



## Cornell University Cornell Statistical Consulting Unit

### Post-hoc Analyses

Let A, B, C represent categorical variables, X and W represent continuous variables. Unless otherwise specified, the following commands will hold any continuous variable at its mean and will average over factor variables not listed in the statement.

#### **SAS**

The LSMEANS command in SAS is able to perform pairwise comparisons from various procedures including **PROC GLM, MIXED, LOGISTIC, and GLIMMIX**.

LSMEANS A/ pdiff=ALL;	Pairwise comparisons of factor A
LSMEANS A/ pdiff lines;	Pairwise comparisons of factor A, the lines option produces a compact letter display (cld).
LSMEANS A*B/ slice=B;	Pairwise comparisons of factor A for each level of factor B. (Gives F test). To get t-tests, use ESTIMATE and determine each contrast.
LSMEANS A*B*C / slice=B*C;	Pairwise comparisons of factor A for all combinations of B and C. (Gives F test) To get t-tests, use ESTIMATE and determine each contrast.
LSMEANS A/ at X=5;	Pairwise comparisons of factor A when X is 5

#### **SPSS**

In the SPSS menus, only post-hoc testing on main effects can be done. In order to do more sophisticated analyses, you need to use the syntax. The EMMEANS statement can be executed for general linear models (**UNIANOVA**) generalized linear models (**GENLIN**) and linear mixed models (**MIXED**).

/EMMEANS=TABLES(A)	Pairwise comparisons of all the levels of factor A
/EMMEANS=TABLES(A*B) COMPARE(A)	Pairwise comparisons of all the levels of factor A for each level of factor B
/EMMEANS=TABLES(A*B*C) COMPARE(A)	Pairwise comparisons of all the levels of factor A for all combinations of B and C.
/EMMEANS=TABLES(A) with(X=5) COMPARE	Pairwise comparisons of all the levels of factor A when X is 5
/EMMEANS=TABLES(A*B*C) with(X=5) COMPARE(A)	Pairwise comparisons of all levels of factor A for all combinations of B and C when X=5.

## R

In R, the *lsmeans* function from the **lsmeans** package can easily and effectively handle post-hoc analyses. The *lsmeans* function supports aov, lm, and glm models as well as models estimated via functions from the **nlme**, **lme4**, **survival**, and **geepack** packages. The *glht* function in the **multcomp** package can also be used to specify contrasts. The **multcompView** package contains the *cld* function, which assigns comparisons different letters when they are significantly different.

<code>lsmeans(model, pairwise~A)</code>	Pairwise comparisons of factor A
<code>lsmeans(model, pairwise~A B)</code>	Pairwise comparisons of factor A for each level of factor B
<code>lsmeans(model, pairwise~A B*C)</code>	Pairwise comparisons of factor A for all combinations of B and C.
<code>lsmeans(model, pairwise~A X, at=list(X=c(1,5,10)))</code>	Pairwise comparisons of factor A when X is 1, 5, and 10
<code>lsmeans(model, pairwise~A X*W, at=list(X=c(1,5,10), W=c(1,2)))</code>	Pairwise comparisons of factor A when X is 1, 5, and 10 and W=2 and 3
<code>lsm &lt;- lsmeans(model, ~ A   B)</code> <code>pl &lt;- contrast(lsm, "poly", name = "order")</code> <code>test(pl, joint = TRUE, by = "B")</code>	This gives global F tests for each level of B, comparing the means of the levels of A. This matches JMP's "test slices" command.
<code>lsmip(model, A~B)</code>	An interaction plot, where the levels of B are plotted on the x-axis, and each level of A is given a line.
<code>lsmip(model, A~B C)</code>	Three-way interaction plot, where for each level of C, the levels of B are plotted on the x-axis, and each level of A is given a line.
<code>lsmip(model, A~B C*X ,at = list(X = c(1,5,10)))</code>	Four-way interaction plot, where for every combination of C and X, the levels of B are plotted on the x-axis, and each level of A is given a line.
<code>cld(lsmeans(model, ~A))</code>	Cld (compact letter display) lists the LS means along with grouping symbols for pairwise contrasts.

## **STATA**

Stata has a few commands that are useful for post-estimation purposes: `pwcompare`, `contrast`, `margins`, and `marginsplot` (for graphing). Note: In order to obtain p-values for pairwise comparisons, you must specify the `pwcompare(effects)` option for the `margins` command.

<code>pwcompare A, mcompare(tukey)</code> <code>pveffects</code>	Pairwise comparisons of factor A with Tukey Correction. (Sets any continuous variables to 0)
<code>margins A, pwcompare(effects)</code> <code>mcomp(bonferroni)</code>	Pairwise comparisons of factor A with Bonferroni correction. Any continuous variable is evaluated at the mean.
<code>contrast A@B</code>	For each level of B, tests if the means of all the levels of A are equal. (Gives F test). To obtain the t-tests, you need to specify the contrast
<code>margins A, at(B=1)</code> <code>pwcompare(effects)</code>	Pairwise comparisons of all levels of A for the first level of B.
<code>margins A#B, at(C=1)</code> <code>pwcompare(effects)</code>	Pairwise comparisons of all levels of A#B at C="1".
<code>margins A#i(1).B#i(1).C,</code> <code>pwcompare(effects)</code>	Pairwise comparisons of A when both B="1" and C="1"
<code>contrast A@B#C, effects</code>	Marginal means for A over all combinations of B and C. (Gives F test)
<code>margins A, at(X=5)</code> <code>pwcompare(effects)</code>	Pairwise comparisons of factor A when X=5
<code>margins B#A</code> <code>marginsplot</code>	An interaction plot, where the levels of B are plotted on the x-axis, and each level of A will be given a line.
<code>margins B#A#C</code> <code>marginsplot, by(C)</code>	Three-way interaction plot, where for each level of C, the levels of B are plotted on the x-axis, and each level of A will be given a line.
<code>margins A, at(X=(1,4) Y=(3,5))</code> <code>marginsplot, by(A)</code>	Three-way interaction plot, where for each level of A has its own graph, the x-axis contains the specified values for X, and 2 lines for when Y=3 and Y=5 are graphed.

## JMP

The options or post-hoc analysis are a bit limited in JMP. For interaction terms, you can use the test slices to obtain a global F test, and obtain the pairwise comparisons. Tukey HSD adjusted p-values can be obtained when comparing all possible cells of the interaction term; however, it is impossible to apply a multiple comparisons adjustment to the contrasts from slices.

LSMeans Differences Tukey HSD	Pairwise comparisons of all the levels of factor A using Tukey Correction
Select "test slices".	If A*B is in the model, this provides pairwise comparisons of factor A for each level of B and vice versa. (Gives F test). For t-tests, you need to manually insert the contrast.
After running the model, go to Factor Profiling->Profiler	Marginal Means for factor A when X is 5