SOURCEBOOK

EASI Articles

Annotated Output

Abstract: This chapter is intended to facilitate the connection between standard introductory statistics concepts and their implementation in EASI. It shows the output from various types of analyses, describes how to interpret the output, and shows the link between hand calculation formulas and EASI output. Results derive from the examples in the other sections of this project.

Keywords: EASI output, annotation, statistical interpretation

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https://cwendorf.github.io/Sourcebook

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Frequencies

```
> ### Frequency Distribution

> (Outcome) |> describeFrequencies()

Frequencies for the Data

     Freq    Perc CumFreq CumPerc
0   2.000   0.250   2.000   0.250
3   1.000   0.125   3.000   0.375
4   2.000   0.250   5.000   0.625
5   1.000   0.125   6.000   0.750
7   1.000   0.125   7.000   0.875
9   1.000   0.125   8.000   1.000

> ### Descriptive Statistics

> (Outcome) |> describePercentiles()

Percentiles for the Data

              0%     25%     50%     75%    100%
Outcome    0.000   2.250   4.000   5.500   9.000
```

The first column lists all the actual scores in the entire data set. “Freq” indicates the number of times that score exists. For example, the score 4 was listed 2 times.

The “Perc” column provides the percentage of cases for each possible score. For example, of the 8 scores in the entire data set, the score of 4 was listed 2 times and 2/8 is 25.0%.

Cumulative Frequency (“CumFreq”) and Cumulative Percent (“CumPerc”) involve the sum of all frequencies or percentages up to and including the row in question. For example, 62.5% of scores were a 4 or smaller. Similarly, 37.5% were a 3 or smaller.

“Percentiles” provide the scores associated with particular percentile ranks. For example, the 50th percentile is the score in the following position:

$$Position = PR(N+1) = .50(8+1) = 4.5$$

Thus, the score at the 50th percentile is the 4.5th score in the frequency distribution – a score of 4.

Descriptives

```
> ### Frequency Distribution

> (Outcome) |> describeFrequencies()

Frequencies for the Data

     Freq    Perc CumFreq CumPerc
0   2.000   0.250   2.000   0.250
3   1.000   0.125   3.000   0.375
4   2.000   0.250   5.000   0.625
5   1.000   0.125   6.000   0.750
7   1.000   0.125   7.000   0.875
9   1.000   0.125   8.000   1.000

> ### Descriptive Statistics

> (Outcome) |> describeMoments()

Summary Statistics for the Data

               N       M      SD    Skew    Kurt
Outcome    8.000   4.000   3.117   0.151  -0.467
```

These statistics were obtained using the command described on the previous page of this guide.

The Mean and Standard Deviation are calculated as unbiased estimates of the respective population parameter. Here, the mean ("M") is determined as the average of the scores weighted by their frequencies:

$$M = \frac{\sum(fY)}{N} = \frac{(2 \times 0) + (1 \times 3) + (2 \times 4) + (1 \times 5) + (1 \times 7) + (1 \times 8)}{8} = 4$$

The Variance and Standard Deviation are both functions of the Sum of Squares (not shown in the output) of the scores in the frequency distribution:

$$SS = \sum f(Y - M)$$

$$SS = 2(0-4)^2 + 1(3-4)^2 + 2(4-4)^2 + 1(5-4)^2 + 1(7-4)^2 + 1(8-4)^2 = 68$$

Then, the Variance (also known as Mean Squares) is calculated as:

$$MS = \frac{SS}{(N-1)} = \frac{68}{7} = 9.714$$

Finally, the Standard Deviation ("SD") is determined by:

$$SD = \sqrt{MS} = \sqrt{9.71} = 3.117$$

Correlations

```
> ### Descriptive Statistics

> (CorrelationData) |> describeMoments()

Summary Statistics for the Data

                N        M       SD     Skew     Kurt
Outcome1    4.000    2.000    2.449    0.544   -2.944
Outcome2    4.000    6.000    2.449    0.544   -2.944

> (CorrelationData) |> describeCovariances()

Covariances for the Data

         Outcome1 Outcome2
Outcome1    6.000    3.000
Outcome2    3.000    6.000

> (CorrelationData) |> describeCorrelations()

Correlations for the Data

         Outcome1 Outcome2
Outcome1    1.000    0.500
Outcome2    0.500    1.000

> ### Inferential Statistics

> (CorrelationData) |> testCorrelations()

Hypothesis Tests for the Correlations

                          R       SE       df        t        p
Outcome1 & Outcome2   0.500    0.612    2.000    0.816    0.500
```

These statistics were obtained using the "Descriptives" command described on the previous page of this guide. Note that they are calculated separately for each variable.

These matrices represent the conjunction of both variables and therefore present the statistics relevant to the relationship between the two variables.

The Sum of Cross Products ("SCP") is not easily determined from the summary statistics of the output, but rather from the data (and the calculations are therefore not shown here).

The Covariance ("COV") is a function of the Sum of Cross Products and the sample size:

$$COV = \frac{SCP}{(N-1)} = \frac{9.000}{(4-1)} = 3.000$$

The Correlation coefficient ("r") is a function of the covariance and the standard deviations of both variables:

$$r = \frac{COV}{(SD_X)(SD_Y)} = \frac{3.000}{(2.449)(2.449)} = .500$$

The "t", "df", and "p" columns provide a statistical significance test of whether the correlation differs from zero:

$$t = \frac{r}{\sqrt{(1-r^2)/(N-2)}} = \frac{.500}{\sqrt{(1-.500^2)/(4-2)}} = .816$$

The t statistic follows a non-normal (studentized or t) distribution that depends on degrees of freedom. Here, $df = N - 2 = 4 - 2 = 2$. A t with 2 df that equals .816 has a two-tailed probability (p) of .500, which is not a

Regression

```
> ### Descriptive Statistics

> (CorrelationData) |> describeMoments()

Summary Statistics for the Data

                N        M       SD     Skew     Kurt
Outcome1    4.000    2.000    2.449    0.544   -2.944
Outcome2    4.000    6.000    2.449    0.544   -2.944

> (CorrelationData) |> describeCovariances()

Covariances for the Data

         Outcome1 Outcome2
Outcome1    6.000    3.000
Outcome2    3.000    6.000

> ### Inferential Statistics

> (CorrelationData) |> estimateModel()

Proportion of Variance Accounted For by the Regression Mo

          Est       LL       UL
Model   0.250    0.000    0.606

> (CorrelationData) |> testCoefficients()

Hypothesis Tests for the Regression Coefficients

                Est       SE        t        p
(Intercept)   5.000    1.785    2.801    0.107
Outcome1      0.500    0.612    0.816    0.500
```

These statistics were obtained using the “Descriptives” command described on the previous page of this guide. Note that they are calculated separately for each variable.

The Covariance (“COV”) is not determinable from the summary statistics provided, but rather the data. Therefore, the calculations for it are not shown here.

“R” is a function of the covariance and the standard deviations of both variables:

$$R = \frac{COV}{(SD_X)(SD_Y)} = \frac{3.000}{(2.45)(2.45)} = 0.500$$

$$R^2 = 0.500^2 = 0.250$$

The Unstandardized Regression Coefficients (“Estimate”) are also a function of the Covariance and the descriptive statistics:

$$B_1 = \frac{COV}{(SD_X)^2} = \frac{3.000}{(2.449)^2} = 0.500$$

$$B_0 = M_Y - (B_1)(M_X) = 6.000 - (0.500)(2.000) = 5.000$$

The Standardized Regression Coefficient for the predictor can be similarly determined:

$$\beta_1 = B_1\left(\frac{SD_X}{SD_Y}\right) = 0.500\left(\frac{2.449}{2.449}\right) = 0.500$$

Confidence Interval for a Mean

```
> ### Descriptive Statistics

> (Outcome) |> describeMoments()

Summary Statistics for the Data

               N        M       SD     Skew     Kurt
Outcome    8.000    4.000    3.117    0.151   -0.467

> ### Inferential Statistics

> (Outcome) |> estimateMeans()

Confidence Intervals for the Means

               M       SE       df       LL       UL
Outcome    4.000    1.102    7.000    1.394    6.606
```

These values are produced by the "Descriptives" commands. See the earlier annotated output for details of how these are computed from frequency distributions.

The Standard Error of the Mean ("SE") provides an estimate of how spread out the distribution of all possible random sample means would be. Here it's calculated as:

$$SE_M = \frac{SD}{\sqrt{N}} = \frac{3.117}{\sqrt{8}} = 1.102$$

This section provides a confidence interval around (centered on) the Mean ("M"). Calculation requires the appropriate critical value. Specifically, the *t* statistic (with 7 *df*) that has a probability of .05 equals 2.365. As a result:

$$CI_M = M \pm (t_{CRITICAL})(SE_M) = 4.000 \pm (2.365)(1.102)$$

Thus, the researcher estimates that the true population mean is somewhere between 1.394 and 6.606 (knowing that the estimate could be incorrect).

One Sample t Test

```
> ### Descriptive Statistics

> (Outcome) |> describeMoments()

Summary Statistics for the Data
              N        M       SD     Skew     Kurt
Outcome   8.000    4.000    3.117    0.151   -0.467

> ### Inferential Statistics

> (Outcome) |> estimateMeans(mu = 7)

Confidence Intervals for the Means
           Diff       SE       df       LL       UL
Outcome  -3.000    1.102    7.000   -5.606   -0.394

> (Outcome) |> testMeans(mu = 7)

Hypothesis Tests for the Means
           Diff       SE       df        t        p
Outcome  -3.000    1.102    7.000   -2.722    0.030

> (Outcome) |> standardizeMeans(mu = 7)

Confidence Intervals for the Standardized Means
              d       SE       LL       UL
Outcome  -0.963    0.438   -1.792   -0.089
```

These values are produced by the "Descriptives" commands. See the earlier annotated output for details of how these are computed from frequency distributions.

The Standard Error of the Difference ("SE") provides an estimate of how spread out the distribution of all possible random sample mean differences would be. Here it's calculated as:

$$SE_M = \frac{SD}{\sqrt{N}} = \frac{3.117}{\sqrt{8}} = 1.102$$

This section provides a confidence interval around (centered on) the Mean Difference ("Diff"). Calculation requires the appropriate critical value. Specifically, the *t* statistic (with 7 *df*) that has a probability of .05 equals 2.365. As a result:

$$CI_{DIFF} = M_{DIFF} \pm (t_{CRITICAL})(SE_M) = -3.000 \pm (2.365)(1.102)$$

Thus, the researcher estimates that the true population mean difference is somewhere between -5.606 and -.394 (knowing that the estimate could be incorrect).

The "t", "df", and "p" columns provide the results of the statistical significance test. First, *t* provides the standardized statistic for the mean difference:

$$t = \frac{M - \mu}{SE_M} = \frac{-3.000}{1.102} = -2.722$$

The *t* statistic follows a non-normal (studentized or *t*) distribution that depends on degrees of freedom. Here, *df* = *N* – 1 = 8 – 1 = 7. A *t* with 7 *df* that equals -2.722 has a two-tailed probability (*p*) of .030, a statistically significant finding.

The Mean Difference ("Diff") is the difference between the sample mean (*M* = 4) and the user-specified test value (*u* = 7). For the example, the sample had a mean one point higher than the test value. This raw effect size is important for the significance test, the confidence interval, and the effect size.

Cohen's "d" provides a standardized effect size for the difference between the two means.

$$d = \frac{M - \mu}{SD} = \frac{-3.000}{3.117} = 0.963$$

Given Cohen's heuristics for interpreting effect sizes, this would be considered a large effect.

Paired Samples t Test

```
> ### Descriptive Statistics

> (PairedData) |> describeMmoments()

Summary Statistics for the Data
               N       M      SD    Skew    Kurt
Outcome1   4.000   2.000   2.449   0.544  -2.944
Outcome2   4.000   6.000   2.449   0.544  -2.944

> ### Inferential Statistics

> (PairedData) |> estimateDifference()

Confidence Interval for the Mean Difference
              Diff      SE      df      LL      UL
Comparison   4.000   1.225   3.000   0.102   7.898

> (PairedData) |> testDifference()

Hypothesis Test for the Mean Difference
              Diff      SE      df       t       p
Comparison   4.000   1.225   3.000   3.266   0.047

> (PairedData) |> standardizeDifference()

Confidence Interval for the Standardized Mean Difference
                 d      SE      LL      UL
Comparison   1.633   0.782   0.101   3.165
```

These descriptive statistics are calculated separately for each variable.

The Mean Difference ("Diff") is simply the difference between the two means listed above. However, the "SE" is not determinable from the summary statistics presented here but rather the raw data.

The Std. Deviation of the differences can be determined from this information:

$$SD_D = (SE_D)(\sqrt{N})$$
$$SD_D = (1.225)(\sqrt{4}) = 2.449$$

This confidence interval is centered on the Mean Difference ("Diff") of the two variables. Calculation requires the appropriate critical value. Specifically, the *t* statistic (with 3 *df*) that has a probability of .05 equals 3.182. As a result:

$$CI_D = M_D \pm (t_{CRITICAL})(SE_D)$$
$$CI_D = 4.00 \pm (3.182)(1.225)$$

Thus, the researcher estimates that the true population mean difference is somewhere between 0.1.02 to 7.898 (knowing that the estimate could be incorrect).

Cohen's "d" provides a standardized effect size for the difference between the two means.

$$d = \frac{M_D}{SD_D} = \frac{4.000}{2.449}$$
$$d = 1.633$$

Given Cohen's heuristics for interpreting effect sizes, this would be considered an extremely large effect.

The "t", "df", and "p" columns provide the results of the statistical significance test. First, *t* provides the standardized statistic for the mean difference:

$$t = \frac{M_D}{SE_D} = \frac{4.000}{1.225} = 3.226$$

The *t* statistic follows a non-normal (studentized or *t*) distribution that depends on degrees of freedom. Here, *df* = *N* – 1 = 4 – 1 = 3. A *t* with 3 *df* that equals 3.226 has a two-tailed probability (*p*) of .047, a statistically significant finding.

Independent Samples t Test

```
> ### Descriptive Statistics

> (Outcome ~ Factor) |> describeMoments()

Summary Statistics for the Data
             N        M       SD     Skew     Kurt
Level1   4.000    2.000    2.449    0.544   -2.944
Level2   4.000    6.000    2.449    0.544   -2.944

> ### Inferential Statistics

> (Outcome ~ Factor) |> estimateDifference()

Confidence Interval for the Mean Difference
              Diff       SE       df       LL       UL
Comparison   4.000    1.732    6.000   -0.238    8.238

> (Outcome ~ Factor) |> testDifference()

Hypothesis Test for the Mean Difference
              Diff       SE       df        t        p
Comparison   4.000    1.732    6.000    2.309    0.060

> (Outcome ~ Factor) |> standardizeDifference()

Confidence Interval for the Standardized Mean Difference
                 d       SE       LL       UL
Comparison   1.633    0.943   -0.215    3.481
```

These values of the group statistics are calculated separately for each level or condition. They are not identical to the values obtained from analyzing the variable as a whole.

The standard errors for each condition can be calculated separately but note that both groups have the same standard deviation and sample size.:

$$SE_M = \frac{SD}{\sqrt{N}} = \frac{2.449}{\sqrt{4}} = 1.225$$

The “SE” is a function of the two groups’ individual standard errors. When sample sizes are equal:

$$SE_{DIFF} = \sqrt{SE_1^2 + SE_2^2} = \sqrt{1.225^2 + 1.225^2} = 1.732$$

This value is important for both the significance test and the confidence interval. [Importantly, the computation of the standard error of the difference is more complex for unequal sample sizes.]

This section provides a confidence interval around (centered on) the Mean Difference (”Diff”). Calculation requires the appropriate critical value. Specifically, the *t* statistic (with 6 *df*) that has a probability of .05 equals 2.447. As a result:

$$CI_{DIFF} = M_{DIFF} \pm (t_{CRITICAL})(SE_{DIFF})$$
$$CI_{DIFF} = 4 \pm (2.447)(1.732)$$

Thus, the researcher estimates that the true population mean difference is somewhere between -.238 and 8.238 (knowing that the estimate could be incorrect).

The pooled (or weighted average) Std. Deviation of the groups can be determined from the group descriptive statistics:

$$SD_{WITHIN} = \sqrt{\frac{(SD_1^2)(df_1) + (SD_2^2)(df_2)}{df_1 + df_2}} = \sqrt{\frac{(2.449^2)(3) + (2.449^2)(3)}{3 + 3}}$$
$$= 2.449$$

Cohen’s “d” provides a standardized effect size for the difference between the two means:

$$d = \frac{M_{DIFF}}{SD_{WITHIN}} = \frac{4.000}{2.449} = 1.633$$

The “t”, “df”, and “p” columns provide the results of the statistical significance test. First, *t* provides the standardized statistic for the mean difference:

$$t = \frac{M_{DIFF}}{SE_{DIFF}} = \frac{4.000}{1.732} = 2.309$$

The *t* statistic follows a non-normal (studentized or *t*) distribution that depends on degrees of freedom. Here, *df* = N – 2 = 8 – 2 = 6. A *t* with 6 df that equals 2.309 has a two-tailed probability (*p*) of .060, a finding that is not statistically significant.

OneWay ANOVA

```
> ### Descriptive Statistics

> (Outcome ~ Factor) |> describeMoments()

Summary Statistics for the Data
             N       M      SD    Skew    Kurt
Level1   4.000   2.000   2.449   0.544  -2.944
Level2   4.000   6.000   2.449   0.544  -2.944
Level3   4.000   7.000   2.449  -0.544  -2.944

> ### Inferential Statistics

> (Outcome ~ Factor) |> describeEffect()

Source Table for the Model
             SS      df      MS
Between  56.000   2.000  28.000
Within   54.000   9.000   6.000

> (Outcome ~ Factor) |> testEffect()

Hypothesis Test for the Model
             F     df1     df2       p
Factor   4.667   2.000   9.000   0.041

> (Outcome ~ Factor) |> estimateEffect()

Proportion of Variance Accounted For by the Model
           Est      LL      UL
Factor   0.509   0.016   0.665
```

These values of the group statistics are calculated separately for each group. They are not identical to the values obtained from analyzing the variable as a whole.

A grand mean can be determined by taking the weighted average of all of the group means:

$$M_{TOTAL} = \frac{\sum n(M_{GROUP})}{N} = \frac{4(2) + 4(6) + 4(7)}{4 + 4 + 4} = 5.000$$

"Between" statistics are a function of the differences among the groups:

$$SS_{BETWEEN} = \sum n(M_{GROUP} - M_{TOTAL})^2$$
$$SS_{BETWEEN} = 4(2-5)^2 + 4(6-5)^2 + 4(7-5)^2 = 56.000$$

The degrees of freedom ("df") are a function of the number of groups:

$$df_{BETWEEN} = \#groups - 1 = 2$$

The "Mean Square" is the ratio of the "Sum of Squares" to the "df":

$$MS_{BETWEEN} = \frac{SS_{BETWEEN}}{df_{BETWEEN}} = \frac{56.000}{2} = 28.000$$

"Within" statistics are a function of the within group variabilities. Because SS for each group equals 2.00 (*SS = SD² x df*):

$$SS_{WITHIN} = SS_1 + SS_2 + SS_3 = 18.000 + 18.000 + 18.000 = 54.000$$

The degrees of freedom ("df") are a function of the number of people in each group:

$$df_{WITHIN} = df_1 + df_2 + df_3 = 9$$

The "Mean Square" is the ratio of the "Sum of Squares" to the "df":

$$MS_{WITHIN} = \frac{SS_{WITHIN}}{df_{WITHIN}} = \frac{54.000}{9} = 6.000$$

The "η²" statistic is a ratio of the between group and the total group variability ("Sum of Squares") estimates:

$$\eta^2 = \frac{SS_{BETWEEN}}{SS_{TOTAL}} = \frac{SS_{BETWEEN}}{SS_{BETWEEN} + SS_{WITHIN}}$$
$$\eta^2 = \frac{56.000}{56.000 + 54.000} = 0.509$$

Thus, 50.9% of the total variability among all of the scores in the study is accounted for by group membership.

The "F" statistic is a ratio of the between and within group variance estimates:

$$F = \frac{MS_{BETWEEN}}{MS_{WITHIN}} = \frac{28.000}{6.000} = 4.667$$

An *F* with 2 and 9 *df* that equals 4.667 has a two-tailed probability (*p*) of .041, a statistically significant finding.

Post Hoc Comparisons

```
> ### Descriptive Statistics

> (Outcome ~ Factor) |> describeMoments()

Summary Statistics for the Data
             N       M      SD    Skew    Kurt
Level1   4.000   2.000   2.449   0.544  -2.944
Level2   4.000   6.000   2.449   0.544  -2.944
Level3   4.000   7.000   2.449  -0.544  -2.944

> ### Inferential Statistics

> (Outcome ~ Factor) |> estimatePosthoc()

Confidence Intervals for the Posthoc Mean Differences
                    Diff      SE      df      LL      UL
Level1 v Level2    4.000   1.732   9.000  -0.836   8.836
Level1 v Level3    5.000   1.732   9.000   0.164   9.836
Level2 v Level3    1.000   1.732   9.000  -3.836   5.836

> (Outcome ~ Factor) |> testPosthoc()

Hypothesis Tests for the Posthoc Mean Differences
                    Diff      SE      df       t       p
Level1 v Level2    4.000   1.732   9.000   2.309   0.106
Level1 v Level3    5.000   1.732   9.000   2.887   0.043
Level2 v Level3    1.000   1.732   9.000   0.577   0.835

> (Outcome ~ Factor) |> standardizePosthoc()

Confidence Intervals for the Posthoc Standardized Mean Differences
                       d      SE      LL      UL
Level1 v Level2    1.633   0.943  -0.215   3.481
Level1 v Level3    2.041   1.007   0.068   4.015
Level2 v Level3    0.408   0.825  -1.209   2.025
```

These values of the group statistics are calculated separately for each group. They are not identical to the values obtained from analyzing the variable as a whole.

Mean Difference (“Diff”) is the difference between the means for the two listed groups.

These “Standard Errors” are for the difference between the two group means. The values are a function of the MS_{WITHIN} (from the ANOVA) and the sample sizes:

$$SE_{DIFF} = \sqrt{\left(\frac{MS_{WITHIN}}{n_{GROUP}}\right) + \left(\frac{MS_{WITHIN}}{n_{GROUP}}\right)}$$

$$SE_{DIFF} = \sqrt{\left(\frac{6}{4}\right) + \left(\frac{6}{4}\right)} = 1.732$$

In this case, because all groups are of the same size, the standard error for each comparison is the same.

This section provides confidence intervals around (centered on) the Mean Differences. Calculation requires the appropriate critical value. Specifically, the HSD statistic (with 2 $df_{BETWEEN}$ and 9 df_{WITHIN}) that has a probability of .05 equals 3.068. For the first comparison in the example:

$$CI_{DIFF} = M_{DIFF} \pm (HSD_{CRITICAL})(SE_{DIFF})$$
$$CI_{DIFF} = 4.000 \pm (2.792)(1.732)$$

Thus, the estimates that the true population mean difference is somewhere between -8.836 and 0.836 (knowing that the estimate could be incorrect).

The “t” column provides an HSD value that is conceptually similar to a *t* statistic in that it is a function of the “Diff” and the “SE”. For the first comparison in the example:

$$HSD = \frac{M_2 - M_1}{SE_{DIFF}} = \frac{4.000}{1.732} = 2.309$$

The “p” column provides the probability of the HSD statistic. An HSD of 2.309 (with 2 $df_{BETWEEN}$ and 9 df_{WITHIN} like in the ANOVA source table) has a two-tailed

The pooled (or weighted average) SD of the groups can be determined from the group descriptive statistics:

$$SD_{WITHIN} = \sqrt{\frac{(2.449^2)(3) + (2.449^2)(3)}{3 + 3}} = 2.449$$

Cohen’s “d” provides a standardized effect size for the difference between the two means:

$$d = \frac{M_{DIFF}}{SD_{WITHIN}} = \frac{4.000}{2.449} = 1.633$$

Repeated Measures ANOVA

```
> ### Descriptive Statistics

> (RepeatedData) |> describeMoments()

Summary Statistics for the Data
               N        M       SD     Skew     Kurt
Outcome1   4.000    2.000    2.449    0.544   -2.944
Outcome2   4.000    6.000    2.449    0.544   -2.944

> ### Inferential Statistics

> (RepeatedData) |> describeEffect()

Source Table for the Model
              SS       df       MS
Subjects  27.000    3.000    9.000
Measures  32.000    1.000   32.000
Error      9.000    3.000    3.000

> (RepeatedData) |> testEffect()

Hypothesis Test for the Model
               F      df1      df2        p
Measures  10.667    1.000    3.000    0.047

> (RepeatedData) |> estimateEffect()

Proportion of Variance Accounted For by the Model
             Est       LL       UL
Measures   0.780    0.011    0.870
```

These descriptive statistics are calculated separately for each level or condition. Because sample sizes are equal, a grand mean can be determined by averaging these two level means:

$$M_{TOTAL} = (M_{LEVEL} + M_{LEVEL})/2 = (2.000 + 6.000)/2 = 4.000$$

Between-subjects error refers to the average differences across the participants of the study. This Sum of Squares is not easily determined from the summary statistics output, but rather from the data (and the calculations are therefore not shown here). However:

$$df_{SUBJECTS} = \#subjects - 1 = 3$$

The "Mean Square" is the usual ratio of the Sum of Squares to the degrees of freedom.

The statistics for the effect ("Measures") are functions of the means of the levels or conditions and the sample sizes:

$$SS_{EFFECT} = \sum n_{LEVEL}(M_{LEVEL} - M_{TOTAL})^2$$
$$SS_{EFFECT} = 4(2.0 - 4.0)^2 + 4(6.0 - 4.0)^2 = 32.000$$
$$df_{EFFECT} = \#levels - 1 = 1$$

The "Mean Square" is the usual ratio of the Sum of Squares to the degrees of freedom.

$$MS_{EFFECT} = \frac{SS_{EFFECT}}{df_{EFFECT}} = \frac{32.000}{1} = 32.000$$

The within-subjects "Error" is a function of variabilities of the separate levels or conditions of the factor and the "between-subjects error" given above. Because SS for each level can be determined (*SS* = *SD*² *x df*, which equals 18.000 for each of the two outcomes):

$$SS_{ERROR} = SS_1 + SS_2 - SS_{SUBJECTS}$$
$$SS_{ERROR} = 18.000 + 18.000 - 27.000 = 9.000$$
$$df_{ERROR} = df_1 + df_2 - df_{SUBJECTS} = 3 + 3 - 3 = 3.000$$

The "Mean Square" is the usual ratio of the Sum of Squares to the degrees of freedom.

The partial "η^2" statistic is a ratio of the effect and the total group variability ("Sum of Squares") estimates:

$$Partial\ \eta^2 = \frac{SS_{EFFECT}}{SS_{EFFECT} + SS_{ERROR}}$$
$$Partial\ \eta^2 = \frac{32.000}{32.000 + 9.000} = 0.780$$

Thus, 78.0% of the variability in Outcome scores (after removing individual differences) is accounted for by the repeated measures.

The "F" statistic is a ratio of the effect and within-subjects error variance estimates:

$$F = \frac{MS_{EFFECT}}{MS_{ERROR}} = \frac{32.000}{3.000} = 10.667$$

An *F* with 1 and 3 *df* that equals 10.667 has a two-tailed probability of .047, a statistically significant finding.

Factorial ANOVA

```
> ### Descriptive Statistics

> (Outcome ~ FactorA) |> describeMoments(by

Summary Statistics for the Data: B1
        N        M       SD     Skew     Kurt
A1  4.000    2.000    2.449    0.544   -2.944
A2  4.000    7.000    2.449   -0.544   -2.944

Descriptive Statistics for the Data: B2
        N        M       SD     Skew     Kurt
A1  4.000    6.000    2.449    0.544   -2.944
A2  4.000    5.000    2.449    0.544   -2.944

> ### Inferential Statistics

> (Outcome ~ FactorA) |> describeFactorial(by =

Source Table for the Model
                    SS      df      MS
Factor           4.000   1.000   4.000
Blocks          16.000   1.000  16.000
Factor:Blocks   36.000   1.000  36.000
Residual        72.000  12.000   6.000

> (Outcome ~ FactorA) |> testFactorial(by = Fact

Hypothesis Tests for the Model
                     F     df1      df2       p
Factor           0.667   1.000   12.000   0.430
Blocks           2.667   1.000   12.000   0.128
Factor:Blocks    6.000   1.000   12.000   0.031

> (Outcome ~ FactorA) |> estimateFactorial(by = FactorB)

Proportion of Variance
                  Est
Factor          0.053
Blocks          0.182
Factor:Blocks   0.333
```

These descriptive statistics are calculated separately for each group or condition. A level (marginal) mean can be determined by taking the weighted average of the appropriate group means. For example, the marginal mean for Level 1 of Factor A:

$$M_{LEVEL} = \frac{\sum n(M_{GROUP})}{n_{LEVEL}} = \frac{4(2)+4(7)}{8} = 4.500$$

A grand mean can be determined by taking the weighted average of all of the group means:

$$M_{TOTAL} = \frac{\sum n(M_{GROUP})}{N} = \frac{4(2)+4(7)+4(6)+4(5)}{4+4+4+4} = 5.000$$

Overall, all of the between-group variability is a function of the group means and sample sizes:

$$SS_{MODEL} = \sum n(M_{GROUP} - M_{TOTAL})^2 = 4(2-5)^2 + 4(7-5)^2 + 4(6-5)^2 + 4(5-5)^2 = 56.000$$
$$df_{MODEL} = \#groups - 1 = 3$$

The statistics for the effects of "Factor A" and Factor B" are functions of the level (marginal) means and sample sizes. For "Factor B":

$$SS_{FACTORB} = \sum n(M_{LEVEL} - M_{TOTAL})^2 = 8(4.5-5)^2 + 8(5.5-5)^2 = 4.000$$
$$df_{FACTORB} = \#levels - 1 = 2 - 1 = 1$$

The "Factor A * Factor B" (interaction) statistics reflect the between- group variability not accounted for by the factors:

$$SS_{INTERACTION} = SS_{MODEL} - SS_{FACTORA} - SS_{FACTORB} == 56.000 - 4.000 - 16.000 = 36.000$$
$$df_{INTERACTION} = df_A \times df_B = 1$$

"Residual" (error) statistics are a function of the within group variabilities. Because SS for each group can be determined ($SS = SD^2 \times df$):

$$SS_{ERROR} = SS_1 + SS_2 + SS_3 + SS_4 = 18.000 + 18.000 + 18.000 + 18.000 = 72.000$$
$$df_{ERROR} = df_1 + df_2 + df_3 + df_4 = 12$$

The "η²p" statistic is a ratio of the effect and the effect plus residual variability. For "Factor B":

$$\eta^2 p = \frac{SS_{FACTOR}}{SS_{FACTOR} + SS_{ERROR}} = \frac{16.000}{16.000 + 72.000} = 0.182$$

Thus, 18.2% of the variability among the scores is accounted for by Factor B.

The "F" statistic is a ratio of the effect and within group (error) variance estimates. For "Factor B":

$$F_{FACTORB} = \frac{MS_{FACTORB}}{MS_{ERROR}} = \frac{16.0}{6.0} = 2.667$$

An F with 1 and 12 df that equals 2.667 has a two-tailed probability of .128, which is not statistically significant.