**Calculating the F-Ratio for a 1-Way ANOVA with Independent Groups**

**Nomenclature**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | a1 | a2 | a3 |  | |
|  | s1 | s6 | s11 |
|  | s2 | s7 | s12 |
|  | s3 | s8 | s13 |
|  | s4 | s9 | s14 |
|  | s5 | s10 | s15 | **T** | **T2** |
| **ΣAi** | **Σa1** | **Σa2** | **Σa3** | **Σ(Σa1+ Σa2+ Σa3)** | **T2** |
| **Σ(Ai)2** | **Σ(a1)2** | **Σ(a2)2** | **Σ(a3)2** |  | |
| **Σ(AS)2** | **Σ(a1si)2** | **Σ(a2si)2** | **Σ(a3si)2** |

**Calculations for: 1-way ANOVA, Independent Groups**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | df | Expanded df | Formula | Letter Code | Coded Formula |
| A | a-1 | a-1 |  | [A] | [A] – [T] |
| S/A | a(s-1) | as-a |  | [AS] | [AS] – [A] |
| Total | as-1 | as-1 |  | [T] | [AS] - [T] |
|  | | | | | |
| Where: | A = sum of scores in each level of factor A | | | | |
|  | a = number of levels of factor A | | | | |
|  | T = total sum of scores | | | | |
|  | s = number of subjects in each level of factor A | | | | |

Example: 1-way ANOVA with independent groups and 1 factor (A) with 3 levels.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | a1 | a2 | a3 |  | |
|  | 16 | 4 | 2 |
|  | 18 | 6 | 10 |
|  | 10 | 8 | 9 |
|  | 12 | 10 | 13 |
|  | 19 | 2 | 11 | T | T2 |
| ΣAi | 75 | 30 | 45 | 150 | 22500 |
| Σ(Ai)2 | 5625 | 900 | 2025 |  | |
| **Σ(AS)2** | **1185** | **220** | **475** |

**Calculation of Sums of Squares:**

SSA = [A] = = 1710 – 1500 = 210

SSS/A = [AS] = = 1880 – 1710 = 170

SST = [T] = = 1880 – 1500 = 380

**Equations for Calculating F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | SSA | a-1 |  |  |
| S/A | SSS/A | a(s-1) |  |  |
| Total | SST | as-1 |  |  |

**Calculation of F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | 210 | 2 | 105 | 7.41\* |
| S/A | 170 | 12 | 14.17 |  |
| Total | 380 | 14 |  |  |

**Post-Hoc Tests Between Levels of Factor A:**

Fischer’s LSD test: Independent t-tests with Bonferroni correction to alpha (α/(# of comparisons).

Alternatively, Tukey HSD and Scheffe post-hoc tests can also be used. Both of these tests hold experimentwise error constant and do not require further correction.

**SPSS Syntax and Output**

ONEWAY Value BY Group

/STATISTICS DESCRIPTIVES HOMOGENEITY

/POSTHOC=TUKEY LSD BONFERRONI ALPHA(0.05).

**Oneway**

[DataSet0] C:\Users\Jim\HESC602\Data Sets\Richards\Kepple1WayIndGrps.sav

| **Descriptives** | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Value | | | | | | | | |
|  | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
| Lower Bound | Upper Bound |
| a1 | 5 | 15.0000 | 3.87298 | 1.73205 | 10.1911 | 19.8089 | 10.00 | 19.00 |
| a2 | 5 | 6.0000 | 3.16228 | 1.41421 | 2.0735 | 9.9265 | 2.00 | 10.00 |
| a3 | 5 | 9.0000 | 4.18330 | 1.87083 | 3.8057 | 14.1943 | 2.00 | 13.00 |
| Total | 15 | 10.0000 | 5.20988 | 1.34519 | 7.1149 | 12.8851 | 2.00 | 19.00 |

| **Test of Homogeneity of Variances** | | | |
| --- | --- | --- | --- |
| Value | | | |
| Levene Statistic | df1 | df2 | Sig. |
| .189 | 2 | 12 | .830 |

| **ANOVA** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Value | | | | | |
|  | Sum of Squares | df | Mean Square | F | Sig. |
| Between Groups | 210.000 | 2 | 105.000 | 7.412 | .008 |
| Within Groups | 170.000 | 12 | 14.167 |  |  |
| Total | 380.000 | 14 |  |  |  |

**Post Hoc Tests**

| **Multiple Comparisons** | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Dependent Variable:Value | | | | | | | | | |
|  | (I) Group | | (J) Group | | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|  | Lower Bound | Upper Bound |
| Tukey HSD |  | a1 |  | a2 | 9.00000\* | 2.38048 | .007 | 2.6492 | 15.3508 |
| a3 | 6.00000 | 2.38048 | .065 | -.3508 | 12.3508 |
| a2 |  | a1 | -9.00000\* | 2.38048 | .007 | -15.3508 | -2.6492 |
| a3 | -3.00000 | 2.38048 | .443 | -9.3508 | 3.3508 |
| a3 |  | a1 | -6.00000 | 2.38048 | .065 | -12.3508 | .3508 |
| a2 | 3.00000 | 2.38048 | .443 | -3.3508 | 9.3508 |
| LSD | dimension2 | a1 | dimension3 | a2 | 9.00000\* | 2.38048 | .003 | 3.8134 | 14.1866 |
| a3 | 6.00000\* | 2.38048 | .027 | .8134 | 11.1866 |
| a2 | dimension3 | a1 | -9.00000\* | 2.38048 | .003 | -14.1866 | -3.8134 |
| a3 | -3.00000 | 2.38048 | .232 | -8.1866 | 2.1866 |
| a3 | dimension3 | a1 | -6.00000\* | 2.38048 | .027 | -11.1866 | -.8134 |
| a2 | 3.00000 | 2.38048 | .232 | -2.1866 | 8.1866 |
| Bonferroni | dimension2 | a1 | dimension3 | a2 | 9.00000\* | 2.38048 | .008 | 2.3835 | 15.6165 |
| a3 | 6.00000 | 2.38048 | .081 | -.6165 | 12.6165 |
| a2 | dimension3 | a1 | -9.00000\* | 2.38048 | .008 | -15.6165 | -2.3835 |
| a3 | -3.00000 | 2.38048 | .695 | -9.6165 | 3.6165 |
| a3 | dimension3 | a1 | -6.00000 | 2.38048 | .081 | -12.6165 | .6165 |
| a2 | 3.00000 | 2.38048 | .695 | -3.6165 | 9.6165 |
| \*. The mean difference is significant at the 0.05 level. | | | | | | | | | |

**Calculating the F-Ratio for a 2-Way ANOVA with Independent Groups**

**Design (2x3)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| a1b1 | a1b2 | a2b1 | a2b2 | a3b1 | a3b2 |
| s1 | S5 | S9 | s13 | S17 | S21 |
| s2 | S6 | s10 | S14 | S18 | S22 |
| s3 | S7 | S11 | s15 | S19 | S23 |
| s4 | S8 | s12 | s16 | S20 | S24 |

**Calculations for: 2-way ANOVA, Independent Groups**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | df | Expanded df | Formula | Letter Code | Coded Formula |
| A | a-1 | a-1 |  | [A] | [A] – [T] |
| B | b-1 | b-1 |  | [B] | [B] – [T] |
| AxB | (a-1)(b-1) | ab-a-b+1 |  | [AB] | [AB] – [A] – [B] + [T] |
| S/A | ab(s-1) | abs-a |  | [ABS] | [ABS] – [AB] |
| Total | abs-1 | abs-1 |  | [T] | [ABS] - [T] |
|  | | | | | |
| Where: | A = sum of scores in each level of factor A | | | | |
|  | a = number of levels of factor A | | | | |
|  | B = sum of scores in each level of factor B | | | | |
|  | B = number of levels of factor B | | | | |
|  | T = total sum of scores | | | | |
|  | s = number of subjects in each level of factor A | | | | |

Example: 2-way ANOVA with independent groups: factor (A) has 2 levels, factor B has 3 levels.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| a1b1 | a1b2 | a2b1 | a2b2 | a3b1 | a3b2 |
| 1 | 15 | 13 | 6 | 9 | 14 |
| 4 | 6 | 5 | 18 | 16 | 7 |
| 0 | 10 | 7 | 9 | 18 | 6 |
| 7 | 13 | 15 | 15 | 13 | 13 |

**Cell and Margin Means**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **a1** | **a2** | **a3** | **Sum** |
| **b1** | 12 | 40 | 56 | **108** |
| **b2** | 44 | 48 | 40 | **132** |
| **Sum** | **56** | **88** | **96** | ***240*** |

**Calculation of Sums of Squares:**

SSA = [A] = = 2512 – 2400 = 112

SSB = [B] = = 2424 – 2400 = 24

SSAxB = [AB] =

= 2680 – 2512 – 2424 +2400 = 144

SSS/AB = [ABS] = [(122+442+…562+402) - ] = 3010 – 2680 = 330

SST = [T] = = 3010 – 2400 = 610

**Equations for Calculating F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | SSA | a-1 |  |  |
| B | SSB | b-1 |  |  |
| AxB | SSAxB | (a-1)(b-1) |  |  |
| S/AB | SSS/A | ab(s-1) |  |  |
| Total | SST | abs-1 |  |  |

**Calculation of F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | 112 | 2 | 56 | 3.06 |
| B | 24 | 1 | 24 | 1.31 |
| AxB | 144 | 2 | 72 | 3.93\* |
| S/AB | 330 | 18 | 18.33 |  |
| Total | 610 | 23 |  |  |

**Post-Hoc Tests Between Levels of Factor A within a Level of Factor B or Between Levels of Factor B within a level of Factor A:**

Fischer’s LSD test: Independent t-tests with Bonferroni correction to alpha (α/(# of comparisons).

Alternatively, Tukey HSD and Scheffepost-hoc tests can also be used. Both of these tests hold experimentwise error constant and do not require further correction.

**SPSS Syntax and Output**

UNIANOVA Score BY A B

/METHOD=SSTYPE(3)

/INTERCEPT=INCLUDE

\*Compare marginal means for factor A\*

/EMMEANS=TABLES(A) COMPARE ADJ(BONFERRONI)

\*Compare marginal means for factor B\*

/EMMEANS=TABLES(B) COMPARE ADJ(BONFERRONI)

\*Compare simple main effects for factor A within levels of factor B\*

/EMMEANS=TABLES(A\*B) COMPARE (A) ADJ(BONFERRONI)

\*Conduct Levene’s test for homogeneity of variance\*

/PRINT=HOMOGENEITY DESCRIPTIVE

/CRITERIA=ALPHA(.05)

/DESIGN=A B A\*B.

**Univariate Analysis of Variance**

[DataSet1] C:\Users\Jim\HESC602\Data Sets\Richards\Kepple2WayIndGrps.sa

| **Between-Subjects Factors** | | |
| --- | --- | --- |
|  | | N |
| A | 1.00 | 8 |
| 2.00 | 8 |
| 3.00 | 8 |
| B | 1.00 | 12 |
| 2.00 | 12 |

| **Descriptive Statistics** | | | | |
| --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | |
| A | B | Mean | Std. Deviation | N |
| 1.00 | 1.00 | 3.0000 | 3.16228 | 4 |
| 2.00 | 11.0000 | 3.91578 | 4 |
| Total | 7.0000 | 5.39841 | 8 |
| 2.00 | 1.00 | 10.0000 | 4.76095 | 4 |
| 2.00 | 12.0000 | 5.47723 | 4 |
| Total | 11.0000 | 4.86973 | 8 |
| 3.00 | 1.00 | 14.0000 | 3.91578 | 4 |
| 2.00 | 10.0000 | 4.08248 | 4 |
| Total | 12.0000 | 4.27618 | 8 |
| Total | 1.00 | 9.0000 | 5.96962 | 12 |
| 2.00 | 11.0000 | 4.19957 | 12 |
| Total | 10.0000 | 5.14993 | 24 |

| **Levene's Test of Equality of Error Variancesa** | | | |
| --- | --- | --- | --- |
| Dependent Variable:Score | | | |
| F | df1 | df2 | Sig. |
| 1.000 | 5 | 18 | .446 |
| Tests the null hypothesis that the error variance of the dependent variable is equal across groups. | | | |
| a. Design: Intercept + A + B + A \* B | | | |

| **Tests of Between-Subjects Effects** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | | |
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
| Corrected Model | 280.000a | 5 | 56.000 | 3.055 | .036 |
| Intercept | 2400.000 | 1 | 2400.000 | 130.909 | .000 |
| A | 112.000 | 2 | 56.000 | 3.055 | .072 |
| B | 24.000 | 1 | 24.000 | 1.309 | .268 |
| A \* B | 144.000 | 2 | 72.000 | 3.927 | .038 |
| Error | 330.000 | 18 | 18.333 |  |  |
| Total | 3010.000 | 24 |  |  |  |
| Corrected Total | 610.000 | 23 |  |  |  |
| a. R Squared = .459 (Adjusted R Squared = .309) | | | | | |

**Estimated Marginal Means**

**1. A**

| **Estimates** | | | | |
| --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | |
| A | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| 1.00 | 7.000 | 1.514 | 3.820 | 10.180 |
| 2.00 | 11.000 | 1.514 | 7.820 | 14.180 |
| 3.00 | 12.000 | 1.514 | 8.820 | 15.180 |

| **Pairwise Comparisons** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | | | |
| (I) A | (J) A | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| 1.00 | 2.00 | -4.000 | 2.141 | .234 | -9.650 | 1.650 |
| 3.00 | -5.000 | 2.141 | .094 | -10.650 | .650 |
| 2.00 | 1.00 | 4.000 | 2.141 | .234 | -1.650 | 9.650 |
| 3.00 | -1.000 | 2.141 | 1.000 | -6.650 | 4.650 |
| 3.00 | 1.00 | 5.000 | 2.141 | .094 | -.650 | 10.650 |
| 2.00 | 1.000 | 2.141 | 1.000 | -4.650 | 6.650 |
| Based on estimated marginal means | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | |

| **Univariate Tests** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | | |
|  | Sum of Squares | df | Mean Square | F | Sig. |
| Contrast | 112.000 | 2 | 56.000 | 3.055 | .072 |
| Error | 330.000 | 18 | 18.333 |  |  |
| The F tests the effect of A. This test is based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | |

**2. B**

| **Estimates** | | | | |
| --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | |
| B | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| 1.00 | 9.000 | 1.236 | 6.403 | 11.597 |
| 2.00 | 11.000 | 1.236 | 8.403 | 13.597 |

| **Pairwise Comparisons** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | | | |
| (I) B | (J) B | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| 1.00 | 2.00 | -2.000 | 1.748 | .268 | -5.672 | 1.672 |
| 2.00 | 1.00 | 2.000 | 1.748 | .268 | -1.672 | 5.672 |
| Based on estimated marginal means | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | |

| **Univariate Tests** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | | |
|  | Sum of Squares | df | Mean Square | F | Sig. |
| Contrast | 24.000 | 1 | 24.000 | 1.309 | .268 |
| Error | 330.000 | 18 | 18.333 |  |  |
| The F tests the effect of B. This test is based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | |

**3. A \* B**

| **Estimates** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | | |
| A | B | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| 1.00 | 1.00 | 3.000 | 2.141 | -1.498 | 7.498 |
| 2.00 | 11.000 | 2.141 | 6.502 | 15.498 |
| 2.00 | 1.00 | 10.000 | 2.141 | 5.502 | 14.498 |
| 2.00 | 12.000 | 2.141 | 7.502 | 16.498 |
| 3.00 | 1.00 | 14.000 | 2.141 | 9.502 | 18.498 |
| 2.00 | 10.000 | 2.141 | 5.502 | 14.498 |

| **Pairwise Comparisons** | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | | | | |
| B | (I) A | (J) A | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| 1.00 | 1.00 | 2.00 | -7.000 | 3.028 | .098 | -14.990 | .990 |
| 3.00 | -11.000\* | 3.028 | .006 | -18.990 | -3.010 |
| 2.00 | 1.00 | 7.000 | 3.028 | .098 | -.990 | 14.990 |
| 3.00 | -4.000 | 3.028 | .609 | -11.990 | 3.990 |
| 3.00 | 1.00 | 11.000\* | 3.028 | .006 | 3.010 | 18.990 |
| 2.00 | 4.000 | 3.028 | .609 | -3.990 | 11.990 |
| 2.00 | 1.00 | 2.00 | -1.000 | 3.028 | 1.000 | -8.990 | 6.990 |
| 3.00 | 1.000 | 3.028 | 1.000 | -6.990 | 8.990 |
| 2.00 | 1.00 | 1.000 | 3.028 | 1.000 | -6.990 | 8.990 |
| 3.00 | 2.000 | 3.028 | 1.000 | -5.990 | 9.990 |
| 3.00 | 1.00 | -1.000 | 3.028 | 1.000 | -8.990 | 6.990 |
| 2.00 | -2.000 | 3.028 | 1.000 | -9.990 | 5.990 |
| Based on estimated marginal means | | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | | |
| \*. The mean difference is significant at the .05 level. | | | | | | | |

| **Univariate Tests** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Dependent Variable:Score | | | | | | |
| B | | Sum of Squares | df | Mean Square | F | Sig. |
| 1.00 | Contrast | 248.000 | 2 | 124.000 | 6.764 | .006 |
| Error | 330.000 | 18 | 18.333 |  |  |
| 2.00 | Contrast | 8.000 | 2 | 4.000 | .218 | .806 |
| Error | 330.000 | 18 | 18.333 |  |  |
| Each F tests the simple effects of A within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | | |

**Calculating the F-Ratio for a 1-Way ANOVA with Repeated Measures**

**Nomenclature**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | a1 | a2 | a3 | SUM |
|  | s1 | s1 | s1 | **Σs1** |
|  | s2 | s2 | s2 | **Σs2** |
|  | s3 | s3 | s3 | **Σs3** |
|  | s4 | s4 | s4 | **Σs4** |
|  | s5 | s5 | s5 | **Σs5** |
| **SUM** | **Σa1** | **Σa2** | **Σa3** | **Σas** |

**Calculations for: 1-way ANOVA, Repeated Measures**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | df | Expanded df | Formula | Letter Code | Coded Formula |
| A | a-1 | a-1 |  | [A] | [A] – [T] |
| S | s-1 | s-1 |  | [S] | [S] – [T] |
| AxS | (a-1)(s-1) | as-a-s+1 |  | [AS] | [AS] – [A] – [S] + [T] |
| Total | as-1 | as-1 |  | [T] | [AS] - [T] |
|  | | | | | |
| Where: | A = sum of scores in each level of factor A | | | | |
|  | a = number of levels of factor A | | | | |
|  | S = sum of scores for each subject | | | | |
|  | s = number of subjects | | | | |
|  | T = total sum of scores | | | | |

**Example: 1-way ANOVA with repeated measures.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | a1 | a2 | a3 | a4 | a5 | a6 | SUM |
| s1 | 7 | 3 | 2 | 2 | 1 | 1 | 16 |
| s2 | 4 | 8 | 3 | 8 | 1 | 2 | 26 |
| s3 | 7 | 6 | 3 | 1 | 5 | 4 | 26 |
| s4 | 8 | 6 | 1 | 0 | 2 | 0 | 17 |
| s5 | 7 | 2 | 3 | 0 | 1 | 3 | 16 |
| s6 | 6 | 3 | 3 | 1 | 1 | 1 | **15** |
| s7 | 4 | 2 | 0 | 0 | 0 | 0 | **6** |
| s8 | 6 | 7 | 5 | 1 | 3 | 2 | **24** |
| **SUM** | **49** | **37** | **20** | **13** | **14** | **13** | **146** |

**Calculation of Sums of Squares:**

SSA = [A] = = 588 – 444.08 = 143.92

SSs = [S] = = 498.33 – 444.08 = 54.25

SSAxB = [AB] = = 740 – 588 - 498.33 + 444.08 = 97.75

SST = [T] = = 740 – 444.08 = 295.92

**Equations for Calculating F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | SSA | a-1 |  |  |
| S | SSs | s-1 |  |  |
| AxS | SSAxs | (a-1)(s-1) |  |  |
| Total | SST | as-1 |  |  |

**Calculation of F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | 143.92 | 5 | 28.78 | 10.32\* |
| S | 54.25 | 7 | 7.75 |  |
| AxS | 97.75 | 35 | 2.79 |  |
| Total | 295.92 | 47 |  |  |

**Post-Hoc Tests Between Levels of Factor A:**

Fischer’s LSD test: Dependent t-tests with Bonferroni correction to alpha (α/(# of comparisons).

Alternatively, Tukey HSD and Scheffe post-hoc tests can also be used. Both of these tests hold experimentwise error constant and do not require further correction.

**SPSS Syntax and Output**

GLM a1 a2 a3 a4 a5 a6

/WSFACTOR=A 6 Simple

/METHOD=SSTYPE(3)

/EMMEANS=TABLES(A) COMPARE ADJ(BONFERRONI)

/PRINT=DESCRIPTIVE

/CRITERIA=ALPHA(.05)

/WSDESIGN=A.

**General Linear Model**

[DataSet2] C:\Users\Jim\HESC602\Data Sets\Richards\Kepple1WayRM.sav

| **Within-Subjects Factors** | |
| --- | --- |
| Measure:MEASURE\_1 | |
| A | Dependent Variable |
| 1 | a1 |
| 2 | a2 |
| 3 | a3 |
| 4 | a4 |
| 5 | a5 |
| 6 | a6 |

| **Descriptive Statistics** | | | |
| --- | --- | --- | --- |
|  | Mean | Std. Deviation | N |
| a1 | 6.1250 | 1.45774 | 8 |
| a2 | 4.6250 | 2.38672 | 8 |
| a3 | 2.5000 | 1.51186 | 8 |
| a4 | 1.6250 | 2.66927 | 8 |
| a5 | 1.7500 | 1.58114 | 8 |
| a6 | 1.6250 | 1.40789 | 8 |

| **Multivariate Testsb** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Effect | | Value | F | Hypothesis df | Error df | Sig. |
| A | Pillai's Trace | .965 | 16.380a | 5.000 | 3.000 | .022 |
| Wilks' Lambda | .035 | 16.380a | 5.000 | 3.000 | .022 |
| Hotelling's Trace | 27.300 | 16.380a | 5.000 | 3.000 | .022 |
| Roy's Largest Root | 27.300 | 16.380a | 5.000 | 3.000 | .022 |
| a. Exact statistic | | | | | | |
| b. Design: Intercept  Within Subjects Design: A | | | | | | |

| **Mauchly's Test of Sphericityb** | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | | | |
| Within Subjects Effect | | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilona | | |
| Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| dimension1 | A | .029 | 18.067 | 14 | .250 | .468 | .717 | .200 |
| Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix. | | | | | | | | |
| a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table. | | | | | | | | |
| b. Design: Intercept  Within Subjects Design: A | | | | | | | | |

| **Tests of Within-Subjects Effects** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
| A | Sphericity Assumed | 143.917 | 5 | 28.783 | 10.306 | .000 |
| Greenhouse-Geisser | 143.917 | 2.339 | 61.523 | 10.306 | .001 |
| Huynh-Feldt | 143.917 | 3.586 | 40.133 | 10.306 | .000 |
| Lower-bound | 143.917 | 1.000 | 143.917 | 10.306 | .015 |
| Error(A) | Sphericity Assumed | 97.750 | 35 | 2.793 |  |  |
| Greenhouse-Geisser | 97.750 | 16.375 | 5.970 |  |  |
| Huynh-Feldt | 97.750 | 25.102 | 3.894 |  |  |
| Lower-bound | 97.750 | 7.000 | 13.964 |  |  |

| **Tests of Within-Subjects Contrasts** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| Source | A | Type III Sum of Squares | df | Mean Square | F | Sig. |
| A | Level 1 vs. Level 6 | 162.000 | 1 | 162.000 | 47.250 | .000 |
| Level 2 vs. Level 6 | 72.000 | 1 | 72.000 | 12.000 | .010 |
| Level 3 vs. Level 6 | 6.125 | 1 | 6.125 | 3.943 | .087 |
| Level 4 vs. Level 6 | .000 | 1 | .000 | .000 | 1.000 |
| Level 5 vs. Level 6 | .125 | 1 | .125 | .080 | .785 |
| Error(A) | Level 1 vs. Level 6 | 24.000 | 7 | 3.429 |  |  |
| Level 2 vs. Level 6 | 42.000 | 7 | 6.000 |  |  |
| Level 3 vs. Level 6 | 10.875 | 7 | 1.554 |  |  |
| Level 4 vs. Level 6 | 56.000 | 7 | 8.000 |  |  |
| Level 5 vs. Level 6 | 10.875 | 7 | 1.554 |  |  |

| **Tests of Between-Subjects Effects** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1  Transformed Variable:Average | | | | | |
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
| Intercept | 74.014 | 1 | 74.014 | 57.301 | .000 |
| Error | 9.042 | 7 | 1.292 |  |  |

**Estimated Marginal Means**

**A**

| **Estimates** | | | | |
| --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | |
| A | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| 1 | 6.125 | .515 | 4.906 | 7.344 |
| 2 | 4.625 | .844 | 2.630 | 6.620 |
| 3 | 2.500 | .535 | 1.236 | 3.764 |
| 4 | 1.625 | .944 | -.607 | 3.857 |
| 5 | 1.750 | .559 | .428 | 3.072 |
| 6 | 1.625 | .498 | .448 | 2.802 |

| **Pairwise Comparisons** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| (I) A | (J) A | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| 1 | 2 | 1.500 | 1.018 | 1.000 | -2.932 | 5.932 |
| 3 | 3.625\* | .706 | .020 | .552 | 6.698 |
| 4 | 4.500 | 1.296 | .155 | -1.143 | 10.143 |
| 5 | 4.375\* | .565 | .002 | 1.914 | 6.836 |
| 6 | 4.500\* | .655 | .004 | 1.649 | 7.351 |
| 2 | 1 | -1.500 | 1.018 | 1.000 | -5.932 | 2.932 |
| 3 | 2.125 | .766 | .413 | -1.212 | 5.462 |
| 4 | 3.000 | .824 | .124 | -.588 | 6.588 |
| 5 | 2.875 | .718 | .077 | -.252 | 6.002 |
| 6 | 3.000 | .866 | .157 | -.772 | 6.772 |
| 3 | 1 | -3.625\* | .706 | .020 | -6.698 | -.552 |
| 2 | -2.125 | .766 | .413 | -5.462 | 1.212 |
| 4 | .875 | .972 | 1.000 | -3.357 | 5.107 |
| 5 | .750 | .559 | 1.000 | -1.685 | 3.185 |
| 6 | .875 | .441 | 1.000 | -1.044 | 2.794 |
| 4 | 1 | -4.500 | 1.296 | .155 | -10.143 | 1.143 |
| 2 | -3.000 | .824 | .124 | -6.588 | .588 |
| 3 | -.875 | .972 | 1.000 | -5.107 | 3.357 |
| 5 | -.125 | 1.156 | 1.000 | -5.161 | 4.911 |
| 6 | .000 | 1.000 | 1.000 | -4.355 | 4.355 |
| 5 | 1 | -4.375\* | .565 | .002 | -6.836 | -1.914 |
| 2 | -2.875 | .718 | .077 | -6.002 | .252 |
| 3 | -.750 | .559 | 1.000 | -3.185 | 1.685 |
| 4 | .125 | 1.156 | 1.000 | -4.911 | 5.161 |
| 6 | .125 | .441 | 1.000 | -1.794 | 2.044 |
| 6 | 1 | -4.500\* | .655 | .004 | -7.351 | -1.649 |
| 2 | -3.000 | .866 | .157 | -6.772 | .772 |
| 3 | -.875 | .441 | 1.000 | -2.794 | 1.044 |
| 4 | .000 | 1.000 | 1.000 | -4.355 | 4.355 |
| 5 | -.125 | .441 | 1.000 | -2.044 | 1.794 |
| Based on estimated marginal means | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | |
| \*. The mean difference is significant at the .05 level. | | | | | | |

| **Multivariate Tests** | | | | | |
| --- | --- | --- | --- | --- | --- |
|  | Value | F | Hypothesis df | Error df | Sig. |
| Pillai's trace | .965 | 16.380a | 5.000 | 3.000 | .022 |
| Wilks' lambda | .035 | 16.380a | 5.000 | 3.000 | .022 |
| Hotelling's trace | 27.300 | 16.380a | 5.000 | 3.000 | .022 |
| Roy's largest root | 27.300 | 16.380a | 5.000 | 3.000 | .022 |
| Each F tests the multivariate effect of A. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | |
| a. Exact statistic | | | | | |

**Calculating the F-Ratio for a 2-Way ANOVA with Repeated Measures on Both Factors**

**Nomenclature**

**ABS Matrix**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| a1 b1 | a1 b2 | a1 b3 | a1 b4 | a2 b1 | a2 b2 | a2 b3 | a2 b4 |
| s1 | s1 | s1 | s1 | s1 | s1 | s1 | s1 |
| s2 | s2 | s2 | s2 | s2 | s2 | s2 | s2 |
| s3 | s3 | s3 | s3 | s3 | s3 | s3 | s3 |
| s4 | s4 | s4 | s4 | s4 | s4 | s4 | s4 |
| s5 | s5 | s5 | s5 | s5 | s5 | s5 | s5 |

**AS Matrix**

(each inner cell represents the sum across all levels of B, so:

A1 S1 = A1B1S1 + A1B2S1 + A1B3S1 + A1B4S1)

|  |  |  |  |
| --- | --- | --- | --- |
|  | a1 | a2 | **SUM** |
| **s1** | A1 S1 | A2 S1 | **S1** |
| **s2** | A1 S2 | A2 S2 | **S2** |
| **s3** | A1 S3 | A2 S3 | **S3** |
| **s4** | A1 S4 | A2 S4 | **S4** |
| **s5** | A1 S5 | A2 S5 | **S5** |
| **SUM** | **A1** | **A2** |  |

**BS Matrix**

(each inner cell represents the sum across all levels of A, so:

B1 S1 = A1B1S1 + A2B1S1)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | b1 | b2 | b3 | b4 | **SUM** |
| **s1** | B1 S1 | B2 S1 | B3 S1 | B4 S1 | **S1** |
| **s2** | B1 S2 | B2 S2 | B3 S2 | B4 S2 | **S2** |
| **s3** | B1 S3 | B2 S3 | B3 S3 | B4 S3 | **S3** |
| **s4** | B1 S4 | B2 S4 | B3 S4 | B4 S4 | **S4** |
| **s5** | B1 S5 | B2 S5 | B3 S5 | B4 S5 | **S5** |
| **SUM** | **B1** | **B2** | **B3** | **B4** |  |

**AB Matrix**

(each inner cell represents the sum across all subjects, so:

A1 B1 = A1B1S1 + A1B1S2+ A1B1S3 + A1B1S4+ A1B1S5)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | b1 | b2 | b3 | b4 | **SUM** |
| **a1** | A1 B1 | A1 B2 | A1 B3 | A1 B4 | **A1** |
| **a2** | A2 B1 | A2 B2 | A2 B3 | A2 B4 | **A2** |
| **SUM** | **B1** | **B2** | **B3** | **B4** |  |

**Calculations for: 2-way ANOVA, Repeated Measures**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | df | Expanded df | Formula | Letter Code | Coded Formula |
| A | a-1 | a-1 |  | [A] | [A] – [T] |
| S | s-1 | s-1 |  | [S] | [S] – [T] |
| AxS | (a-1)(s-1) | as-a-s+1 |  | [AS] | [AS] – [A] – [S] + [T] |
| B | b-1 | b-1 |  | [B] | [B] – [T] |
| BxS | (b-1)(s-1) | bs-b-s+1 |  | [BS] | [BS] – [B] – [S] + [T] |
| AxB | (a-1)(b-1) | ab-a-b+1 |  | [AS] | [AB] – [A] – [B] + [T] |
| AxBxS | (a-1)(b-1)(s-1) | Abs-ab-as-bs+a+b+s-1 |  | [ABS] | [ABS] – [AB]-[AS] – [BS]+[A]+[B] + [S] - [T] |
| Total | abs-1 | abs-1 |  | [T] | [ABS] - [T] |
|  | | | | | |
| Where: | A = sum of scores in each level of factor A | | | | |
|  | a = number of levels of factor A | | | | |
|  | B = sum of scores in each level of factor B | | | | |
|  | b = number of levels of factor B | | | | |
|  | S = sum of scores for each subject | | | | |
|  | s = number of subjects | | | | |
|  | T = total sum of scores | | | | |

**Example: 2-way ANOVA with repeated measures.**

**ABS Matrix**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | a1 | | | | a2 | | | |
|  | b1 | b2 | b3 | b4 | b1 | b2 | b3 | b4 |
| s1 | 3 | 5 | 9 | 6 | 5 | 6 | 11 | 7 |
| s2 | 7 | 11 | 12 | 11 | 10 | 12 | 18 | 15 |
| s3 | 9 | 13 | 14 | 12 | 10 | 15 | 15 | 14 |
| s4 | 4 | 8 | 11 | 7 | 6 | 9 | 13 | 9 |
| s5 | 1 | 3 | 5 | 4 | 3 | 5 | 9 | 7 |

**AS Matrix**

|  |  |  |  |
| --- | --- | --- | --- |
|  | a1 | a2 | **SUM** |
| **s1** | 23 | 29 | **52** |
| **s2** | 41 | 55 | **96** |
| **s3** | 48 | 54 | **102** |
| **s4** | 30 | 37 | **67** |
| **s5** | 13 | 24 | **37** |
| **SUM** | **155** | **199** | 354 |

**BS Matrix**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | b1 | b2 | b3 | b4 | **SUM** |
| **s1** | 8 | 11 | **20** | **13** | **52** |
| **s2** | 17 | 23 | **30** | **26** | **96** |
| **s3** | 19 | 28 | **29** | **26** | **102** |
| **s4** | 10 | 17 | **24** | **16** | **67** |
| **s5** | 4 | 8 | **14** | **11** | **37** |
| **SUM** | **58** | **87** | 117 | 92 | 354 |

**AB Matrix**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | b1 | b2 | b3 | b4 | **SUM** |
| **a1** | 24 | 40 | **51** | **40** | **155** |
| **a2** | 34 | 47 | **66** | **52** | **199** |
| **SUM** | **58** | **87** | 117 | 92 | 354 |

**Calculation of Sums of Squares:**

SSA = [A] = = 3181.30 – 3132.90 = 48.40

SSs = [S] = = 3522.75 – 3132.90 = 389.85

SSAxS = [AS] = = 3577.50 – 3181.30 - 3522.75 + 3132.90 = 6.35

SSB = [B] = = 3308.60 – 3132.90 = 175.70

SSBxS = [BS] = = 3714.00 – 3308.60 - 3522.75 + 3132.90 = 15.55

SSAxB = [AB] = = 3360.40 – 3181.30 - 3308.60 + 3132.90 = 3.40

SSAxBxS = [ABS] =

= 3778.00 – 3360.40 - 3577.50 -3360.40 + 3181.30 +3308.60 +3522.75 -3132.90 = 5.85

SST = [T] = = 3778.00 – 3132.90 = 645.10

**Equations for Calculating F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | SSA | a-1 |  |  |
| S | SSs | s-1 |  |  |
| AxS | SSAxS | (a-1)(s-1) |  |  |
| B | SSB | b-1 |  |  |
| BxS | SSBxS | (b-1)(s-1) |  |  |
| AxB | SSAxB | (a-1)(b-1) |  |  |
| AxBxS | SSAxBxS | (a-1)(b-1)(s-1) |  |  |
| Total | SST | abs-1 |  |  |

**Calculation of F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | 143.92 | 1 | 48.40 | 30.44\* |
| S | 54.25 | 4 | 97.46 |  |
| AxS | 97.75 | 4 | 1.59 |  |
| B | 175.70 | 3 | 58.57 | 45.05\* |
| BxS | 15.55 | 12 | 1.30 |  |
| AxB | 3.40 | 3 | 1.13 | 2.31 |
| AxBxS | 5.85 | 12 | 0.49 |  |
| Total | 645.10 | 39 |  |  |

**Post-Hoc Tests Between Levels of Factor A within a Level of Factor B or Between Levels of Factor B within a level of Factor A:**

Fischer’s LSD test: Dependent t-tests with Bonferroni correction to alpha (α/(# of comparisons).

Alternatively, Tukey HSD and Scheffepost-hoc tests can also be used. Both of these tests hold experimentwise error constant and do not require further correction.

**SPSS Syntax and Output**

GLM a1b1 a1b2 a1b3 a1b4 a2b1 a2b2 a2b3 a2b4

/WSFACTOR=A 2 Simple B 4 Simple

/METHOD=SSTYPE(3)

\*Compare marginal means for factor A\*

/EMMEANS=TABLES(A) COMPARE ADJ(BONFERRONI)

\*Compare marginal means for factor B\*

/EMMEANS=TABLES(B) COMPARE ADJ(BONFERRONI)

\*Compare simple main effects for factor B within levels of factor A\*

\*Factor A has 2 levels, so it is not necessary to test simple main effects\*

\*of factor A within levels of factor B\*

/EMMEANS=TABLES(A\*B) COMPARE (B) ADJ(BONFERRONI)

/PRINT=DESCRIPTIVE

/CRITERIA=ALPHA(.05)

/WSDESIGN=A B A\*B.

**General Linear Model**

[DataSet3] C:\Users\Jim\HESC602\Data Sets\Richards\Kepple2WayRM.sav

| **Within-Subjects Factors** | | | |
| --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | |
| A | B | Dependent Variable | |
| 1 | 1 | a1b1 | |
| 2 | a1b2 | |
| 3 | a1b3 | |
| 4 | a1b4 | |
| 2 | 1 | a2b1 | |
| 2 | a2b2 | |
| 3 | a2b3 | |
| 4 | a2b4 | |
| **Descriptive Statistics** | | | | | |
|  | Mean | | Std. Deviation | | N |
| a1b1 | 4.8000 | | 3.19374 | | 5 |
| a1b2 | 8.0000 | | 4.12311 | | 5 |
| a1b3 | 10.2000 | | 3.42053 | | 5 |
| a1b4 | 8.0000 | | 3.39116 | | 5 |
| a2b1 | 6.8000 | | 3.11448 | | 5 |
| a2b2 | 9.4000 | | 4.15933 | | 5 |
| a2b3 | 13.2000 | | 3.49285 | | 5 |
| a2b4 | 10.4000 | | 3.84708 | | 5 |

| **Multivariate Testsb** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Effect | | Value | F | Hypothesis df | Error df | Sig. |
| A | Pillai's Trace | .884 | 30.488a | 1.000 | 4.000 | .005 |
| Wilks' Lambda | .116 | 30.488a | 1.000 | 4.000 | .005 |
| Hotelling's Trace | 7.622 | 30.488a | 1.000 | 4.000 | .005 |
| Roy's Largest Root | 7.622 | 30.488a | 1.000 | 4.000 | .005 |
| B | Pillai's Trace | .988 | 55.527a | 3.000 | 2.000 | .018 |
| Wilks' Lambda | .012 | 55.527a | 3.000 | 2.000 | .018 |
| Hotelling's Trace | 83.290 | 55.527a | 3.000 | 2.000 | .018 |
| Roy's Largest Root | 83.290 | 55.527a | 3.000 | 2.000 | .018 |
| A \* B | Pillai's Trace | .458 | .563a | 3.000 | 2.000 | .690 |
| Wilks' Lambda | .542 | .563a | 3.000 | 2.000 | .690 |
| Hotelling's Trace | .844 | .563a | 3.000 | 2.000 | .690 |
| Roy's Largest Root | .844 | .563a | 3.000 | 2.000 | .690 |
| a. Exact statistic | | | | | | |
| b. Design: Intercept  Within Subjects Design: A + B + A \* B | | | | | | |

| **Mauchly's Test of Sphericityb** | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | | | |
| Within Subjects Effect | | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilona | | |
| Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| dimension1 | A | 1.000 | .000 | 0 | . | 1.000 | 1.000 | 1.000 |
| B | .510 | 1.833 | 5 | .879 | .729 | 1.000 | .333 |
| A \* B | .103 | 6.192 | 5 | .315 | .470 | .650 | .333 |
| Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix. | | | | | | | | |
| a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table. | | | | | | | | |
| b. Design: Intercept  Within Subjects Design: A + B + A \* B | | | | | | | | |

| **Tests of Within-Subjects Effects** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
| A | Sphericity Assumed | 48.400 | 1 | 48.400 | 30.488 | .005 |
| Greenhouse-Geisser | 48.400 | 1.000 | 48.400 | 30.488 | .005 |
| Huynh-Feldt | 48.400 | 1.000 | 48.400 | 30.488 | .005 |
| Lower-bound | 48.400 | 1.000 | 48.400 | 30.488 | .005 |
| Error(A) | Sphericity Assumed | 6.350 | 4 | 1.587 |  |  |
| Greenhouse-Geisser | 6.350 | 4.000 | 1.587 |  |  |
| Huynh-Feldt | 6.350 | 4.000 | 1.587 |  |  |
| Lower-bound | 6.350 | 4.000 | 1.587 |  |  |
| B | Sphericity Assumed | 175.700 | 3 | 58.567 | 45.196 | .000 |
| Greenhouse-Geisser | 175.700 | 2.187 | 80.330 | 45.196 | .000 |
| Huynh-Feldt | 175.700 | 3.000 | 58.567 | 45.196 | .000 |
| Lower-bound | 175.700 | 1.000 | 175.700 | 45.196 | .003 |
| Error(B) | Sphericity Assumed | 15.550 | 12 | 1.296 |  |  |
| Greenhouse-Geisser | 15.550 | 8.749 | 1.777 |  |  |
| Huynh-Feldt | 15.550 | 12.000 | 1.296 |  |  |
| Lower-bound | 15.550 | 4.000 | 3.887 |  |  |
| A \* B | Sphericity Assumed | 3.400 | 3 | 1.133 | 2.325 | .127 |
| Greenhouse-Geisser | 3.400 | 1.410 | 2.411 | 2.325 | .184 |
| Huynh-Feldt | 3.400 | 1.950 | 1.744 | 2.325 | .162 |
| Lower-bound | 3.400 | 1.000 | 3.400 | 2.325 | .202 |
| Error(A\*B) | Sphericity Assumed | 5.850 | 12 | .488 |  |  |
| Greenhouse-Geisser | 5.850 | 5.640 | 1.037 |  |  |
| Huynh-Feldt | 5.850 | 7.798 | .750 |  |  |
| Lower-bound | 5.850 | 4.000 | 1.463 |  |  |

| **Tests of Within-Subjects Contrasts** | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | | | | | | |
| Source |  |  | |  | B | | Type III Sum of Squares | df | Mean Square | F | Sig. |
| A |  | Level 1 vs. Level 2 | |  |  | | 24.200 | 1 | 24.200 | 30.488 | .005 |
| Error(A) |  | Level 1 vs. Level 2 | |  |  | | 3.175 | 4 | .794 |  |  |
| B |  |  |  | | | Level 1 vs. Level 4 | 57.800 | 1 | 57.800 | 105.091 | .001 |
|  |  | Level 2 vs. Level 4 | 1.250 | 1 | 1.250 | .909 | .394 |
|  |  | Level 3 vs. Level 4 | 31.250 | 1 | 31.250 | 22.727 | .009 |
| Error(B) |  |  |  | | | Level 1 vs. Level 4 | 2.200 | 4 | .550 |  |  |
|  |  | Level 2 vs. Level 4 | 5.500 | 4 | 1.375 |  |  |
|  |  | Level 3 vs. Level 4 | 5.500 | 4 | 1.375 |  |  |
| A \* B |  | Level 1 vs. Level 2 | |  | | Level 1 vs. Level 4 | .800 | 1 | .800 | 1.000 | .374 |
|  |  | | Level 2 vs. Level 4 | 5.000 | 1 | 5.000 | 3.333 | .142 |
|  |  | | Level 3 vs. Level 4 | 1.800 | 1 | 1.800 | 1.385 | .305 |
| Error(A\*B) |  | Level 1 vs. Level 2 | |  | | Level 1 vs. Level 4 | 3.200 | 4 | .800 |  |  |
|  |  | | Level 2 vs. Level 4 | 6.000 | 4 | 1.500 |  |  |
|  |  | | Level 3 vs. Level 4 | 5.200 | 4 | 1.300 |  |  |

| **Tests of Between-Subjects Effects** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1  Transformed Variable:Average | | | | | |
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
| Intercept | 391.613 | 1 | 391.613 | 32.145 | .005 |
| Error | 48.731 | 4 | 12.183 |  |  |

**Estimated Marginal Means**

**1. A**

| **Estimates** | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | | | |
| A | Mean | | Std. Error | 95% Confidence Interval | | | | |
| Lower Bound | | | Upper Bound | |
| 1 | 7.750 | | 1.559 | 3.421 | | | 12.079 | |
| 2 | 9.950 | | 1.588 | 5.541 | | | 14.359 | |
| **Pairwise Comparisons** | | | | | | | | | | |
| Measure:MEASURE\_1 | | | | | | | | | | |
| (I) A | (J) A | Mean Difference (I-J) | | | Std. Error | Sig.a | | 95% Confidence Interval for Differencea | | |
| Lower Bound | | Upper Bound |
| 1 | 2 | -2.200\* | | | .398 | .005 | | -3.306 | | -1.094 |
| 2 | 1 | 2.200\* | | | .398 | .005 | | 1.094 | | 3.306 |
| Based on estimated marginal means | | | | | | | | | | |
| \*. The mean difference is significant at the .05 level. | | | | | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | | | | | |

| **Multivariate Tests** | | | | | |
| --- | --- | --- | --- | --- | --- |
|  | Value | F | Hypothesis df | Error df | Sig. |
| Pillai's trace | .884 | 30.488a | 1.000 | 4.000 | .005 |
| Wilks' lambda | .116 | 30.488a | 1.000 | 4.000 | .005 |
| Hotelling's trace | 7.622 | 30.488a | 1.000 | 4.000 | .005 |
| Roy's largest root | 7.622 | 30.488a | 1.000 | 4.000 | .005 |
| Each F tests the multivariate effect of A. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | |
| a. Exact statistic | | | | | |

**2. B**

| Estimates | | | | |
| --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | |
| B | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| 1 | 5.800 | 1.402 | 1.908 | 9.692 |
| 2 | 8.700 | 1.848 | 3.569 | 13.831 |
| 3 | 11.700 | 1.480 | 7.591 | 15.809 |
| 4 | 9.200 | 1.602 | 4.753 | 13.647 |

| **Pairwise Comparisons** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| (I) B | (J) B | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| 1 | 2 | -2.900\* | .534 | .033 | -5.490 | -.310 |
| 3 | -5.900\* | .400 | .001 | -7.840 | -3.960 |
| 4 | -3.400\* | .332 | .003 | -5.009 | -1.791 |
| 2 | 1 | 2.900\* | .534 | .033 | .310 | 5.490 |
| 3 | -3.000 | .671 | .066 | -6.254 | .254 |
| 4 | -.500 | .524 | 1.000 | -3.044 | 2.044 |
| 3 | 1 | 5.900\* | .400 | .001 | 3.960 | 7.840 |
| 2 | 3.000 | .671 | .066 | -.254 | 6.254 |
| 4 | 2.500 | .524 | .053 | -.044 | 5.044 |
| 4 | 1 | 3.400\* | .332 | .003 | 1.791 | 5.009 |
| 2 | .500 | .524 | 1.000 | -2.044 | 3.044 |
| 3 | -2.500 | .524 | .053 | -5.044 | .044 |
| Based on estimated marginal means | | | | | | |
| \*. The mean difference is significant at the .05 level. | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | |

| **Multivariate Tests** | | | | | |
| --- | --- | --- | --- | --- | --- |
|  | Value | F | Hypothesis df | Error df | Sig. |
| Pillai's trace | .988 | 55.527a | 3.000 | 2.000 | .018 |
| Wilks' lambda | .012 | 55.527a | 3.000 | 2.000 | .018 |
| Hotelling's trace | 83.290 | 55.527a | 3.000 | 2.000 | .018 |
| Roy's largest root | 83.290 | 55.527a | 3.000 | 2.000 | .018 |
| Each F tests the multivariate effect of B. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | |
| a. Exact statistic | | | | | |

**3. A \* B**

| **Estimates** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | |
| A | B | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| 1 | 1 | 4.800 | 1.428 | .834 | 8.766 |
| 2 | 8.000 | 1.844 | 2.880 | 13.120 |
| 3 | 10.200 | 1.530 | 5.953 | 14.447 |
| 4 | 8.000 | 1.517 | 3.789 | 12.211 |
| 2 | 1 | 6.800 | 1.393 | 2.933 | 10.667 |
| 2 | 9.400 | 1.860 | 4.236 | 14.564 |
| 3 | 13.200 | 1.562 | 8.863 | 17.537 |
| 4 | 10.400 | 1.720 | 5.623 | 15.177 |

| **Pairwise Comparisons** | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | | |
| A | (I) B | (J) B | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| 1 | 1 | 2 | -3.200\* | .490 | .017 | -5.576 | -.824 |
| 3 | -5.400\* | .510 | .003 | -7.874 | -2.926 |
| 4 | -3.200\* | .200 | .001 | -4.170 | -2.230 |
| 2 | 1 | 3.200\* | .490 | .017 | .824 | 5.576 |
| 3 | -2.200 | .583 | .117 | -5.029 | .629 |
| 4 | .000 | .447 | 1.000 | -2.169 | 2.169 |
| 3 | 1 | 5.400\* | .510 | .003 | 2.926 | 7.874 |
| 2 | 2.200 | .583 | .117 | -.629 | 5.029 |
| 4 | 2.200 | .583 | .117 | -.629 | 5.029 |
| 4 | 1 | 3.200\* | .200 | .001 | 2.230 | 4.170 |
| 2 | .000 | .447 | 1.000 | -2.169 | 2.169 |
| 3 | -2.200 | .583 | .117 | -5.029 | .629 |
| 2 | 1 | 2 | -2.600 | .678 | .111 | -5.890 | .690 |
| 3 | -6.400\* | .510 | .001 | -8.874 | -3.926 |
| 4 | -3.600\* | .510 | .013 | -6.074 | -1.126 |
| 2 | 1 | 2.600 | .678 | .111 | -.690 | 5.890 |
| 3 | -3.800 | 1.020 | .122 | -8.747 | 1.147 |
| 4 | -1.000 | .707 | 1.000 | -4.430 | 2.430 |
| 3 | 1 | 6.400\* | .510 | .001 | 3.926 | 8.874 |
| 2 | 3.800 | 1.020 | .122 | -1.147 | 8.747 |
| 4 | 2.800 | .583 | .052 | -.029 | 5.629 |
| 4 | 1 | 3.600\* | .510 | .013 | 1.126 | 6.074 |
| 2 | 1.000 | .707 | 1.000 | -2.430 | 4.430 |
| 3 | -2.800 | .583 | .052 | -5.629 | .029 |
| Based on estimated marginal means | | | | | | | |
| \*. The mean difference is significant at the .05 level. | | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | | |

| **Multivariate Tests** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| A | | Value | F | Hypothesis df | Error df | Sig. |
| 1 | Pillai's trace | .992 | 83.500a | 3.000 | 2.000 | .012 |
| Wilks' lambda | .008 | 83.500a | 3.000 | 2.000 | .012 |
| Hotelling's trace | 125.250 | 83.500a | 3.000 | 2.000 | .012 |
| Roy's largest root | 125.250 | 83.500a | 3.000 | 2.000 | .012 |
| 2 | Pillai's trace | .987 | 48.772a | 3.000 | 2.000 | .020 |
| Wilks' lambda | .013 | 48.772a | 3.000 | 2.000 | .020 |
| Hotelling's trace | 73.158 | 48.772a | 3.000 | 2.000 | .020 |
| Roy's largest root | 73.158 | 48.772a | 3.000 | 2.000 | .020 |
| Each F tests the multivariate simple effects of B within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | | |
| a. Exact statistic | | | | | | |

**Calculating the F-Ratio for a 2-Way ANOVA with Repeated Measures on One Factor (B)**

**Nomenclature**

**ABS Matrix**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| a1 b1 | a1 b2 | a1 b3 | a1 b4 | a2 b1 | a2 b2 | a2 b3 | a2 b4 |
| s1 | s1 | s1 | s1 | s6 | s6 | s6 | s6 |
| s2 | s2 | s2 | s2 | s7 | s7 | s7 | s7 |
| s3 | s3 | s3 | s3 | s8 | s8 | s8 | s8 |
| s4 | s4 | s4 | s4 | s9 | s9 | s9 | s9 |
| s5 | s5 | s5 | s5 | s10 | s10 | s10 | s10 |

**AS Matrix**

(each inner cell represents the sum across all levels of B, so:

A1 S1 = A1B1S1 + A1B2S1 + A1B3S1 + A1B4S1)

|  |  |  |  |
| --- | --- | --- | --- |
|  | a1 |  | a2 |
| **s1** | A1 S1 | s6 | A2 S6 |
| **s2** | A1 S2 | s7 | A2 S7 |
| **s3** | A1 S3 | s8 | A2 S8 |
| **s4** | A1 S4 | s9 | A2 S9 |
| **s5** | A1 S5 | s10 | A2 S10 |
| **SUM** | **A1** |  | **A2** |

**AB Matrix**

(each inner cell represents the sum across all subjects, so:

A1 B1 = A1B1S1 + A1B1S2+ A1B1S3 + A1B1S4+ A1B1S5)

|  |  |  |  |
| --- | --- | --- | --- |
|  | a1 | a2 | **SUM** |
| **b1** | A1 B1 | A2 B1 | **B1** |
| **b2** | A1 B2 | A2 B2 | **B2** |
| **b3** | A1 B3 | A2 B3 | **B3** |
| **b4** | A1 B4 | A2 B4 | **B4** |
| **SUM** | **A1** | **A2** | T |

**Calculations for: 2-way ANOVA with Repeated Measures on One Factor (B)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Source | df | Expanded df | Formula | Letter Code | Coded Formula |
| A | a-1 | a-1 |  | [A] | [A] – [T] |
| S/A | a(s-1) | as-a |  | [AS] | [AS] – [A] |
| B | b-1 | b-1 |  | [B] | [B] – [T] |
| AxB | (a-1)(b-1) | ab-a-b+1 |  | [AB] | [AB] – [A] – [B] + [T] |
| BxS/A | a(b-1)(s-1) | abs-ab-as+a |  | [ABS] | [ABS] – [AB]-[AS] – [BS]+[A]+[B] + [S] - [T] |
| Total | abs-1 | abs-1 |  | [T] | [ABS] - [T] |
|  | | | | | |
| Where: | A = sum of scores in each level of factor A | | | | |
|  | a = number of levels of factor A | | | | |
|  | B = sum of scores in each level of factor B | | | | |
|  | b = number of levels of factor B | | | | |
|  | S = sum of scores for each subject | | | | |
|  | s = number of subjects | | | | |
|  | T = total sum of scores | | | | |

**Example: 2-way ANOVA with repeated measures on one factor (B).**

**ABS Matrix**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| a1 | | | | | a2 | | | | |
|  | b1 | b2 | b3 | b4 |  | b1 | b2 | b3 | b4 |
| s1 | 3 | 5 | 9 | 6 | s6 | 5 | 6 | 11 | 7 |
| s2 | 7 | 11 | 12 | 11 | s7 | 10 | 12 | 18 | 15 |
| s3 | 9 | 13 | 14 | 12 | s8 | 10 | 15 | 15 | 14 |
| s4 | 4 | 8 | 11 | 7 | s9 | 6 | 9 | 13 | 9 |
| s5 | 1 | 3 | 5 | 4 | s10 | 3 | 5 | 9 | 7 |

**AS Matrix**

|  |  |  |  |
| --- | --- | --- | --- |
|  | a1 |  | a2 |
| **s1** | 23 | s6 | 29 |
| **s2** | 41 | s7 | 55 |
| **s3** | 48 | s8 | 54 |
| **s4** | 30 | s9 | 37 |
| **s5** | 13 | s10 | 24 |
| **SUM** | **155** |  | **199** |

**AB Matrix**

|  |  |  |  |
| --- | --- | --- | --- |
|  | a1 | a2 | **SUM** |
| **b1** | 24 | 34 | **58** |
| **b2** | 40 | 47 | **87** |
| **b3** | 51 | 66 | **117** |
| **b4** | 40 | 52 | **92** |
| **SUM** | **155** | **199** | 354 |

**Calculation of Sums of Squares:**

SSA = [A] = = 3181.30 – 3132.90 = 48.40

SSS/A = [AS] = = 3577.50 – 3181.30 = 396.20

SSB = [B] = = 3308.60 – 3132.90 = 175.70

SSAxB = [AB] = = 3360.40 – 3181.30 - 3308.60 + 3132.90 = 3.40

SSBxS/A = [ABS] =

= 3778.00 – 3360.40 - 3577.50 -3360.40 + 3181.30 = 21.40

SST = [T] = = 3778.00 – 3132.90 = 645.10

**Equations for Calculating F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | SSA | a-1 |  |  |
| S/A | SSS/A | a(s-1) |  |  |
| B | SSB | b-1 |  |  |
| AxB | SSAxB | (a-1)(b-1) |  |  |
| BxS/A | SSAxBxS | a(b-1)(s-1) |  |  |
| Total | SST | abs-1 |  |  |

**Calculation of F-Ratio:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | SS | df | Mean Square (MS) | F-Ratio |
| A | 48.40 | 1 | 48.40 | 0.97 |
| S/A | 396.20 | 8 | 49.52 |  |
| B | 175.70 | 3 | 58.57 | 65.81\* |
| AxB | 3.40 | 3 | 1.13 | 1.27 |
| BxS/A | 21.40 | 24 | 0.89 |  |
| Total | 645.10 | 39 |  |  |

**Post-Hoc Tests Between Levels of Factor A (independent groups) within a Level of Factor B (repeated measure)**

Fischer’s LSD test: Independent t-tests with Bonferroni correction to alpha (α/(# of comparisons).

Alternatively, Tukey HSD and Scheffepost-hoc tests can also be used. Both of these tests hold experimentwise error constant and do not require further correction.

**Post-Hoc Tests Between Levels of Factor B (repeated measures) within a level of Factor A independent group):**

Fischer’s LSD test: Dependent t-tests with Bonferroni correction to alpha (α/(# of comparisons).

Alternatively, Tukey HSD and Scheffepost-hoc tests can also be used. Both of these tests hold experimentwise error constant and do not require further correction.

**SPSS Syntax and Output**

GLM b1 b2 b3 b4 BY A

/WSFACTOR=B 4 Simple

/METHOD=SSTYPE(3)

\*Compare marginal means for factor A\*

/EMMEANS=TABLES(A) COMPARE ADJ(BONFERRONI)

\*Compare marginal means for factor B\*

/EMMEANS=TABLES(B) COMPARE ADJ(BONFERRONI)

\*Compare simple main effects for factor B within levels of factor A\*

\*Factor A has 2 levels, so it is not necessary to test simple main effects\*

\*of factor A within levels of factor B\*

/EMMEANS=TABLES(A\*B) COMPARE (B) ADJ(BONFERRONI)

/PRINT=DESCRIPTIVE

/CRITERIA=ALPHA(.05)

/WSDESIGN=B

/DESIGN=A.

**General Linear Model**

[DataSet3] C:\Users\Jim\HESC602\Data Sets\Richards\Kepple2WayMixed.sav

| **Within-Subjects Factors** | |
| --- | --- |
| Measure:MEASURE\_1 | |
| B | Dependent Variable |
| 1 | b1 |
| 2 | b2 |
| 3 | b3 |
| 4 | b4 |

| **Between-Subjects Factors** | | | |
| --- | --- | --- | --- |
|  | | Value Label | N |
| A | 1.00 | a1 | 5 |
| 2.00 | a2 | 5 |

| **Descriptive Statistics** | | | | |
| --- | --- | --- | --- | --- |
|  | A | Mean | Std. Deviation | N |
| b1 | a1 | 4.8000 | 3.19374 | 5 |
| a2 | 6.8000 | 3.11448 | 5 |
| Total | 5.8000 | 3.15524 | 10 |
| b2 | a1 | 8.0000 | 4.12311 | 5 |
| a2 | 9.4000 | 4.15933 | 5 |
| Total | 8.7000 | 3.97352 | 10 |
| b3 | a1 | 10.2000 | 3.42053 | 5 |
| a2 | 13.2000 | 3.49285 | 5 |
| Total | 11.7000 | 3.62246 | 10 |
| b4 | a1 | 8.0000 | 3.39116 | 5 |
| a2 | 10.4000 | 3.84708 | 5 |
| Total | 9.2000 | 3.64539 | 10 |

| **Multivariate Testsb** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Effect | | Value | F | Hypothesis df | Error df | Sig. |
| B | Pillai's Trace | .980 | 99.659a | 3.000 | 6.000 | .000 |
| Wilks' Lambda | .020 | 99.659a | 3.000 | 6.000 | .000 |
| Hotelling's Trace | 49.830 | 99.659a | 3.000 | 6.000 | .000 |
| Roy's Largest Root | 49.830 | 99.659a | 3.000 | 6.000 | .000 |
| B \* A | Pillai's Trace | .256 | .688a | 3.000 | 6.000 | .591 |
| Wilks' Lambda | .744 | .688a | 3.000 | 6.000 | .591 |
| Hotelling's Trace | .344 | .688a | 3.000 | 6.000 | .591 |
| Roy's Largest Root | .344 | .688a | 3.000 | 6.000 | .591 |
| a. Exact statistic | | | | | | |
| b. Design: Intercept + A  Within Subjects Design: B | | | | | | |

| **Mauchly's Test of Sphericityb** | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | | | |
| Within Subjects Effect | | Mauchly's W | Approx. Chi-Square | df | Sig. | Epsilona | | |
| Greenhouse-Geisser | Huynh-Feldt | Lower-bound |
| dimension1 | B | .498 | 4.680 | 5 | .460 | .683 | 1.000 | .333 |
| Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix. | | | | | | | | |
| a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table. | | | | | | | | |
| b. Design: Intercept + A  Within Subjects Design: B | | | | | | | | |

| **Tests of Within-Subjects Effects** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
| B | Sphericity Assumed | 175.700 | 3 | 58.567 | 65.682 | .000 |
| Greenhouse-Geisser | 175.700 | 2.049 | 85.755 | 65.682 | .000 |
| Huynh-Feldt | 175.700 | 3.000 | 58.567 | 65.682 | .000 |
| Lower-bound | 175.700 | 1.000 | 175.700 | 65.682 | .000 |
| B \* A | Sphericity Assumed | 3.400 | 3 | 1.133 | 1.271 | .307 |
| Greenhouse-Geisser | 3.400 | 2.049 | 1.659 | 1.271 | .308 |
| Huynh-Feldt | 3.400 | 3.000 | 1.133 | 1.271 | .307 |
| Lower-bound | 3.400 | 1.000 | 3.400 | 1.271 | .292 |
| Error(B) | Sphericity Assumed | 21.400 | 24 | .892 |  |  |
| Greenhouse-Geisser | 21.400 | 16.391 | 1.306 |  |  |
| Huynh-Feldt | 21.400 | 24.000 | .892 |  |  |
| Lower-bound | 21.400 | 8.000 | 2.675 |  |  |

| **Tests of Within-Subjects Contrasts** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| Source | B | Type III Sum of Squares | df | Mean Square | F | Sig. |
| B | Level 1 vs. Level 4 | 115.600 | 1 | 115.600 | 154.133 | .000 |
| Level 2 vs. Level 4 | 2.500 | 1 | 2.500 | 1.429 | .266 |
| Level 3 vs. Level 4 | 62.500 | 1 | 62.500 | 36.765 | .000 |
| B \* A | Level 1 vs. Level 4 | .400 | 1 | .400 | .533 | .486 |
| Level 2 vs. Level 4 | 2.500 | 1 | 2.500 | 1.429 | .266 |
| Level 3 vs. Level 4 | .900 | 1 | .900 | .529 | .488 |
| Error(B) | Level 1 vs. Level 4 | 6.000 | 8 | .750 |  |  |
| Level 2 vs. Level 4 | 14.000 | 8 | 1.750 |  |  |
| Level 3 vs. Level 4 | 13.600 | 8 | 1.700 |  |  |

| **Tests of Between-Subjects Effects** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1  Transformed Variable:Average | | | | | |
| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
| Intercept | 783.225 | 1 | 783.225 | 63.259 | .000 |
| A | 12.100 | 1 | 12.100 | .977 | .352 |
| Error | 99.050 | 8 | 12.381 |  |  |

**Estimated Marginal Means**

**1. A**

| **Estimates** | | | | |
| --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | |
| A | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| a1 | 7.750 | 1.574 | 4.121 | 11.379 |
| a2 | 9.950 | 1.574 | 6.321 | 13.579 |

| **Pairwise Comparisons** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| (I) A | (J) A | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| a1 | a2 | -2.200 | 2.225 | .352 | -7.332 | 2.932 |
| a2 | a1 | 2.200 | 2.225 | .352 | -2.932 | 7.332 |
| Based on estimated marginal means | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | |

| **Univariate Tests** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | |
|  | Sum of Squares | df | Mean Square | F | Sig. |
| Contrast | 12.100 | 1 | 12.100 | .977 | .352 |
| Error | 99.050 | 8 | 12.381 |  |  |
| The F tests the effect of A. This test is based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | |

**2. B**

| **Estimates** | | | | |
| --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | |
| B | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| 1 | 5.800 | .997 | 3.500 | 8.100 |
| 2 | 8.700 | 1.310 | 5.680 | 11.720 |
| 3 | 11.700 | 1.093 | 9.179 | 14.221 |
| 4 | 9.200 | 1.147 | 6.556 | 11.844 |

| **Pairwise Comparisons** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | |
| (I) B | (J) B | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| 1 | 2 | -2.900\* | .418 | .001 | -4.355 | -1.445 |
| 3 | -5.900\* | .361 | .000 | -7.154 | -4.646 |
| 4 | -3.400\* | .274 | .000 | -4.353 | -2.447 |
| 2 | 1 | 2.900\* | .418 | .001 | 1.445 | 4.355 |
| 3 | -3.000\* | .587 | .006 | -5.043 | -.957 |
| 4 | -.500 | .418 | 1.000 | -1.955 | .955 |
| 3 | 1 | 5.900\* | .361 | .000 | 4.646 | 7.154 |
| 2 | 3.000\* | .587 | .006 | .957 | 5.043 |
| 4 | 2.500\* | .412 | .002 | 1.066 | 3.934 |
| 4 | 1 | 3.400\* | .274 | .000 | 2.447 | 4.353 |
| 2 | .500 | .418 | 1.000 | -.955 | 1.955 |
| 3 | -2.500\* | .412 | .002 | -3.934 | -1.066 |
| Based on estimated marginal means | | | | | | |
| \*. The mean difference is significant at the .05 level. | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | |

| **Multivariate Tests** | | | | | |
| --- | --- | --- | --- | --- | --- |
|  | Value | F | Hypothesis df | Error df | Sig. |
| Pillai's trace | .980 | 99.659a | 3.000 | 6.000 | .000 |
| Wilks' lambda | .020 | 99.659a | 3.000 | 6.000 | .000 |
| Hotelling's trace | 49.830 | 99.659a | 3.000 | 6.000 | .000 |
| Roy's largest root | 49.830 | 99.659a | 3.000 | 6.000 | .000 |
| Each F tests the multivariate effect of B. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | |
| a. Exact statistic | | | | | |

**3. A \* B**

| **Estimates** | | | | | |
| --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | |
| A | B | Mean | Std. Error | 95% Confidence Interval | |
| Lower Bound | Upper Bound |
| a1 | 1 | 4.800 | 1.411 | 1.547 | 8.053 |
| 2 | 8.000 | 1.852 | 3.729 | 12.271 |
| 3 | 10.200 | 1.546 | 6.635 | 13.765 |
| 4 | 8.000 | 1.622 | 4.260 | 11.740 |
| a2 | 1 | 6.800 | 1.411 | 3.547 | 10.053 |
| 2 | 9.400 | 1.852 | 5.129 | 13.671 |
| 3 | 13.200 | 1.546 | 9.635 | 16.765 |
| 4 | 10.400 | 1.622 | 6.660 | 14.140 |

| **Pairwise Comparisons** | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Measure:MEASURE\_1 | | | | | | | |
| A | (I) B | (J) B | Mean Difference (I-J) | Std. Error | Sig.a | 95% Confidence Interval for Differencea | |
| Lower Bound | Upper Bound |
| a1 | 1 | 2 | -3.200\* | .592 | .004 | -5.258 | -1.142 |
| 3 | -5.400\* | .510 | .000 | -7.174 | -3.626 |
| 4 | -3.200\* | .387 | .000 | -4.547 | -1.853 |
| 2 | 1 | 3.200\* | .592 | .004 | 1.142 | 5.258 |
| 3 | -2.200 | .831 | .176 | -5.090 | .690 |
| 4 | -1.776E-15 | .592 | 1.000 | -2.058 | 2.058 |
| 3 | 1 | 5.400\* | .510 | .000 | 3.626 | 7.174 |
| 2 | 2.200 | .831 | .176 | -.690 | 5.090 |
| 4 | 2.200\* | .583 | .033 | .171 | 4.229 |
| 4 | 1 | 3.200\* | .387 | .000 | 1.853 | 4.547 |
| 2 | 1.776E-15 | .592 | 1.000 | -2.058 | 2.058 |
| 3 | -2.200\* | .583 | .033 | -4.229 | -.171 |
| a2 | 1 | 2 | -2.600\* | .592 | .014 | -4.658 | -.542 |
| 3 | -6.400\* | .510 | .000 | -8.174 | -4.626 |
| 4 | -3.600\* | .387 | .000 | -4.947 | -2.253 |
| 2 | 1 | 2.600\* | .592 | .014 | .542 | 4.658 |
| 3 | -3.800\* | .831 | .011 | -6.690 | -.910 |
| 4 | -1.000 | .592 | .777 | -3.058 | 1.058 |
| 3 | 1 | 6.400\* | .510 | .000 | 4.626 | 8.174 |
| 2 | 3.800\* | .831 | .011 | .910 | 6.690 |
| 4 | 2.800\* | .583 | .008 | .771 | 4.829 |
| 4 | 1 | 3.600\* | .387 | .000 | 2.253 | 4.947 |
| 2 | 1.000 | .592 | .777 | -1.058 | 3.058 |
| 3 | -2.800\* | .583 | .008 | -4.829 | -.771 |
| Based on estimated marginal means | | | | | | | |
| \*. The mean difference is significant at the .05 level. | | | | | | | |
| a. Adjustment for multiple comparisons: Bonferroni. | | | | | | | |

| **Multivariate Tests** | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| A | | Value | F | Hypothesis df | Error df | Sig. |
| a1 | Pillai's trace | .957 | 44.482a | 3.000 | 6.000 | .000 |
| Wilks' lambda | .043 | 44.482a | 3.000 | 6.000 | .000 |
| Hotelling's trace | 22.241 | 44.482a | 3.000 | 6.000 | .000 |
| Roy's largest root | 22.241 | 44.482a | 3.000 | 6.000 | .000 |
| a2 | Pillai's trace | .965 | 55.865a | 3.000 | 6.000 | .000 |
| Wilks' lambda | .035 | 55.865a | 3.000 | 6.000 | .000 |
| Hotelling's trace | 27.933 | 55.865a | 3.000 | 6.000 | .000 |
| Roy's largest root | 27.933 | 55.865a | 3.000 | 6.000 | .000 |
| Each F tests the multivariate simple effects of B within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means. | | | | | | |
| a. Exact statistic | | | | | | |