Human-Computer Interaction

# Statistics III

## Intermediate Inferential Statistics

Professor Bilge Mutlu

# Today's Agenda

- *Contingency analysis*
- *Intermediate inferential statistics*
- Updated format: *Lecture* ➜ *Tutorial* ➜ *Q&A* ⟲

# *What about when we have nominal output variables?*

| | **Nominal** | **Categorical (2+)** | **Ordinal** | **Quantitative Discrete** | **Quantitative Non-Normal** | **Quantitative Normal** |
|---|---|---|---|---|---|---|
| **Nominal** | Chi-squared, Fisher's | Chi-squared | Chi-squared Trend, Mann-Whitney | Mann-Whitney | Mann-Whitney, log-rank† | Student's *t* |
| **Categorical (2+)** | Chi-squared | Chi-squared | Kruskal-Wallis‡ | Kruskal-Wallis‡ | Kruskal-Wallis‡ | ANOVA†† |
| **Ordinal** | Chi-squared Trend, Mann-Whitney | ** | Spearman rank | Spearman rank | Spearman rank | Spearman rank, linear regression* |
| **Quantitative Discrete** | Logistic regression | ** | ** | Spearman rank | Spearman rank | Spearman rank, linear regression |
| **Quantitative Non-Normal** | Logistic regression | ** | ** | ** | Plot data-Pearson, Spearman rank | Plot data-Pearson, Spearman rank & linear regression |
| **Quantitative Normal** | Logistic regression | ** | ** | ** | Linear regression* | Pearson, linear regression |

*Contingency analysis*

In contingency analysis, we calculate a chi-squared, $X^2$, statistic:

$$X^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

$X^2$ is the Pearson's test statistic, $n$ is the number of observations, $O_i$ is the observed frequency, and $E_i$ is the expected frequency.

Data is summarized in a **contingency table** that cross-tabulates multivariate frequency distributions of variables in a matrix format.

| Robot | Reported Gaze Cue |
|---|---|
| Robovie | Yes |
| Geminoid | Yes |
| Robovie | Yes |
| Geminoid | No |
| Robovie | Yes |
| Geminoid | No |
| Geminoid | No |
| Robovie | No |
| Robovie | Yes |
| Geminoid | No |
| Robovie | Yes |
| Geminoid | No |
| Robovie | No |

```
            Reported.Gaze.Cue
Robot       No Yes
  Geminoid  10   3
  Robovie    3  10
```

*Chi-squared test in R*

```
gaze <- read.table('robot-gaze.csv', sep=",", header=TRUE)
chisq.test(table(gaze))
```

```
Pearson's Chi-squared test with Yates' continuity correction

data:  table(gaze)
X-squared = 5.5385, df = 1, p-value = 0.0186
```

## *Chi-squared test in JMP*

Analyze > Fit X by Y

| N | DF | -LogLike | RSquare (U) |
| --- | --- | --- | --- |
| 26 | 1 | 3.9765190 | 0.2207 |

| Test | ChiSquare | Prob>ChiSq |
| --- | --- | --- |
| Likelihood Ratio | 7.953 | 0.0048* |
| Pearson | 7.538 | 0.0060* |

| Fisher's Exact Test | Prob | Alternative Hypothesis |
| --- | --- | --- |
| Left | 0.9994 | Prob(Robot=Robovie) is greater for Reported Gaze Cue=No than Yes |
| Right | 0.0085* | Prob(Robot=Robovie) is greater for Reported Gaze Cue=Yes than No |
| 2-Tail | 0.0169* | Prob(Robot=Robovie) is different across Reported Gaze Cue |

# *Tutorial, Q&A*

# *Multifactorial analysis*

| | Nominal | Categorical (2+) | Ordinal | Quantitative Discrete | Quantitative Non-Normal | Quantitative Normal |
|---|---|---|---|---|---|---|
| **Nominal** | Chi-squared, Fisher's | Chi-squared | Chi-squared Trend, Mann-Whitney | Mann-Whitney | Mann-Whitney, log-rank† | Student's *t* |
| **Categorical (2+)** | Chi-squared | Chi-squared | Kruskal-Wallis‡ | Kruskal-Wallis‡ | Kruskal-Wallis‡ | ANOVA†† |
| **Ordinal** | Chi-squared Trend, Mann-Whitney | ** | Spearman rank | Spearman rank | Spearman rank | Spearman rank, linear regression* |
| **Quantitative Discrete** | Logistic regression | ** | ** | Spearman rank | Spearman rank | Spearman rank, linear regression |
| **Quantitative Non-Normal** | Logistic regression | ** | ** | ** | Plot data-Pearson, Spearman rank | Plot data-Pearson, Spearman rank & linear regression |
| **Quantitative Normal** | Logistic regression | ** | ** | ** | Linear regression* | Pearson, linear regression |

*Consider this dataset. Can we use multiple t-tests?*

| Participant ID | Group | Time | Coding |
|---|---|---|---|
| **Participant 01** | Standard | 245 | 0 |
| **Participant 02** | Standard | 236 | 0 |
| **Participant 03** | Standard | 321 | 0 |
| **Participant 04** | Standard | 212 | 0 |
| **Participant 05** | Standard | 267 | 0 |
| **Participant 06** | Standard | 334 | 0 |
| **Participant 07** | Standard | 287 | 0 |
| **Participant 08** | Standard | 259 | 0 |
| **Participant 09** | Prediction | 246 | 1 |
| **Participant 10** | Prediction | 213 | 1 |
| **Participant 11** | Prediction | 265 | 1 |
| **Participant 12** | Prediction | 189 | 1 |
| **Participant 13** | Prediction | 201 | 1 |
| **Participant 14** | Prediction | 197 | 1 |
| **Participant 15** | Prediction | 289 | 1 |
| **Participant 16** | Prediction | 224 | 1 |
| **Participant 17** | Speech-based dictation | 178 | 2 |
| **Participant 18** | Speech-based dictation | 289 | 2 |
| **Participant 19** | Speech-based dictation | 222 | 2 |
| **Participant 20** | Speech-based dictation | 189 | 2 |
| **Participant 21** | Speech-based dictation | 245 | 2 |
| **Participant 22** | Speech-based dictation | 311 | 2 |
| **Participant 23** | Speech-based dictation | 267 | 2 |
| **Participant 24** | Speech-based dictation | 197 | 2 |

$H_0 : \mu_1 = \mu_2 = \mu_3 \, , \, \alpha = .05$

3 pairwise tests: $(1 - \alpha)^3 = 0.86$

Reject $H_0$ when $p < 0.14$ instead of $p < 0.05$

➜ **Type I error** (reject $H_0$ when it is true)

*What are errors in hypothesis testing?*

**Type I error:** Rejecting $H_0$ when it is true

**Type II error:** Accepting $H_0$ when it is false

**Type III error:** Correctly rejecting $H_0$ for the wrong reason

| | $H_0$ **Is true** | $H_1$ **Is true** |
|---|---|---|
| Fail to reject $H_0$ | *Right decision* | *Wrong decision*<br>**Type II error**<br>(False negative) |
| Reject $H_0$ | Wrong decision<br>**Type I error**<br>(False positive) | *Right decision* |

*Analysis of Variance (ANOVA)*

**Definition:** Analysis of variance (ANOVA) is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among group means in a sample.[1]

**Procedures:**

1. One-way (single factor)
2. Two-way (two factors)
3. Multi-way (multiple factors)

**Models:**

1. Fixed effects (between)
2. Random effects (within)
3. Mixed effects (mixed)

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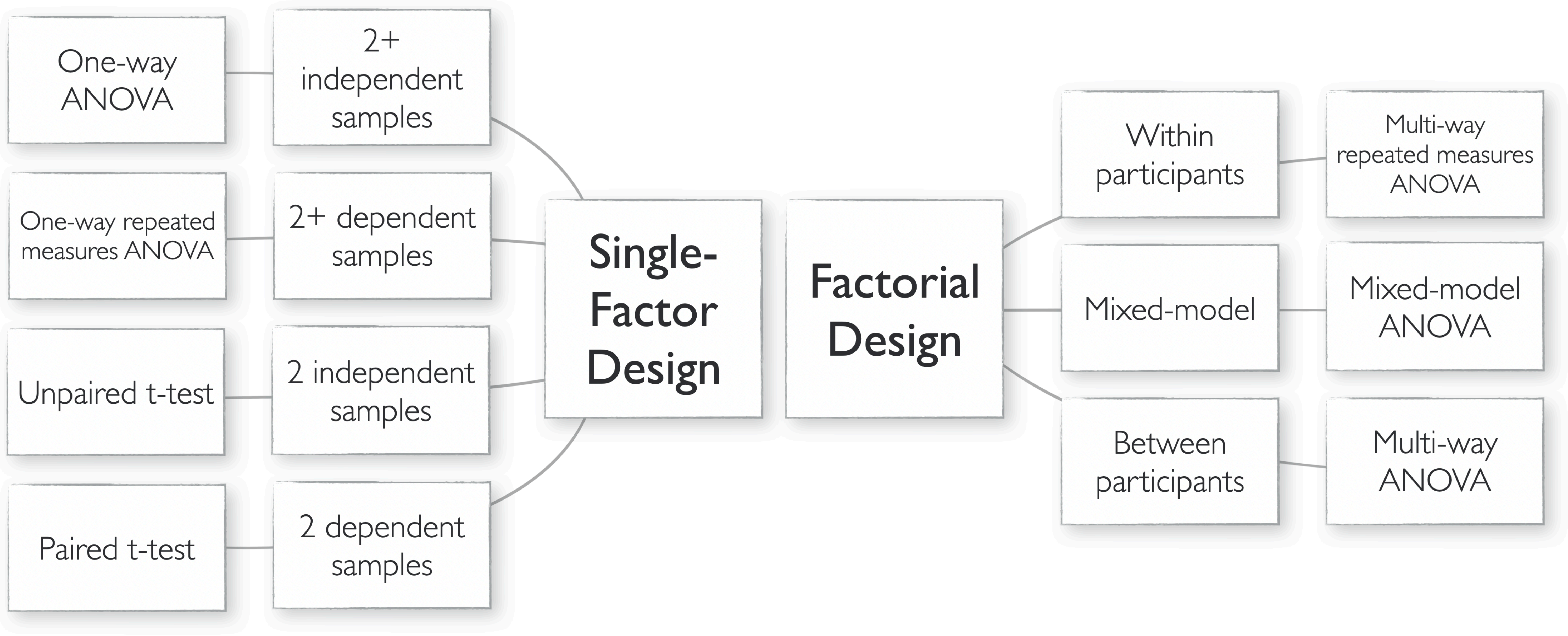
[1] Wikipedia: ANOVA

# *How do we choose among these procedures?*



# *How do we conduct ANOVA?*

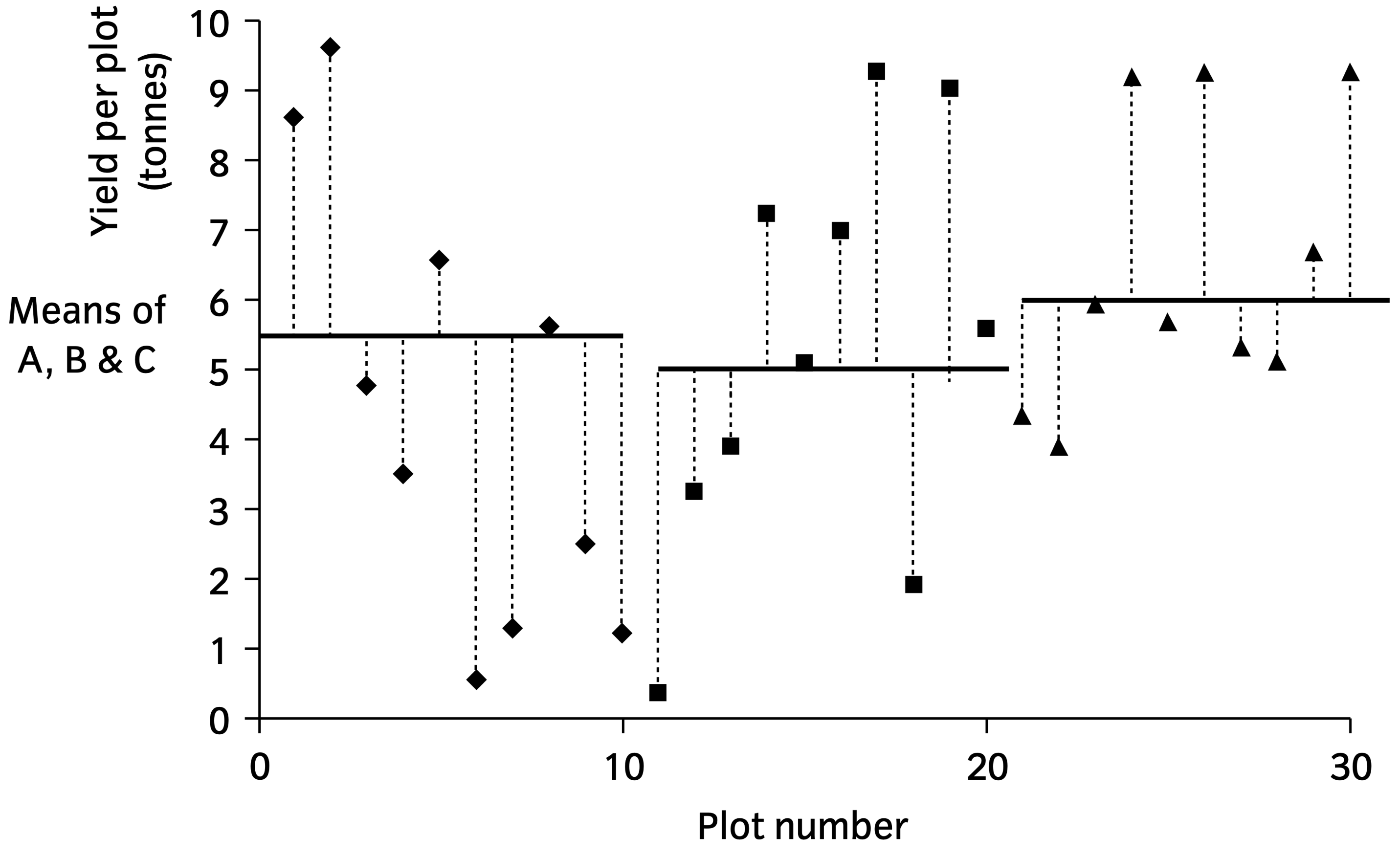
We calculate the *F*-statistic.

$$F = \frac{\sigma_{explained}}{\sigma_{unexplained}} = \frac{SS_{treatment}/(k-1)}{SS_{error}/(n-k)}$$

$$F = \frac{\sum n_i(M_i - \sum(Mi/k))^2/(k-1)}{\sum\sum(X_{it} - M_i)^2/(n-k)}$$

$k$: number of populations

$n$: sample size



*One-way ANOVA in R*

```
model = aov(Time~Group,data=data)
summary(model)
            Df Sum Sq Mean Sq F value Pr(>F)
Group        2   7842    3921   2.174  0.139
Residuals   21  37880    1804
```

*One-way ANOVA in JMP*

# Analyze > Fit X by Y

## Oneway Anova

### Summary of Fit

| | |
|---|---|
| Rsquare | 0.171518 |
| Adj Rsquare | 0.092615 |
| Root Mean Square Error | 42.47149 |
| Mean of Response | 245.125 |
| Observations (or Sum Wgts) | 24 |

### Analysis of Variance

| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Group | 2 | 7842.250 | 3921.13 | 2.1738 | 0.1387 |
| Error | 21 | 37880.375 | 1803.83 | | |
| C. Total | 23 | 45722.625 | | | |

### Means for Oneway Anova

| Level | Number | Mean | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|
| Prediction | 8 | 228.000 | 15.016 | 196.77 | 259.23 |
| Speech-based dictation | 8 | 237.250 | 15.016 | 206.02 | 268.48 |
| Standard | 8 | 270.125 | 15.016 | 238.90 | 301.35 |

Std Error uses a pooled estimate of error variance

*Are we done?*

The ANOVA analysis only told us whether the *methods* had a significant effect on *time*, not which method is more effective.

We can make two types of *pairwise* comparisons:

1. *A priori* comparisons (planned contrasts)

   $H_0\colon \mu_1 = \mu_2;\ H_1\colon \mu_1 > \mu_2$

2. *Post hoc* comparisons (exploratory pairwise tests)

   Test $\mu_1$ vs $\mu_2$, $\mu_1$ vs $\mu_3$, $\mu_2$ vs $\mu_3$

## *A priori comparisons in R*

```
levels(data$Group)
comparison = c(1,-1,0)
mat = cbind(comparison)
contrasts(data$Group) <- mat
model = aov(Time~Group, data= data)
summary.aov(model, split = list(Group=list("mu1 vs mu2"=1)))
```

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Group                2   7842    3921   2.174  0.139
  Group: mu1 vs mu2  1    342     342   0.190  0.668
Residuals           21  37880    1804
```

# *A prior comparisons in JMP*

## Compare Means > Each pair, Student's t

### Means Comparisons

#### Comparisons for each pair using Student's t

**Confidence Quantile**

| t | Alpha |
|---|---|
| 2.07961 | 0.05 |

**LSD Threshold Matrix**

Abs(Dif)-LSD

| | Standard | Speech-based dictation | Prediction |
|---|---|---|---|
| Standard | -44.162 | -11.287 | -2.037 |
| Speech-based dictation | -11.287 | -44.162 | -34.912 |
| Prediction | -2.037 | -34.912 | -44.162 |

Positive values show pairs of means that are significantly different.

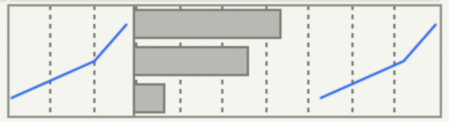
**Connecting Letters Report**

| Level | | Mean |
|---|---|---|
| Standard | A | 270.12500 |
| Speech-based dictation | A | 237.25000 |
| Prediction | A | 228.00000 |

Levels not connected by same letter are significantly different.

**Ordered Differences Report**

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| Standard | Prediction | 42.12500 | 21.23574 | -2.0371 | 86.28715 | 0.0605 |
| Standard | Speech-based dictation | 32.87500 | 21.23574 | -11.2871 | 77.03715 | 0.1365 |
| Speech-based dictation | Prediction | 9.25000 | 21.23574 | -34.9121 | 53.41215 | 0.6676 |



## *Post hoc comparison in R*

```
TukeyHSD(model)

  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Time ~ Group, data = data)

$Group
                                     diff       lwr      upr     p adj
Speech-based dictation-Prediction   9.250 -44.27619 62.77619 0.9011856
Standard-Prediction                42.125 -11.40119 95.65119 0.1409733
Standard-Speech-based dictation    32.875 -20.65119 86.40119 0.2896872
```

# *Post hoc comparison in JMP*

## Compare Means > All Pairs, Tukey HSD

### Comparisons for all pairs using Tukey-Kramer HSD

#### Confidence Quantile

| q* | Alpha |
|---|---|
| 2.52057 | 0.05 |

#### HSD Threshold Matrix

Abs(Dif)-HSD

| | Standard | Speech-based dictation | Prediction |
|---|---|---|---|
| Standard | -53.526 | -20.651 | -11.401 |
| Speech-based dictation | -20.651 | -53.526 | -44.276 |
| Prediction | -11.401 | -44.276 | -53.526 |

Positive values show pairs of means that are significantly different.

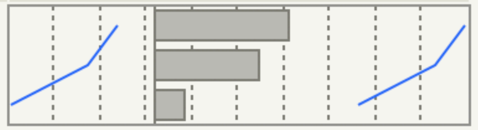
#### Connecting Letters Report

| Level | | Mean |
|---|---|---|
| Standard | A | 270.12500 |
| Speech-based dictation | A | 237.25000 |
| Prediction | A | 228.00000 |

Levels not connected by same letter are significantly different.

#### Ordered Differences Report

| Level | - Level | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|---|---|---|---|---|---|---|
| Standard | Prediction | 42.12500 | 21.23574 | -11.4012 | 95.65119 | 0.1410 |
| Standard | Speech-based dictation | 32.87500 | 21.23574 | -20.6512 | 86.40119 | 0.2897 |
| Speech-based dictation | Prediction | 9.25000 | 21.23574 | -44.2762 | 62.77619 | 0.9012 |



# *What if we had a within-participants design?*

| Participant ID | Group | Time | Coding |
|---|---|---|---|
| **Participant 01** | Standard | 245 | 0 |
| **Participant 01** | Prediction | 246 | 1 |
| **Participant 01** | Speech-based dictation | 178 | 2 |
| **Participant 02** | Standard | 236 | 0 |
| **Participant 02** | Prediction | 213 | 1 |
| **Participant 02** | Speech-based dictation | 289 | 2 |
| **Participant 03** | Standard | 321 | 0 |
| **Participant 03** | Prediction | 265 | 1 |
| **Participant 03** | Speech-based dictation | 222 | 2 |
| **Participant 04** | Standard | 212 | 0 |
| **Participant 04** | Prediction | 189 | 1 |
| **Participant 04** | Speech-based dictation | 189 | 2 |
| **Participant 05** | Standard | 267 | 0 |
| **Participant 05** | Prediction | 201 | 1 |
| **Participant 05** | Speech-based dictation | 245 | 2 |
| **Participant 06** | Standard | 334 | 0 |
| **Participant 06** | Prediction | 197 | 1 |
| **Participant 06** | Speech-based dictation | 311 | 2 |
| **Participant 07** | Standard | 287 | 0 |
| **Participant 07** | Prediction | 289 | 1 |
| **Participant 07** | Speech-based dictation | 267 | 2 |
| **Participant 08** | Standard | 259 | 0 |
| **Participant 08** | Prediction | 224 | 1 |
| **Participant 08** | Speech-based dictation | 197 | 2 |

We conduct a *repeated-measures* or *random-effects* one-way ANOVA

## *Within-participants one-way ANOVA in R*

```
model = aov(Time~Group+Error(Participant.ID/Group), data= data)
summary(model)

Error: Participant.ID
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals  7  19113    2730

Error: Participant.ID:Group
          Df Sum Sq Mean Sq F value Pr(>F)
Group      2   7842    3921   2.925 0.0868 .
Residuals 14  18767    1341
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

# *Within-participants one-way ANOVA in JMP*

*Using the Full Factorial Repeated Measures ANOVA Add-In:*

Add-ins > Repeated Measures > Full-Factorial Design (Mixed Effects)

*For additional options (e.g., comparisons):*

Launch Dialog > Emphasis: Effect Leverage

**Response Time**

**Effect Summary**

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.48879 |
| RSquare Adj | 0.440103 |
| Root Mean Square Error | 36.61292 |
| Mean of Response | 245.125 |
| Observations (or Sum Wgts) | 24 |

**Parameter Estimates**

**Random Effect Predictions**

**REML Variance Component Estimates**

| Random Effect | Var Ratio | Var Component | Std Error | 95% Lower | 95% Upper | Wald p-Value | Pct of Total |
|---|---|---|---|---|---|---|---|
| Participant ID | 0.3456318 | 463.32143 | 514.98022 | -546.0213 | 1472.6641 | 0.3683 | 25.685 |
| Participant ID*Group | | 1340.506 | 506.66363 | 718.52371 | 3334.1618 | <.0001* | 74.315 |
| Total | | 1803.8274 | 592.26174 | 1037.3604 | 3890.013 | | 100.000 |

-2 LogLikelihood = 224.22780502

Note: Total is the sum of the positive variance components.

Total including negative estimates = 1803.8274

**Covariance Matrix of Variance Component Estimates**

Residual is confounded with Participant ID*Group and has been removed.

**Iterations**

**Fixed Effect Tests**

| Source | Nparm | DF | DFDen | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Group | 2 | 2 | 14 | 2.9251 | 0.0868 |

**Effect Details**

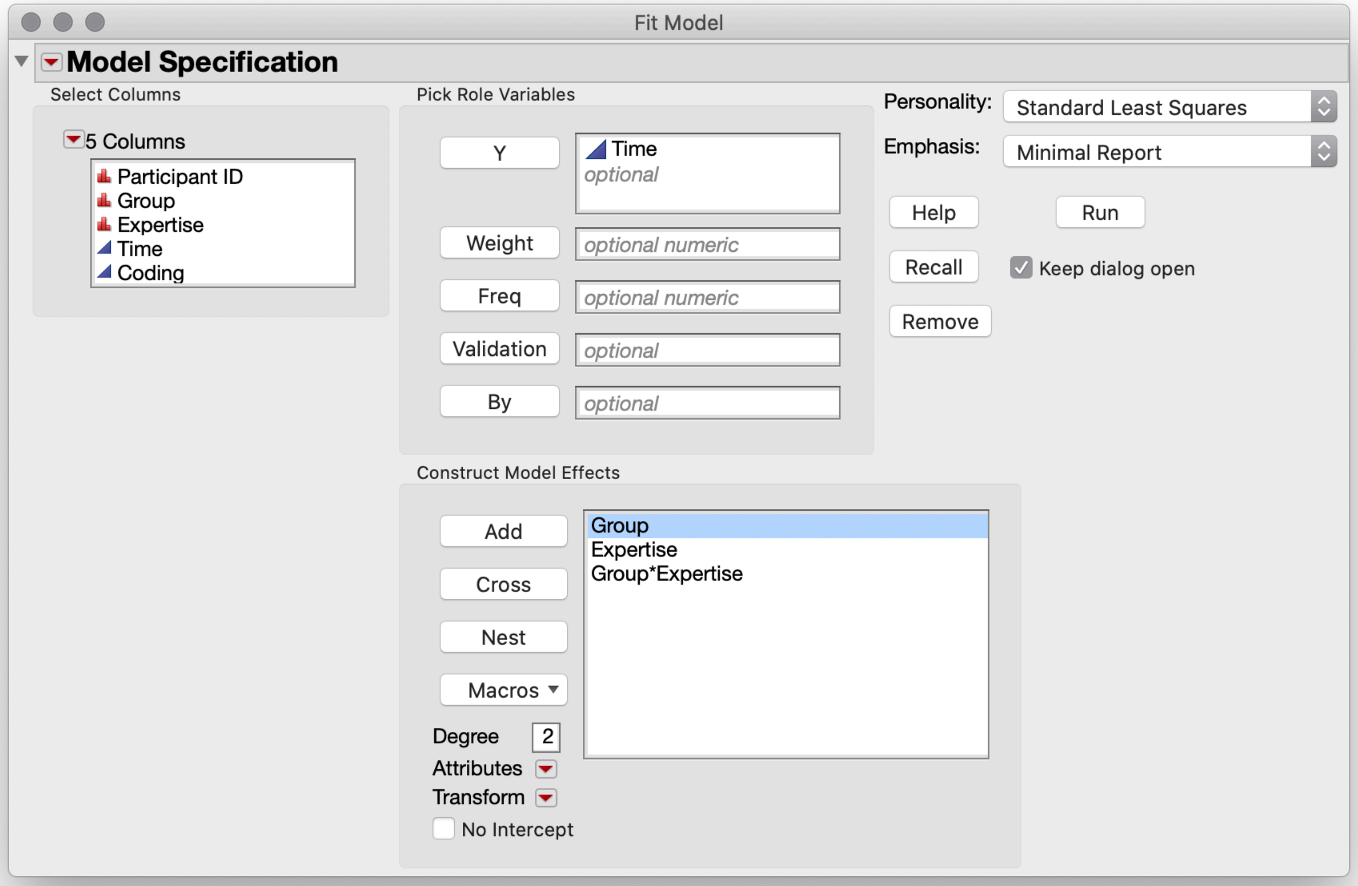
*Between-participants two-way ANOVA in R*

```
model = aov(Time~Group*Expertise, data=data)
summary(model)
```

```
                 Df Sum Sq Mean Sq F value Pr(>F)
Group             2   7842    3921   2.175  0.143
Expertise         1   1395    1395   0.774  0.391
Group:Expertise   2   4030    2015   1.117  0.349
Residuals        18  32455    1803
```

# *Between-participants two-way ANOVA in JMP*

## Analyze > Fit Model




### Summary of Fit

| | |
|---|---|
| RSquare | 0.290171 |
| RSquare Adj | 0.092996 |
| Root Mean Square Error | 42.46257 |
| Mean of Response | 245.125 |
| Observations (or Sum Wgts) | 24 |

### Analysis of Variance

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 5 | 13267.375 | 2653.48 | 1.4716 |
| Error | 18 | 32455.250 | 1803.07 | **Prob > F** |
| C. Total | 23 | 45722.625 | | 0.2477 |

### Parameter Estimates

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 245.125 | 8.667635 | 28.28 | <.0001* |
| Group[Prediction] | -17.125 | 12.25789 | -1.40 | 0.1794 |
| Group[Speech-based dictation] | -7.875 | 12.25789 | -0.64 | 0.5287 |
| Expertise[Expert] | -7.625 | 8.667635 | -0.88 | 0.3906 |
| Group[Prediction]*Expertise[Expert] | -14.625 | 12.25789 | -1.19 | 0.2483 |
| Group[Speech-based dictation]*Expertise[Expert] | 16.875 | 12.25789 | 1.38 | 0.1855 |

### Effect Tests

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Group | 2 | 2 | 7842.2500 | 2.1747 | 0.1426 |
| Expertise | 1 | 1 | 1395.3750 | 0.7739 | 0.3906 |
| Group*Expertise | 2 | 2 | 4029.7500 | 1.1175 | 0.3488 |

# *Within-participants two-way ANOVA in R*

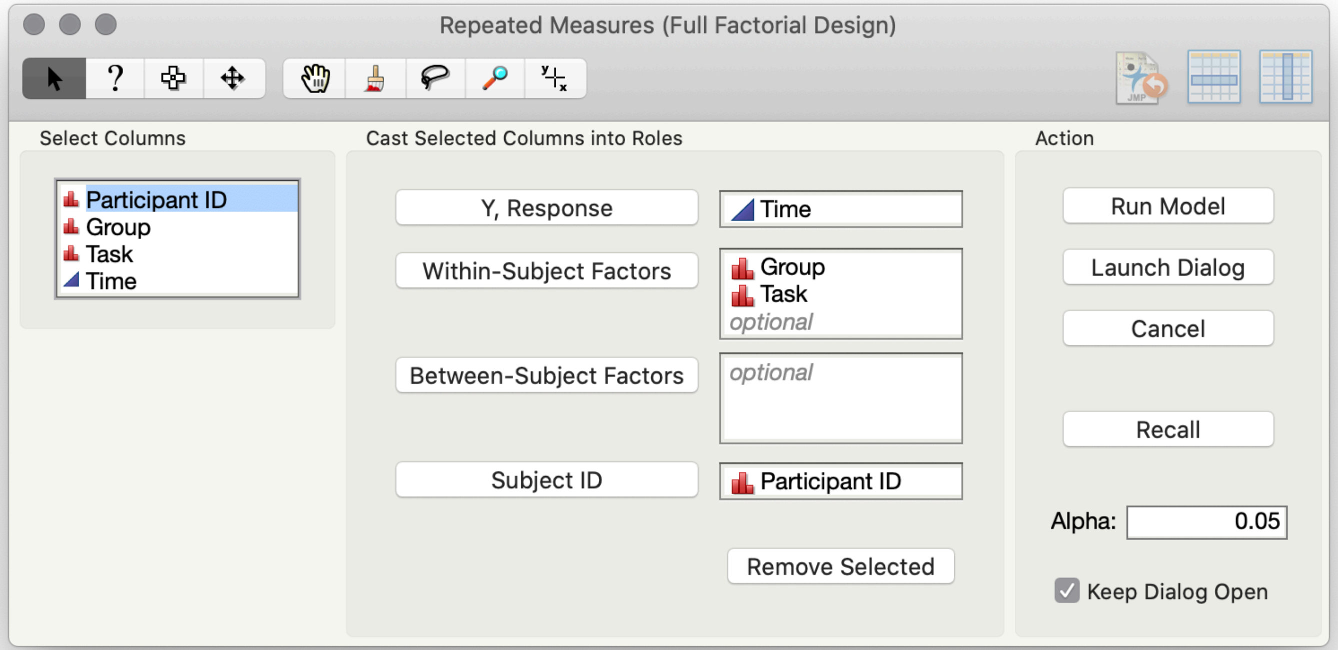
```
model = aov(Time~(Group*Task)+Error(Participant.ID/(Group*Task)), data= data)
summary(model)
```

| Participant ID | Group | Task | Time |
|---|---|---|---|
| Participant 01 | Standard | Complex | 285 |
| Participant 01 | Prediction | Complex | 160 |
| Participant 01 | Speech-based dictation | Complex | 201 |
| Participant 01 | Standard | Simple | 272 |
| Participant 01 | Prediction | Simple | 191 |
| Participant 01 | Speech-based dictation | Simple | 161 |
| Participant 02 | Standard | Complex | 189 |
| Participant 02 | Prediction | Complex | 250 |
| Participant 02 | Speech-based dictation | Complex | 178 |
| Participant 02 | Standard | Simple | 247 |
| Participant 02 | Prediction | Simple | 288 |
| Participant 02 | Speech-based dictation | Simple | 180 |
| Participant 03 | Standard | Complex | 233 |
| Participant 03 | Prediction | Complex | 285 |
| Participant 03 | Speech-based dictation | Complex | 225 |
| Participant 03 | Standard | Simple | 200 |
| Participant 03 | Prediction | Simple | 202 |
| Participant 03 | Speech-based dictation | Simple | 162 |

```
Error: Participant.ID
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals  7   7224    1032

Error: Participant.ID:Group
          Df Sum Sq Mean Sq F value Pr(>F)
Group      2   1650   825.2   0.345  0.714
Residuals 14  33441  2388.6

Error: Participant.ID:Task
          Df Sum Sq Mean Sq F value Pr(>F)
Task       1    341   341.3   0.119   0.74
Residuals  7  20055  2865.0

Error: Participant.ID:Group:Task
           Df Sum Sq Mean Sq F value Pr(>F)
Group:Task  2   1845   922.5   0.644   0.54
Residuals  14  20053  1432.3
```

# *Within-participants two-way ANOVA in JMP*

## Add-ins > Repeated Measures > Full-Factorial Design (Mixed Effects)




### Summary of Fit

| | |
|---|---|
| RSquare | 0.397171 |
| RSquare Adj | 0.325405 |
| Root Mean Square Error | 37.84614 |
| Mean of Response | 216.625 |
| Observations (or Sum Wgts) | 48 |

### Parameter Estimates

| Term | Estimate | Std Error | DFDen | t Ratio | Prob>\|t\| |
|---|---|---|---|---|---|
| Intercept | 216.625 | 4.636889 | 7 | 46.72 | <.0001* |
| Group[Prediction] | 1.6875 | 9.976255 | 14 | 0.17 | 0.8681 |
| Group[Speech-based dictation] | -7.875 | 9.976255 | 14 | -0.79 | 0.4431 |
| Task[Complex] | 2.6666667 | 7.725769 | 7 | 0.35 | 0.7401 |
| Group[Prediction]*Task[Complex] | -2.229167 | 7.725311 | 14 | -0.29 | 0.7772 |
| Group[Speech-based dictation]*Task[Complex] | 8.4583333 | 7.725311 | 14 | 1.09 | 0.2920 |

### Random Effect Predictions

### REML Variance Component Estimates

| Random Effect | Var Ratio | Var Component | Std Error | 95% Lower | 95% Upper | Wald p-Value | Pct of Total |
|---|---|---|---|---|---|---|---|
| Participant ID | -0.324559 | -464.875 | 323.07858 | -1098.097 | 168.34739 | 0.1502 | 0.000 |
| Participant ID*Group | 0.3338216 | 478.14286 | 526.34376 | -553.4719 | 1509.7577 | 0.3637 | 20.022 |
| Participant ID*Task | 0.3334123 | 477.55655 | 541.42698 | -583.6208 | 1538.7339 | 0.3778 | 19.998 |
| Participant ID*Group*Task | | 1432.3304 | 541.36999 | 767.74244 | 3562.5512 | <.0001* | 59.980 |
| Total | | 2388.0298 | 687.37698 | 1457.7831 | 4611.3193 | | 100.000 |

-2 LogLikelihood = 455.15548778

Note: Total is the sum of the positive variance components.

Total including negative estimates = 1923.1548

### Covariance Matrix of Variance Component Estimates

Residual is confounded with Participant ID*Group*Task and has been removed.

### Iterations

### Fixed Effect Tests

| Source | Nparm | DF | DFDen | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Group | 2 | 2 | 14 | 0.3455 | 0.7138 |
| Task | 1 | 1 | 7 | 0.1191 | 0.7401 |
| Group*Task | 2 | 2 | 14 | 0.6441 | 0.5400 |

# *Two-way mixed-effects ANOVA in R*

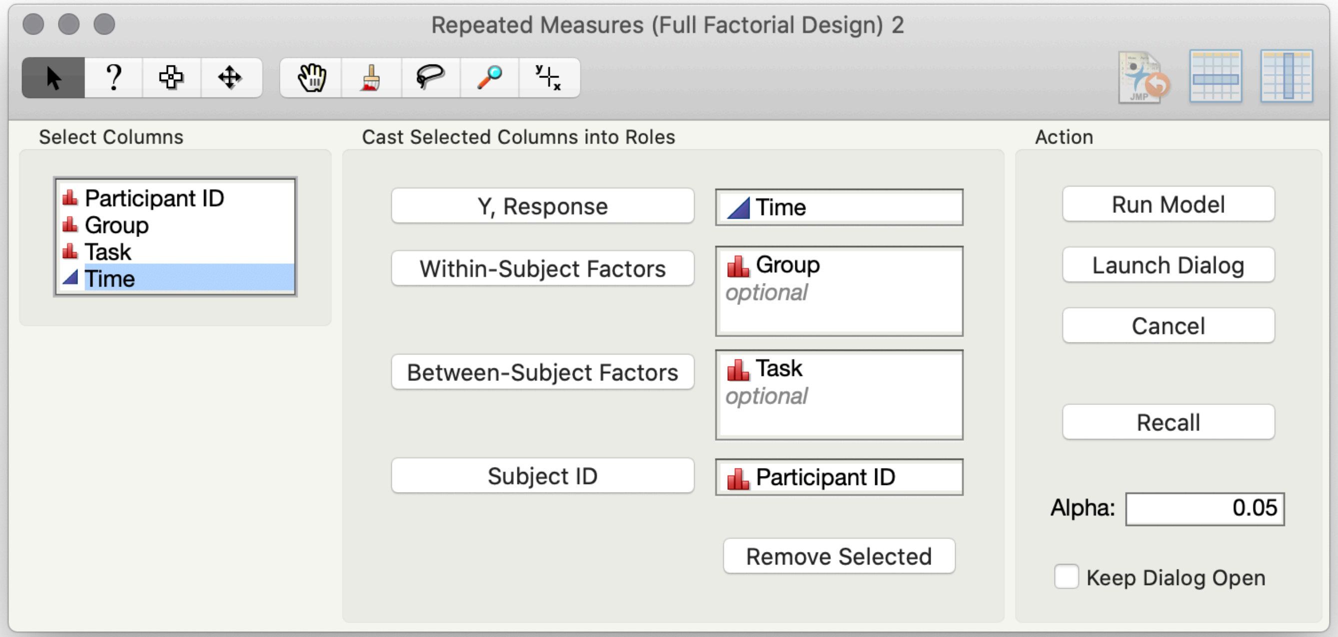
```
model = aov(Time~(Group*Task)+Error(Participant.ID/Group)+Task,data=data)
summary(model)
```

| Participant ID | Group | Task | Time |
|---|---|---|---|
| **Participant 01** | Standard | Complex | 285 |
| **Participant 01** | Prediction | Complex | 160 |
| **Participant 01** | Speech-based dictation | Complex | 201 |
| **Participant 02** | Standard | Simple | 272 |
| **Participant 02** | Prediction | Simple | 191 |
| **Participant 02** | Speech-based dictation | Simple | 161 |
| **Participant 03** | Standard | Complex | 189 |
| **Participant 03** | Prediction | Complex | 250 |
| **Participant 03** | Speech-based dictation | Complex | 178 |
| **Participant 04** | Standard | Simple | 247 |
| **Participant 04** | Prediction | Simple | 288 |
| **Participant 04** | Speech-based dictation | Simple | 180 |
| **Participant 05** | Standard | Complex | 233 |
| **Participant 05** | Prediction | Complex | 285 |
| **Participant 05** | Speech-based dictation | Complex | 225 |
| **Participant 06** | Standard | Simple | 200 |
| **Participant 06** | Prediction | Simple | 202 |
| **Participant 06** | Speech-based dictation | Simple | 162 |

```
Error: Participant.ID
          Df Sum Sq Mean Sq F value Pr(>F)
Task       1    341   341.3   0.175  0.682
Residuals 14  27279  1948.5

Error: Participant.ID:Group
           Df Sum Sq Mean Sq F value Pr(>F)
Group       2   1650   825.2   0.432  0.654
Group:Task  2   1845   922.5   0.483  0.622
Residuals  28  53493  1910.5
```

# *Two-way mixed-effects ANOVA in JMP*

## Add-ins > Repeated Measures > Full-Factorial Design (Mixed Effects)




**Summary of Fit**

| | |
|---|---|
| RSquare | 0.057814 |
| RSquare Adj | -0.05435 |
| Root Mean Square Error | 43.70896 |
| Mean of Response | 216.625 |
| Observations (or Sum Wgts) | 48 |

**Parameter Estimates**

| Term | Estimate | Std Error | DFDen | t Ratio | Prob>\|t\| |
|---|---|---|---|---|---|
| Intercept | 216.625 | 6.371352 | 14 | 34.00 | <.0001* |
| Task[Complex] | 2.6666667 | 6.371352 | 14 | 0.42 | 0.6819 |
| Group[Prediction] | 1.6875 | 8.922054 | 28 | 0.19 | 0.8513 |
| Group[Speech-based dictation] | -7.875 | 8.922054 | 28 | -0.88 | 0.3849 |
| Task[Complex]*Group[Prediction] | -2.229167 | 8.922054 | 28 | -0.25 | 0.8045 |
| Task[Complex]*Group[Speech-based dictation] | 8.4583333 | 8.922054 | 28 | 0.95 | 0.3512 |

**Random Effect Predictions**

**REML Variance Component Estimates**

| Random Effect | Var Ratio | Var Component | Std Error | 95% Lower | 95% Upper | Wald p-Value | Pct of Total |
|---|---|---|---|---|---|---|---|
| Participant ID[Task] | 0.0066379 | 12.681548 | 298.71885 | -572.7966 | 598.15973 | 0.9661 | 0.659 |
| Participant ID*Group[Task] | | 1910.4732 | 510.59544 | 1203.1556 | 3494.4955 | <.0001* | 99.341 |
| Total | | 1923.1548 | 419.68502 | 1307.4704 | 3106.8671 | | 100.000 |

-2 LogLikelihood = 457.81133323

Note: Total is the sum of the positive variance components.

Total including negative estimates = 1923.1548

**Covariance Matrix of Variance Component Estimates**

Residual is confounded with Participant ID*Group[Task] and has been removed.

**Iterations**

**Fixed Effect Tests**

| Source | Nparm | DF | DFDen | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Task | 1 | 1 | 14 | 0.1752 | 0.6819 |
| Group | 2 | 2 | 28 | 0.4319 | 0.6535 |
| Task*Group | 2 | 2 | 28 | 0.4829 | 0.6221 |

## *What if I would like to include a covariate?*

| Participant ID | Group | Time | Years |
|---|---|---|---|
| **Participant 01** | Standard | 245 | 12 |
| **Participant 02** | Standard | 236 | 5 |
| **Participant 03** | Standard | 321 | 6 |
| **Participant 04** | Standard | 212 | 13 |
| **Participant 05** | Standard | 267 | 19 |
| **Participant 06** | Standard | 334 | 18 |
| **Participant 07** | Standard | 287 | 18 |
| **Participant 08** | Standard | 259 | 18 |
| **Participant 09** | Prediction | 246 | 14 |
| **Participant 10** | Prediction | 213 | 3 |
| **Participant 11** | Prediction | 265 | 19 |
| **Participant 12** | Prediction | 189 | 13 |
| **Participant 13** | Prediction | 201 | 24 |
| **Participant 14** | Prediction | 197 | 21 |
| **Participant 15** | Prediction | 289 | 5 |
| **Participant 16** | Prediction | 224 | 18 |
| **Participant 17** | Speech-based dictation | 178 | 21 |
| **Participant 18** | Speech-based dictation | 289 | 18 |
| **Participant 19** | Speech-based dictation | 222 | 23 |
| **Participant 20** | Speech-based dictation | 189 | 16 |
| **Participant 21** | Speech-based dictation | 245 | 12 |
| **Participant 22** | Speech-based dictation | 311 | 15 |
| **Participant 23** | Speech-based dictation | 267 | 16 |
| **Participant 24** | Speech-based dictation | 197 | 9 |

Consider the one-way between-subjects analysis and also measuring the *years of experience* the user had in the task to control for that factor.

We conduct what is called an analysis of co-variance (ANCOVA).

*One-way between-participants ANCOVA in R*

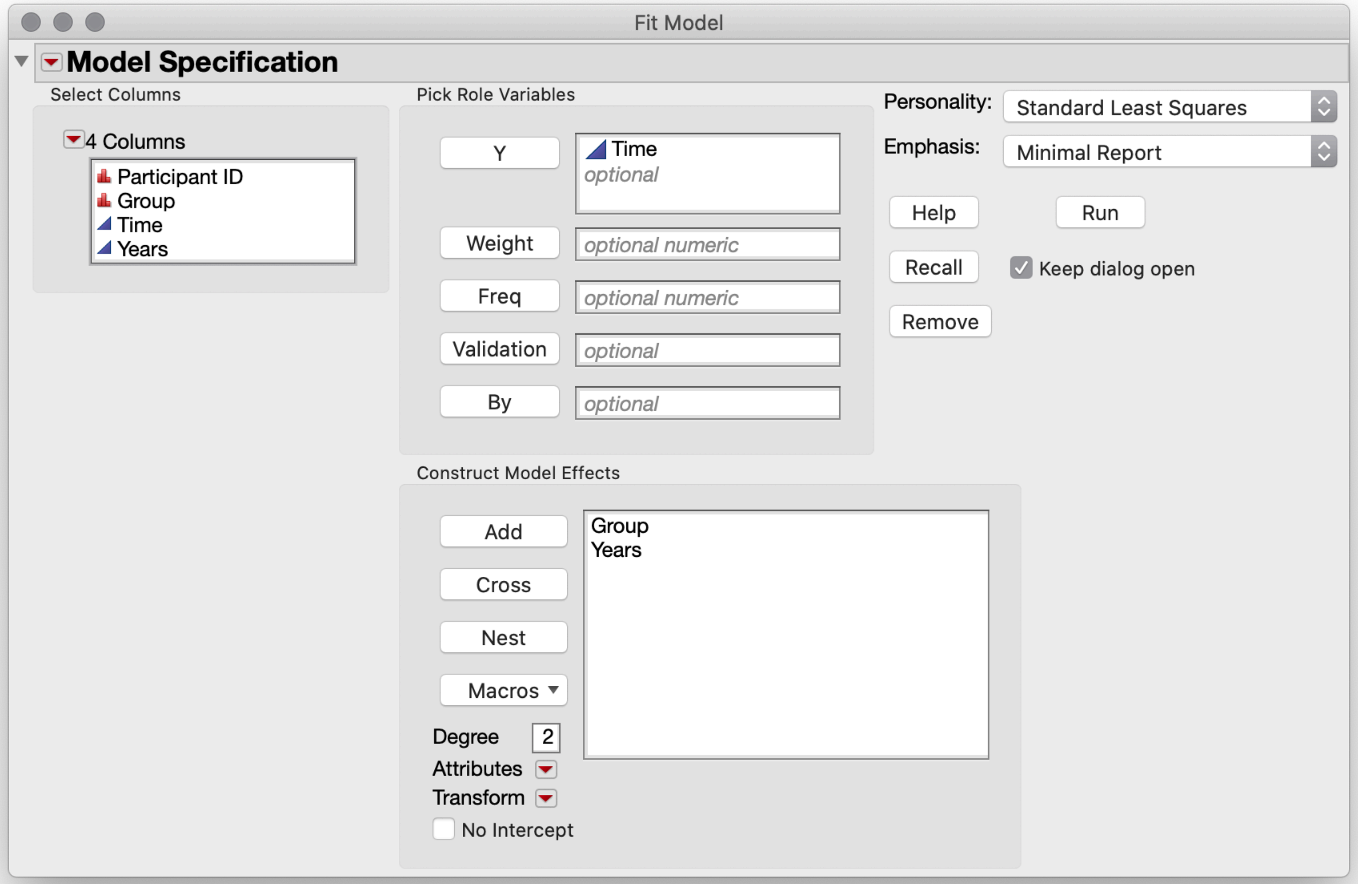
```
model = aov(Time~Group+Years, data=data)
summary(model)
```

```
            Df  Sum Sq  Mean Sq  F value  Pr(>F)
Group        2    7842     3921    2.090    0.15
Years        1     350      350    0.187    0.67
Residuals   20   37530     1877
```

Because `Years` has no effect, we would remove it from our model (called *model simplification*) and rerun our analysis as an ANOVA.

# *One-way between-participants ANCOVA in JMP*

## Analyze > Fit Model




### Summary of Fit

| | |
|---|---|
| RSquare | 0.179172 |
| RSquare Adj | 0.056048 |
| Root Mean Square Error | 43.31881 |
| Mean of Response | 245.125 |
| Observations (or Sum Wgts) | 24 |

### Analysis of Variance

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 3 | 8192.233 | 2730.74 | 1.4552 |
| Error | 20 | 37530.392 | 1876.52 | Prob > F |
| C. Total | 23 | 45722.625 | | 0.2568 |

### Parameter Estimates

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 255.22257 | 24.99753 | 10.21 | <.0001* |
| Group[Prediction] | -17.26682 | 12.50938 | -1.38 | 0.1827 |
| Group[Speech-based dictation] | -6.910626 | 12.70288 | -0.54 | 0.5924 |
| Years | -0.680735 | 1.576272 | -0.43 | 0.6705 |

### Effect Tests

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Group | 2 | 2 | 7341.1619 | 1.9561 | 0.1675 |
| Years | 1 | 1 | 349.9828 | 0.1865 | 0.6705 |

*Data files used in Statistics I, II, and III*