of results when the slopes are heterogeneous. This graph shows differences in slopes as well as differences between estimated group means on the dependent variable for low, medium, and high values on the covariate. To obtain the graph, create a simple scatterplot with the covariate on the *X*-axis, the dependent variable on the *Y*-axis, and set markers by the factor. In editing the graph, choose Fit Line at Subgroups within Elements (main menu) and choose *X*-axis reference lines within Options (main menu) to portray low, medium, and high values on the covariate. The option *X*-axis reference line must be chosen three times, once for each line. Each time, type the value of the covariate of interest in the Position box.

The scatterplot for our example is presented in Figure 167. An estimated group mean on the dependent variable for a low, medium, or high covariate score can be determined by following the appropriate vertical line from the covariate axis to the regression line for the group of interest and reading the corresponding dependent variable score at that point. For example, for individuals with a low number of pretreatment days with cold symptoms, the estimated mean on posttreatment days with cold symptoms is approximately 5 if given a low dose of vitamin C and only slightly higher if given a high dose of vitamin C. We are able to describe the results in the sample more easily based on our scatterplot. For example, in comparison with placebo, a high dose of vitamin C demonstrated, on average, greater effectiveness to the extent that individuals had a greater number of days with cold symptoms prior to treatment.

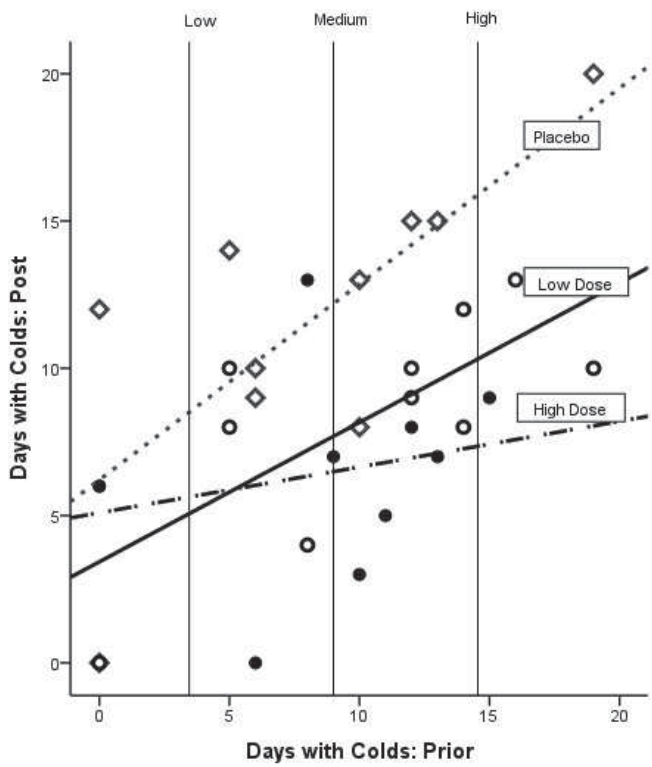

Figure 167. Graph showing the differences between groups for three levels of the covariate.

AN APA RESULTS SECTION

We present two results sections, one in which homogeneity of slope is assumed and one in which it is not.

Results Assuming Homogeneity of Slopes

A one-way analysis of covariance (ANCOVA) was conducted. The independent variable, vitamin C, included three levels: placebo, a low dose of vitamin C, and a high dose of vitamin C. The dependent variable was the number of days of cold symptoms during treatment, and the covariate was the number of days of cold symptoms before treatment. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(2, 24) = 1.47$, $MSE = 11.88$, $p = .25$, partial $\eta^2 = .11$. The ANCOVA was significant, $F(2, 26) = 6.45$, $MSE = 12.32$, $p < .01$. The strength of relationship between the vitamin C factor and dependent variable was very strong, as assessed by a partial η^2, with the vitamin C factor accounting for 33% of the variance of the dependent variable, holding constant the number of days with pretreatment cold symptoms.

The means of the number of days with cold symptoms adjusted for initial differences were ordered as expected across the three vitamin C groups. The placebo group had the largest adjusted mean ($M = 12.01$), the low-dose vitamin C group had a smaller adjusted mean ($M = 7.71$), and the high-dose vitamin C group had the smallest adjusted mean ($M = 6.67$). Follow-up tests were conducted to evaluate pairwise differences among these adjusted means. Based on the LSD procedure, the adjusted means for both vitamin C groups differed significantly from the placebo group, but the adjusted means for the two vitamin C groups did not differ significantly from each other.

Results Not Assuming Homogeneity of Slopes

A one-way analysis of covariance (ANCOVA) was planned. The independent variable, vitamin C, included three levels: placebo, a low dose of vitamin C, and a high dose of vitamin C. The dependent variable was the number of days of cold symptoms during treatment, and the covariate was the number of days of cold symptoms before treatment. A preliminary analysis was conducted to evaluate homogeneity of slopes between the covariate and the dependent variable across groups, an assumption underlying ANCOVA. The partial η^2 for the interaction was .11, indicating that in the sample the mean differences in days of cold symptoms among the vitamin C groups varied moderately as a function of the number of pretreatment days of cold symptoms. As shown in Figure 167, the regression line was less steep for the high-dose vitamin C group versus the other two groups. However, the interaction effect was nonsignificant, $F(2, 24) = 1.47$, $MSE = 11.88$, $p = .25$, possibly due to a lack of power.

Based on the results of the partial η^2, simple main effects tests were conducted that allow for heterogeneity of slopes rather than ANCOVA. Simple main effect tests were conducted to assess differences among groups at low (1 SD below the mean), medium (mean), and high (1 SD above the mean) values on the covariate. A p value of .017 (.05/3) was required for significance for each of these tests. If any one simple main effect was significant, pairwise comparisons were evaluated at the same level (i.e., .017) as the simple main effects test, following the LSD procedure.

The simple main effects test was not significant for a low number of pretreatment days of cold symptoms, $F(2, 24) = 1.48$, $p = .25$, partial η^2 of .11. In contrast, the simple main effects test was significant for a medium value on the covariate, $F(2, 24) = 7.43$, $p < .01$, partial η^2 of .38, and for a high level on the covariate, $F(2, 24) = 6.58$, $p < .01$, partial η^2 of .35. The low and high levels of vitamin C yielded significantly fewer days of colds during treatment than the placebo for both the medium and high number of pretreatment days of cold symptoms. However, the differences between the two doses of vitamin C were not significant.

ALTERNATIVE ANALYSES

SPSS offers no procedures for conducting nonparametric alternatives to ANCOVA. See Huitema (1980) for a discussion of nonparametric alternatives.

As for parametric methods, researchers sometimes use alternative methods such as ANOVA on change scores. If subjects are randomly assigned to groups or assigned based on pretest scores, ANCOVA is in most cases more powerful than these alternatives. If it is unclear how subjects are assigned to groups, none of the methods including ANCOVA are likely to control adequately for prior differences. (See Maxwell and Delaney, 2000, for a discussion of this topic.)

EXERCISES

The data for Exercises 1 through 5 are in the data set named *Lesson 27 Exercise File 1* on the Web at http://www.pearsonhighered.com/greensalkindSPSS. The data are from the following research problem.

Sam is interested in the relationship between college professors' academic discipline and their actual ability to fix a car, holding constant mechanical aptitude. Five professors were randomly selected from mechanical engineering, psychology, and philosophy departments at a major university. Each professor completed a mechanical aptitude scale. Scores on this measure have a mean of 100 and a standard deviation of 15. The professors were then rated on how well they performed four automotive maintenance tasks: changing oil, changing the points and plugs, adjusting the carburetor, and setting the timing on a 1985 Pontiac. Ratings were based on the degree of success in completing a task and the amount of time needed to complete it. Lower scores reflect more efficiency at completing the automotive maintenance tasks.

1. Transform the scores on the four mechanical task ratings by *z*-scoring them and then summing the *z* scores so that Sam has a single measure of professors' mechanical performance efficiency.
2. Evaluate whether the relationship between mechanical aptitude and mechanical performance efficiency is the same for all three types of professors (homogeneity-of-slopes assumption). What should Sam conclude about the homogeneity-of-slopes assumption? Report the appropriate statistics from the output to justify your conclusion.
3. Conduct the standard ANCOVA on these data. From the output, identify the following:
   a. *p* value associated with the effect due to professor type
   b. Effect size associated with the effect due to professor type
   c. *F* value associated with the covariate, mechanical aptitude
4. Conduct the appropriate post hoc tests.
5. Write a Results section based on your analyses.

The data for Exercises 6 through 8 are in the data set named *Lesson 27 Exercise File 2* on the Web at http://www.pearsonhighered.com/greensalkindSPSS. The data are from the following research problem.

Marilyn was interested in the effects of journal therapy on depression. She randomly assigned 60 individuals who had been clinically diagnosed as having severe depression to three treatment groups. Individuals in the first group wrote intensively about their feelings in journals for an hour each day for three weeks (journal therapy) and received regular counseling. The second group received only journal therapy, and the third group received only regular counseling. All 60 participants were given a depression subscale before and after treatment.

6. Evaluate the homogeneity-of-slopes assumption. What should Marilyn conclude about this assumption? Report the appropriate statistics from the output to justify this conclusion.
7. Conduct an ANCOVA on these data. What conclusions should Marilyn draw?
8. Should Marilyn conduct post hoc tests? Why or why not? Report the appropriate statistics from the output to justify your conclusion.