More About Analysis of Variance: Follow-up Tests and Two-Way ANOVA

The basic *F* test for analysis of variance and data analysis to verify necessary conditions were presented in Chapter 24. That test only says at least one group's mean is different from the others; it does not say which group (or groups) differ from the rest. Making that determination is the job of follow-up analysis. Your text presents two methods. Tukey intervals calculate a set of family-wise $100(1 – 1/\alpha)\%$ confidence intervals for pairwise differences in population means; if any of these do not contain 0, that pair of means can be said to differ from each other. Contrasts are ways to test specific hypotheses that compare two or more means at once. Note that follow-up analyses need to be done *only* if the null hypothesis of no difference in population means is rejected.

This chapter also covers two-way ANOVA—where there are two categorical explanatory variables of interest. In such cases, we are interested in determining not only whether any of the treatment combinations make a difference in mean response, but also whether the factors are independent of each other or interact.

Comparing Group Means

A significant ANOVA tells us only that at least one population mean is different from the rest. We would like to know which one(s) differ.

Excel

Excel has no built-in function to calculate these intervals and tests.

JMP

JMP does not compute contrasts.

To calculate the Tukey intervals:

1. Click the red triangle next to Oneway Analysis of Y by X.
2. Select **Compare Means**, then **All Pairs, Tukey HSD.**

The confidence intervals appear at the bottom of this analysis.

Minitab

Minitab does not compute contrasts.

It has four different methods to compute simultaneous confidence intervals (the LSD (labeled Fisher in Minitab), Tukey's HSD, and two others.

From the main ANOVA dialog, click the **Comparisons** button in the main ANOVA dialog and check the box for the comparison type you desire. The output will be added to the bottom of the ANOVA results.

SPSS

To create a contrast:

1. Click **Contrasts** at the upper right of the One-Way ANOVA dialog.
2. Enter the coefficients for the contrast (specify a coefficient for each group in numerical order, and make sure the coefficients sum to 0), clicking **Add** after each.
3. To add another contrast, click **Next**.
4. When you are finished adding contrasts, click **Continue** to return to the main dialog.

To compute simultaneous confidence intervals:

1. Click **Post Hoc** in the main ANOVA dialog.
2. Check the box for the type of intervals you would like. There are several methods to choose from; the Tukey method described in your text appears in the second column.
3. Click **Continue** to return to the main dialog.

CRUNCHIT!

CrunchIt! cannot compute these intervals and tests.

TI-83/-84

 TI calculators cannot compute these intervals and tests.

R

For Tukey multiple comparisons, you can use the command

>   `TukeyHSD(mod)`

where **mod** was used to store the model in the **aov** command. This gives pairwise comparisons of all possible combinations of group means with confidence intervals for the differences as well as P-values. By default, the family-wise confidence level is 95%.

Means Plots and Two-Way ANOVA

Excel

To create the means plot, as with one-way ANOVA, copy and paste the data so each treatment combination is in a separate column.

Use **Data ➔ Data Analysis ➔ Descriptive Statistics**.

1. Select the data columns with the treatment combinations as the input range. Check the box labeled **Labels in first row** (you'll want to use those labels in your graph). Make sure the box for **Summary statistics** is checked and click **OK**.
2. Copy and paste the group means (and labels) into a contiguous area in the spreadsheet in the form of a two-way table, with levels of one factor as rows and levels of the other factor as columns.
3. Drag to select the means table just created, select **Insert ➔** [icon], and select the 2-D type with connected lines [icon]. You can further format the chart (e.g., add titles) if you wish.

To perform the ANOVA, use **Data ➔ Data Analysis ➔ ANOVA: Two-Factor with Replication** (each treatment group has more than one individual/observation). Here you will need another layout of the data. One factor should be in columns and the second factor grouped into rows. The first row should be labels for the levels of factor A. Labels for the levels of factor B should appear in the first column of the data. Further, each treatment combination must contain the same number of observations.

1. Select the input range of interest.
2. Enter the number of observations for each group into the **Rows per Sample** box.
3. Click **OK**.

For more information and examples, see the Excel Video Technology Manuals videos *Means Plots* and *Two-Way ANOVA*.

To create a means plot, click **Graph ➔ Graph Builder**.

1. Click and drag the response variable into the **Y-axis** area.
2. Click and drag one of the factors into the **X-axis** area.
3. Click and drag the other factor variable into the **Overlay** area.
4. At this point, you should see data point dots in different colors.
5. At the left, use the drop-down to select **Mean** as the summary statistic. You should have one dot for each treatment combination.
6. Select **Line** using the **Connect** drop-down at left. This completes the means plot, with the possible exception of adding titles or other identifiers. Click **Done** when finished.

To perform the ANOVA, select **Analyze ➔ Fit Model**.

1. Select and enter the response variable into the **Y** box.
2. Select each factor and click **Add** to add them into the **Construct Model Effects** box.
3. To add the interaction, click (use CTRL if needed) to select both factors, then click **Cross** to add that term into the **Effects**.
4. Click **Run**. The ANOVA summary table appears just below the Summary of Fit. For the *F* tests on the individual factors and interaction, click the triangle next to **Effect Tests** to expand that section.

For more information and examples, see the JMP Video Technology Manuals videos *Means Plots* and *Two-Way ANOVA*.

Minitab

To create the means plot, use **Stat ➔ ANOVA ➔ Interaction Plot**.

1. Click to enter the response variable and the two factor variables into their respective boxes.
2. Use **Options** if you want to add a graph title or use specific axis scaling.
3. **OK**

To perform the ANOVA, use **Stat ➔ ANOVA ➔ Balanced ANOVA** (assuming there are the same number of observations in each treatment group).

1. Click to enter the response variable and the two factors into their respective boxes.
2. To add the interaction into the model enter one factor, type ***** (the asterisk) and enter the second factor.

3. If you want residuals plots, select those by clicking on **Graphs.**
4. **OK**

The Minitab Video Technology Manual: *Two-Way ANOVA* gives more information and an example.

SPSS must have numeric group identifiers. If the grouping variables are categorical, you will have to create numeric versions. Use **Transform ➔ Recode into Different Variables**.

1. Select and enter the original variable into the box.
2. Give the new variable a name in the box labeled **Name** and click **Change**.
3. For each value of the original variable, type it into the **Old Value** box (exactly as entered) and enter a numeric value into the **New Value** box. Click **Add**. Repeat until you have assigned numeric labels to all the groups. Click **Continue** and **OK**.

To create a means plot (this can use either form of the categorical variables), use **Graphs ➔ Chart Builder**.

1. Click on **Chart Style Line** and select the plot with multiple lines [image]. Drag it into the chart area.
2. Drag the response variable into the **Y-axis** region.
3. Drag one of the factor variables into the **X-axis** region.
4. Drag the second factor variable into the **Set color** region at the upper right. At this point, you should have the basic means plot created.
5. If desired, use **Titles/Footnotes** to annotate the plot. When finished, click **OK**.

To perform the ANOVA, use **Analyze ➔ General Linear Model ➔ Univariate**.

1. Select and enter the response variable into the **Dependent** variable box and the two factor variables into the **Fixed Factor** box.
2. You can also create the means plot here by clicking **Plots**. Select one factor to be on the *x*-axis and the second factor to be represented by different lines.
3. Click **OK** in the main dialog.

The SPSS Video Technology Manual videos *Means Plots* and *Two-Way ANOVA* give more information and examples.

To create the interaction plot:

1. **Graphics ➔ Means Plot**
2. Use the drop-downs to select the two factors and the response (**Values**) variable.
3. If desired, add a title and *y*-axis labeling.
4. Click **Calculate.**

To perform the ANOVA:

1. **Statistics ➔ ANOVA ➔ Two-Way**
2. Use the drop-downs to select the two factors and the response (**Values**) variable.
3. If desired, add a title and *y*-axis labeling.
4. Click **Calculate**.

TI-83/-84

TI calculators cannot do two-way ANOVA.

The following command form will create the interaction (means) plot:

```
> interaction.plot(factor1, factor2, response)
```

To create the ANOVA model and obtain the table of results, use the following commands:

```
> model=aov(Response ~ Factor1 + Factor2 +
Factor1*Factor2)
```

```
> Summary(model)
```

The R Video Technology Manual videos *Means Plots* and *Two-Way ANOVA* give more information and examples.