Problem Set 11

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When we speak sets of words, the more words we speak, the longer it takes. The spokenduration data set describes data from speeded spoken duration of words. Each column decribes whether a particular word was on the list they spoke, but we will ignore those columns for the moment. The last column tells how long it took to speak the word.

```
subject cult    dare    fate    guess   hint    mood    oath    plea    rush
verb    zeal    time
s02 1   1   0   1   0   0   0   1   1   0   1   4.886719
s02 1   1   0   0   0   1   1   0   0   0   0   2.738281
s02 0   0   1   0   1   1   1   1   0   1   0   4.179688
s02 1   0   0   1   0   0   1   1   0   0   1   3.628906
```

Read in the data, and compute a list-length using the following function:

```
data <- read.csv("spokenduration.csv") # reading the file
data$length <- as.factor(rowSums(data[,2:12])) # adding the length column
```

1. Categorical effect of length

First, we'd like to determine whether there is a significant relationship between list length and spoken duration. Create an anova model and test this relationship, treating list length as a factor. On the basis of the anova model, compute the effect size of this relationship. Also, compute a post-hoc Tukey HSD test and describe which differences are significant at a p=.05 level. Finally, compute the effect size for length, and describe what that means. Run both lm and aov models so you can examine the coefficients or the factor effects.

```
sapply(data, class)

##   subject      cult      dare      fate     guess      hint      mood
##  "factor" "integer" "integer" "integer" "integer" "integer" "integer"
##      oath      plea      rush      verb      zeal      time    length
## "integer" "integer" "integer" "integer" "integer" "numeric"  "factor"
```

We can see that the subject and length columns are of factor type.

```
aggregate(data$time, list(data$length), mean)

##   Group.1        x
## 1       3 2.838423
## 2       4 3.475511
## 3       5 4.313921
## 4       6 5.386790
```

Calculating the means of time as per the length of words.

```
library(ggpubr)

## Loading required package: ggplot2

## Loading required package: magrittr

ggboxplot(data, x = "length", y = "time",
          color = "length", palette = c("red", "gold", "green", "blue"),
```

```r
        order = c("3", "4", "5", "6"),
        ylab = "Time", xlab = "Length")
```

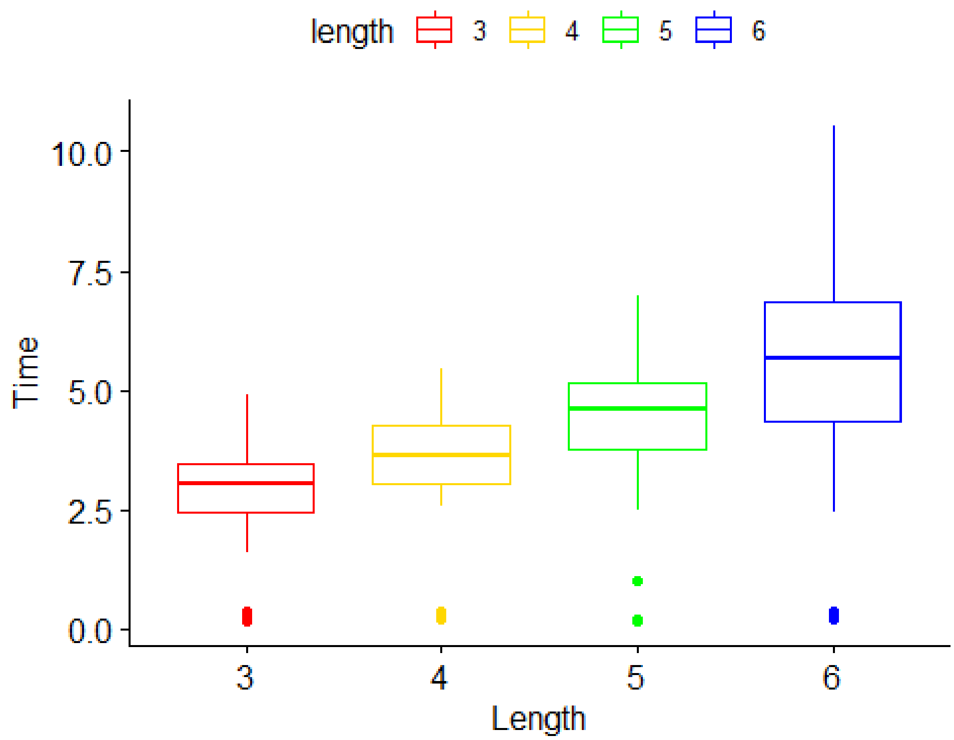

Figure 1: Boxplot of duration vs length

```r
res.aov <- aov(time ~ length, data = data)
summary(res.aov)

##              Df Sum Sq Mean Sq F value   Pr(>F)    
## length        3  199.7   66.56   23.17 5.06e-13 ***
## Residuals   213  611.8    2.87                     
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

As the p-value is less than the significance level 0.05, we can conclude that there are significant differences between the groups highlighted with "*" in the model summary.

We can say that there is a significant relation between spoken duration and length.

```r
library(sjstats)

anova_stats(res.aov) #computing the effect size of the relationship

##        term  df   sumsq meansq statistic p.value etasq partial.etasq
## 1    length   3 199.683 66.561    23.174       0 0.246         0.246
## 2 Residuals 213 611.773  2.872        NA      NA    NA            NA
##   omegasq partial.omegasq cohens.f power
## 1   0.235           0.235    0.571     1
## 2      NA              NA       NA    NA
```

As the ANOVA test is significant, we can compute Tukey HSD for performing multiple pairwise-comparison between the means of groups.

```
TukeyHSD(res.aov)

##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = time ~ length, data = data)
##
## $length
##          diff         lwr      upr     p adj
## 4-3 0.6370875 -0.21173713 1.485912 0.2131346
## 5-3 1.4754972  0.63865652 2.312338 0.0000496
## 6-3 2.5483665  1.71152584 3.385207 0.0000000
## 5-4 0.8384096 -0.01041502 1.687234 0.0542585
## 6-4 1.9112790  1.06245431 2.760104 0.0000001
## 6-5 1.0728693  0.23602868 1.909710 0.0058012
```

It can be seen from the output, that the difference between 5 and 3, 6 and 3, 6 and 4 is significant with an adjusted p-value of 0.0000496, 0.0, 0.0000001 respectively.

```
eta_sq(res.aov, partial = T) #computing the effect size of length

##     term partial.etasq
## 1 length         0.246
```

Now calculating the effect size of length we got the value as 0.243 for partial ETA squared which is small, this means that two lengths mens does not differ by 0.243 std deviations or more, the difference is trivial, even if it is statistically signficant.

It also means that it accounts for 24.3% of variance.

```
res.lm <- lm(time ~ length, data = data)
summary(res.lm)

##
## Call:
## lm(formula = time ~ length, data = data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -5.1680 -0.5068  0.1939  0.8710  5.1523
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   2.8384     0.2285  12.421  < 2e-16 ***
## length4       0.6371     0.3278   1.944   0.0533 .
## length5       1.4755     0.3232   4.566 8.42e-06 ***
## length6       2.5484     0.3232   7.885 1.61e-13 ***
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.695 on 213 degrees of freedom
## Multiple R-squared:  0.2461, Adjusted R-squared:  0.2355
## F-statistic: 23.17 on 3 and 213 DF,  p-value: 5.063e-13
```

```
res.aov <- aov(time ~ length, data = data)
summary(res.aov)
```

```
##              Df Sum Sq Mean Sq F value   Pr(>F)
## length        3  199.7   66.56   23.17 5.06e-13 ***
## Residuals   213  611.8    2.87
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

From lm() function we can see each of the levels effect of length and aov() function gives an overall effect of length.

We can see that length is statistically significant from the aov() result but from the result of lm() we see that all the 3 levels(3,5 and 6) are statistically significant except level 4 which is just above 0.05 value.

2. Subject effects

Next, we might expect that different people speak more quickly or more slowly. We'd like to incorporate an overall speed-by-subject factor. To do so, reset the contrasts of subject to use sum-to-zero coding (so that they will all be coded with respect to the mean), and add subject to the model. Use a type-II ANOVA to test whether subject accounts for a significant proportion of variance. Compute the effect sizes (eta^2 and omega^2). Then do a post-hoc Tukey test to determine whether any individual participants were significantly faster or slower than you'd expect. Describe your findings in words.

```
contrasts(data$subject) <- contr.sum(levels(data$subject))
```

Resetting the contrasts of subject to use sum-to-zero coding so that they will all be coded with respect to the mean

We had seen earlier that subject is also a factor. Adding subject to the model.

```
res.aov2 <- aov(time ~ length + subject, data = data)
summary(res.aov2)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## length        3  199.7   66.56   60.38 <2e-16 ***
## subject       7  384.7   54.95   49.85 <2e-16 ***
## Residuals   206  227.1    1.10
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

From the ANOVA table we can conclude that both length and subject are statistically significant. These results would lead us to believe that changing length or the subject, will impact significantly the mean time.

```
res.aov3 <- aov(time ~ length * subject, data = data)
summary(res.aov3)

##                  Df Sum Sq Mean Sq F value   Pr(>F)
## length            3  199.7   66.56  71.872  < 2e-16 ***
## subject           7  384.7   54.95  59.338  < 2e-16 ***
## length:subject   21   55.8    2.66   2.867 7.77e-05 ***
## Residuals       185  171.3    0.93
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

It can be seen that length and subject are statistically significant, as well as their interaction.

Applying Type-II Anova

```
library(car)

## Loading required package: carData

Anova(res.aov3, type = "II")

## Anova Table (Type II tests)
##
## Response: time
##                 Sum Sq  Df F value    Pr(>F)
## length          197.26   3 70.9987 < 2.2e-16 ***
## subject         384.68   7 59.3383 < 2.2e-16 ***
## length:subject   55.77  21  2.8674  7.77e-05 ***
## Residuals       171.33 185
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

We have seen earlier that subject is statistically significant and in the Type-II Anova result we get the p-value < 0.05, hence subject is statistically significant and accounts for a significant proportion of variance.

```
anova_stats(res.aov3)

##             term  df   sumsq meansq statistic p.value etasq partial.etasq
## 1         length   3 199.683 66.561    71.872       0 0.246         0.538
## 2        subject   7 384.676 54.954    59.338       0 0.474         0.692
## 3 length:subject  21  55.767  2.656     2.867       0 0.069         0.246
## 4      Residuals 185 171.330  0.926        NA      NA    NA            NA
##   omegasq partial.omegasq cohens.f power
## 1   0.242           0.495    1.080     1
## 2   0.466           0.653    1.498     1
## 3   0.045           0.153    0.571     1
## 4      NA              NA       NA    NA

anova_stats(res.aov2)
```

```
##        term  df   sumsq meansq statistic p.value etasq partial.etasq
## 1    length   3 199.683 66.561    60.378       0 0.246         0.468
## 2   subject   7 384.676 54.954    49.849       0 0.474         0.629
## 3 Residuals 206 227.097  1.102        NA      NA    NA            NA
##   omegasq partial.omegasq cohens.f power
## 1   0.242           0.451    0.938     1
## 2   0.464           0.612    1.301     1
## 3      NA              NA       NA    NA
```

We can see the effect sizes (eta^2 and omega^2) from the above results.

```
TukeyHSD(res.aov2)$subject
```

```
##                diff        lwr        upr        p adj
## s02-s01 -1.48151912 -2.3650003 -0.5980379 1.778598e-05
## s03-s01 -3.89438926 -4.7700969 -3.0186817 0.000000e+00
## s04-s01 -1.28487443 -2.1605820 -0.4091668 3.087581e-04
## s05-s01 -0.75244166 -1.6442186  0.1393353 1.678404e-01
## s06-s01 -0.63863715 -1.5221183  0.2448440 3.479371e-01
## s07-s01  0.39492774 -0.4885534  1.2784089 8.702848e-01
## s08-s01  0.45787089 -0.4178367  1.3335785 7.491808e-01
## s03-s02 -2.41287015 -3.2801283 -1.5456120 1.181277e-13
## s04-s02  0.19664468 -0.6706134  1.0639028 9.970765e-01
## s05-s02  0.72907746 -0.1544037  1.6125586 1.900044e-01
## s06-s02  0.84288196 -0.0322248  1.7179887 6.823137e-02
## s07-s02  1.87644685  1.0013401  2.7515536 1.148811e-08
## s08-s02  1.93939000  1.0721319  2.8066481 2.360736e-09
## s04-s03  2.60951483  1.7501770  3.4688526 1.931788e-14
## s05-s03  3.14194760  2.2662400  4.0176552 0.000000e+00
## s06-s03  3.25575211  2.3884940  4.1230102 0.000000e+00
## s07-s03  4.28931700  3.4220589  5.1565751 0.000000e+00
## s08-s03  4.35226015  3.4929224  5.2115979 0.000000e+00
## s05-s04  0.53243277 -0.3432748  1.4081404 5.786002e-01
## s06-s04  0.64623728 -0.2210208  1.5134954 3.086493e-01
## s07-s04  1.67980217  0.8125441  2.5470603 3.478654e-07
## s08-s04  1.74274532  0.8834075  2.6020831 7.992787e-08
## s06-s05  0.11380451 -0.7696767  0.9972857 9.999290e-01
## s07-s05  1.14736940  0.2638882  2.0308506 2.415950e-03
## s08-s05  1.21031255  0.3346050  2.0860201 8.979360e-04
## s07-s06  1.03356489  0.1584581  1.9086717 8.815968e-03
## s08-s06  1.09650804  0.2292499  1.9637662 3.570835e-03
## s08-s07  0.06294315 -0.8043150  0.9302013 9.999986e-01
```

From the above Tukey result we got the following findings:

1. ***Subject 2,3,4 are faster than Subject 1***
2. ***Subject 3,7,8 are faster than Subject 2***
3. ***Subject 4,5,6,7,8 are faster than Subject 3***
4. ***Subject 7,8 are faster than Subject 4***
5. ***Subject 7,8 are faster than Subject 5***
6. ***Subject 7,8 are faster than Subject 6 as well***
7. ***Subject 7 is faster than Subject 8***

We can derive which subjects are slower from the above statements.

3. Subject x length interactions

Not everyone pronounces words the same. It may be true that individuals interacts with word-length. Add the subject by length interaction to the model. Do this in an lm and examine the coefficients. Describe the effects–which people are slower, or which length:subject interaction terms are significantly different than the baseline? Perform a post-hoc tukey test and determine which participants have significantly different durations for 6-item lists (e.g., the result for 6:s06-6:s01 shows whether participants s06 and s01 differed in how they pronounced 6-item lists)

Creating subject by length interaction as we did in last question

```
res.lm1 <- lm(time ~ length * subject, data = data)
summary(res.lm1)

##
## Call:
## lm(formula = time ~ length * subject, data = data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.9877 -0.5156 -0.0670  0.2712  7.4353
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)      2.85524    0.12993  21.975  < 2e-16 ***
## length4          0.62866    0.18654   3.370 0.000915 ***
## length5          1.47745    0.18375   8.040 1.04e-13 ***
## length6          2.53131    0.18375  13.776  < 2e-16 ***
## subject1         0.92471    0.36421   2.539 0.011941 *
## subject2        -0.39207    0.34075  -1.151 0.251377
## subject3        -1.86863    0.34075  -5.484 1.35e-07 ***
## subject4         0.23517    0.34075   0.690 0.490965
## subject5         0.04767    0.34075   0.140 0.888903
## subject6        -0.35245    0.34075  -1.034 0.302329
## subject7         0.69164    0.34075   2.030 0.043812 *
## length4:subject1  0.06739    0.49979   0.135 0.892881
## length5:subject1  0.10719    0.51506   0.208 0.835374
## length6:subject1 -0.23760    0.49875  -0.476 0.634366
## length4:subject2 -0.24873    0.49979  -0.498 0.619303
## length5:subject2 -0.31562    0.48189  -0.655 0.513310
## length6:subject2 -0.19035    0.48189  -0.395 0.693295
## length4:subject3 -0.66549    0.48296  -1.378 0.169884
## length5:subject3 -1.82120    0.48189  -3.779 0.000212 ***
## length6:subject3 -2.00396    0.48189  -4.159 4.90e-05 ***
## length4:subject4 -0.21125    0.48296  -0.437 0.662324
## length5:subject4 -0.57454    0.48189  -1.192 0.234679
## length6:subject4 -1.68198    0.48189  -3.490 0.000603 ***
## length4:subject5 -0.07063    0.49979  -0.141 0.887777
## length5:subject5  0.49354    0.48189   1.024 0.307091
## length6:subject5 -0.06116    0.49875  -0.123 0.902532
## length4:subject6  0.46620    0.49979   0.933 0.352136
## length5:subject6  0.79543    0.48189   1.651 0.100505
## length6:subject6  1.18409    0.48189   2.457 0.014924 *
```

```
## length4:subject7  0.29452    0.49979   0.589 0.556392
## length5:subject7  0.65202    0.48189   1.353 0.177691
## length6:subject7  1.43409    0.48189   2.976 0.003311 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.9623 on 185 degrees of freedom
## Multiple R-squared:  0.7889, Adjusted R-squared:  0.7535
## F-statistic:  22.3 on 31 and 185 DF,  p-value: < 2.2e-16
```

As the p-value is less than the significance level 0.05, we can conclude that the variables highlighted with "*" in the model summary are statistically significant.

We can see that length4,5,6 and subject1, subject3, subject7 are statistically significant and from the estimate value we can say that subject3 is slower (negative value).

With the interaction with length5 we see that only subject3 is statistically significant and with length 6 subject7,6,4 and 3 are statistically significant and we can say that those 5 interactions are significantly different than the baseline.

```
TukeyHSD(aov(time ~ length * subject, data = data))$`length:subject`
```

```
##                     diff          lwr          upr        p adj
## 6:s02-6:s01 -1.269531286 -3.245946380  0.706883809 8.213560e-01
## 6:s03-6:s01 -4.559710043 -6.536125137 -2.583294948 6.958878e-13
## 6:s04-6:s01 -2.133928571 -4.110343666 -0.157513477 1.771188e-02
## 6:s05-6:s01 -0.700614000 -2.757732052  1.356504052 9.999904e-01
## 6:s06-6:s01  0.144531143 -1.831883952  2.120946237 1.000000e+00
## 6:s07-6:s01  1.438616000 -0.537799095  3.415031095 5.826277e-01
## 6:s08-6:s01  1.583705000 -0.392710095  3.560120095 3.648679e-01
## 6:s03-6:s02 -3.290178757 -5.266593852 -1.313763663 6.161695e-07
## 6:s04-6:s02 -0.864397286 -2.840812380  1.112017809 9.987185e-01
## 6:s05-6:s02  0.568917286 -1.488200766  2.626035337 9.999999e-01
## 6:s06-6:s02  1.414062429 -0.562352666  3.390477523 6.206872e-01
## 6:s07-6:s02  2.708147286  0.731732191  4.684562380 1.752815e-04
## 6:s08-6:s02  2.853236286  0.876821191  4.829651380 4.631379e-05
## 6:s04-6:s03  2.425781471  0.449366377  4.402196566 1.958367e-03
## 6:s05-6:s03  3.859096043  1.801977991  5.916214094 6.903430e-09
## 6:s06-6:s03  4.704241186  2.727826091  6.680656280 4.405365e-13
## 6:s07-6:s03  5.998326043  4.021910948  7.974741137 1.436629e-13
## 6:s08-6:s03  6.143415043  4.166999948  8.119830137 1.139089e-13
## 6:s05-6:s04  1.433314571 -0.623803480  3.490432623 6.768025e-01
## 6:s06-6:s04  2.278459714  0.302044620  4.254874809 6.203691e-03
## 6:s07-6:s04  3.572544571  1.596129477  5.548959666 3.057381e-08
## 6:s08-6:s04  3.717633571  1.741218477  5.694048666 6.180777e-09
## 6:s06-6:s05  0.845145143 -1.211972909  2.902263194 9.995801e-01
## 6:s07-6:s05  2.139230000  0.082111948  4.196348052 3.017340e-02
## 6:s08-6:s05  2.284319000  0.227200948  4.341437052 1.151516e-02
## 6:s07-6:s06  1.294084857 -0.682330237  3.270499952 7.916674e-01
## 6:s08-6:s06  1.439173857 -0.537241237  3.415588952 5.817593e-01
## 6:s08-6:s07  0.145089000 -1.831326095  2.121504095 1.000000e+00
```

The following participants have significantly different durations for 6-item lists: Subject3 and 1, Subject4 and 1, Subject3 and 2, Subject7 and 2, Subject8 and 2, Subject4 and 3, Subject5 and 3, Subject6 and 3, Subject7 and 3, Subject8 and 3, Subject6 and 4, Subject7 and 4, Subject8 and 4, Subject8 and 5, Subject7 and 5.

4. ANCOVA

Finally, run the interaction model again, but use length as a continuous predictor instead of a categorical run both the regresion and anova models. Look at and interpret the sets of coefficients in the regression model, and interpret the results of a Type-II ANOVA. Run a post-hoc test on subject, and compute eta^2 and omega. describe in words how you would interpret each part of this.

```
class(data$length)

## [1] "factor"

data$length <- as.numeric(data$length)
class(data$length)

## [1] "numeric"
```

Converted length to continuous predictor.

```
res4.aov <- aov(time ~ length * subject, data = data) #anova model
summary(res4.aov)

##                  Df Sum Sq Mean Sq F value   Pr(>F)    
## length            1  197.1  197.10 220.603  < 2e-16 ***
## subject           7  384.9   54.98  61.541  < 2e-16 ***
## length:subject    7   49.9    7.12   7.974 1.54e-08 ***
## Residuals       201  179.6    0.89                     
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

From the anova model we can see that length and subject are statistically significant and their interaction as well.

```
res4.lm <- lm(time ~ length * subject, data = data) #regression model
summary(res4.lm)

## 
## Call:
## lm(formula = time ~ length * subject, data = data)
## 
## Residuals:
##     Min      1Q  Median      3Q     Max 
## -1.8926 -0.5372 -0.0917  0.2532  7.7347 
## 
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept)      1.90883    0.15692  12.164  < 2e-16 ***
## length           0.84366    0.05712  14.771  < 2e-16 ***
## subject1         1.06870    0.42827   2.495 0.013387 *
## subject2        -0.41121    0.41447  -0.992 0.322329
## subject3        -1.20431    0.41014  -2.936 0.003709 **
## subject4         0.96561    0.41014   2.354 0.019520 *
## subject5         0.04836    0.41890   0.115 0.908206
## subject6        -0.71185    0.41447  -1.717 0.087432 .
## subject7         0.13008    0.41447   0.314 0.753956
## length:subject1 -0.06640    0.15461  -0.429 0.668059
## length:subject2 -0.06617    0.15017  -0.441 0.659937
## length:subject3 -0.71615    0.14969  -4.784 3.32e-06 ***
## length:subject4 -0.54031    0.14969  -3.609 0.000387 ***
## length:subject5  0.04001    0.15461   0.259 0.796095
## length:subject6  0.38787    0.15017   2.583 0.010508 *
## length:subject7  0.46396    0.15017   3.090 0.002288 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.9452 on 201 degrees of freedom
## Multiple R-squared:  0.7787, Adjusted R-squared:  0.7622
## F-statistic: 47.15 on 15 and 201 DF,  p-value: < 2.2e-16
```

From the regression model we can see that length, subject1,3,4 and interaction between length and subjects 3,4,6,7 are statistically significant.

```
library(car)
#Anova(res4.aov, type = "II")
Anova(res4.lm, type = "II")
```

```
## Anova Table (Type II tests)
##
## Response: time
##                 Sum Sq  Df F value    Pr(>F)
## length          194.89   1 218.133 < 2.2e-16 ***
## subject         384.89   7  61.541 < 2.2e-16 ***
## length:subject   49.87   7   7.974 1.542e-08 ***
## Residuals       179.59 201
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

From the Type-II ANOVA model we can see that length and subject are statistically significant and their interaction as well.

```
TukeyHSD(res4.aov, which = 'subject')
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = time ~ length * subject, data = data)
##
## $subject
```

```
##                 diff         lwr         upr     p adj
## s02-s01 -1.47793460 -2.27350166 -0.68236754 0.0000012
## s03-s01 -3.89466634 -4.68323336 -3.10609933 0.0000000
## s04-s01 -1.28515151 -2.07371853 -0.49658450 0.0000351
## s05-s01 -0.75299582 -1.55603316  0.05004152 0.0838362
## s06-s01 -0.63505264 -1.43061970  0.16051443 0.2257274
## s07-s01  0.39851225 -0.39705481  1.19407931 0.7879385
## s08-s01  0.45759381 -0.33097321  1.24616082 0.6360178
## s03-s02 -2.41673174 -3.19769008 -1.63577341 0.0000000
## s04-s02  0.19278309 -0.58817525  0.97374142 0.9950208
## s05-s02  0.72493878 -0.07062828  1.52050584 0.1030212
## s06-s02  0.84288196  0.05485599  1.63090794 0.0267010
## s07-s02  1.87644685  1.08842088  2.66447282 0.0000000
## s08-s02  1.93552841  1.15457007  2.71648674 0.0000000
## s04-s03  2.60951483  1.83568869  3.38334097 0.0000000
## s05-s03  3.14167052  2.35310351  3.93023754 0.0000000
## s06-s03  3.25961371  2.47865537  4.04057204 0.0000000
## s07-s03  4.29317859  3.51222026  5.07413693 0.0000000
## s08-s03  4.35226015  3.57843401  5.12608629 0.0000000
## s05-s04  0.53215569 -0.25641132  1.32072271 0.4398585
## s06-s04  0.65009888 -0.13085946  1.43105721 0.1810415
## s07-s04  1.68366377  0.90270543  2.46462210 0.0000000
## s08-s04  1.74274532  0.96891918  2.51657146 0.0000000
## s06-s05  0.11794318 -0.67762388  0.91351025 0.9998166
## s07-s05  1.15150807  0.35594101  1.94707513 0.0004004
## s08-s05  1.21058963  0.42202261  1.99915664 0.0001277
## s07-s06  1.03356489  0.24553892  1.82159086 0.0020881
## s08-s06  1.09264644  0.31168811  1.87360478 0.0007324
## s08-s07  0.05908156 -0.72187678  0.84003989 0.9999981
```

Post hoc test for the model

```
anova_stats(res4.aov)

##             term  df   sumsq  meansq statistic p.value etasq partial.etasq
## 1         length   1 197.102 197.102   220.603       0 0.243         0.523
## 2        subject   7 384.895  54.985    61.541       0 0.474         0.682
## 3 length:subject   7  49.872   7.125     7.974       0 0.061         0.217
## 4      Residuals 201 179.587   0.893        NA      NA    NA            NA
##   omegasq partial.omegasq cohens.f power
## 1   0.242           0.503    1.048     1
## 2   0.466           0.661    1.464     1
## 3   0.054           0.184    0.527     1
## 4      NA              NA       NA    NA
```

Computed eta^2 and omega for aov model.

```
anova_stats(res4.lm)

##             term  df   sumsq  meansq statistic p.value etasq partial.etasq
## 1         length   1 197.102 197.102   220.603       0 0.243         0.523
## 2        subject   7 384.895  54.985    61.541       0 0.474         0.682
```

```
## 3 length:subject   7  49.872   7.125     7.974       0 0.061          0.217
## 4      Residuals 201 179.587   0.893        NA      NA    NA             NA
##   omegasq partial.omegasq cohens.f power
## 1   0.242           0.503    1.048     1
## 2   0.466           0.661    1.464     1
## 3   0.054           0.184    0.527     1
## 4      NA              NA       NA    NA
```

Computed eta^2 and omega for lm model.

For length (1 degree of freedom), the square root of eta squared is equal to the correlation coefficient r. For subject and length subject interaction (more than 1 degree of freedom), eta squared equals R-squared.

While eta squared estimates tend to be biased in certain situations, e.g. when the sample size is small or the independent variables have many group levels, omega squared estimates are corrected for this bias.

Subject has the highest etasq value and accounts for 47.4% variance.