Homework 12
Applied Mutlivariate Analysis

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1 Workspace

1.1 Packages

```
library(car)
library(knitr)
library(kableExtra)
library(psych)
library(MASS)
library(car)
library(multcomp)
library(Rmisc)
library(broom)
library(plyr)
library(tidyverse)
```

1.2 data

The file, Set_11.csv, contains the data from an experiment investigating the effects of goal- related instructions on performance, persistence, and anxiety. Participants attempted to solve challenging anagrams (words with their letters scrambled, e.g., ULERITO = OUTLIER) during a 30-minute period. Participants could attempt as many anagrams as they wished and could give up and move on to a new one at any time. Persistence was the number of anagrams attempted. Performance was the percentage of anagrams solved correctly, of those attempted. Anxiety was the total score on a questionnaire designed to measure performance-related anxiety, given after the instructions, immediately before starting the task (scores could range from 10 to 40). Participants were given a set of 10 practice anagrams to give them an idea of their difficulty. Performance on this practice set was 51%.

Prior to beginning the task, groups were given instructions intended to influence their motivation on the task. Group 1 was told to simply "do your best." Group 2 was told, most students are able to correctly solve about 60% of the anagrams you will attempt." Given the practice test experience, these instructions were expected to make the task seem challenging, but not impossible. Group 3 was told, most students are able to correctly solve 80% of the anagrams you will attempt." These instructions were expected to make the task seem very difficult.

The researchers posed the following hypotheses:

1. The increasingly challenging instructions should lead to increasing levels of anxiety.

2. Groups 2 and 3 should exert more persistence than Group 1 but should not differ from each other because there is an upper limit to the number of anagrams that can reasonably be attempted in 30 minutes.

3. Performance should be greatest in Group 2. Group 1 should have lower performance than Group 2 because of lower motivation. Group 3 should have lower performance than Group 2 because of the incapacitating effects of high anxiety.

```
wd <- "https://github.com/emoriebeck/homeworks/raw/master/multivariate/homeworks/homework13"

dat <- sprintf("%s/Set_11.csv", wd) %>% read.csv(., stringsAsFactors = F) %>% tbl_df %>%
  mutate(Group = factor(Group))

head(dat)

## # A tibble: 6 x 5
##   Perform Persist Anxiety Group    ID
##     <int>   <int>   <int> <fct> <int>
## 1      43      19      15 1         1
## 2      40      21      15 1         2
## 3      43      27      11 1         3
## 4      36      19      13 1         4
## 5      25      15      19 1         5
## 6      51      34      10 1         6
```

2 Question 1

Analyze each outcome measure separately and comment on the support those analyses provide for the hypotheses. Use any contrasts or follow-up comparisons that you think are important for testing each hypothesis.

```
nested1 <- dat %>%
  gather(key = outcome, value = value, Perform:Anxiety) %>%
  group_by(outcome) %>%
  nest() %>%
  mutate(lm = map(data, ~lm(value ~ Group, data = . )),
         aov = map(data, ~aov(value ~ Group, data = .)),
         tidy.lm = map(lm, broom::tidy),
         tidy.aov = map(aov, broom::tidy))

nested1 %>%
  unnest(tidy.lm) %>%
  filter(grepl("Group", term)) %>%
  mutate(p.value = ifelse(p.value < .001, "<.001", ifelse(p.value < .01,
                          "<.01", ifelse(p.value < .05, "<.05", ">.05")))) %>%
  kable(., "latex", booktabs = T, escape = F, digits = 2) %>%
  kable_styling(full_width = F)
```

outcome	term	estimate	std.error	statistic	p.value
Perform	Group2	13.75	4.25	3.23	¡.01
Perform	Group3	3.35	4.17	0.80	¿.05
Persist	Group2	17.15	2.78	6.16	¡.001
Persist	Group3	15.74	2.73	5.77	¡.001
Anxiety	Group2	4.29	1.68	2.56	¡.05
Anxiety	Group3	8.50	1.64	5.18	¡.001

```r
# linear contrast -1*G1 + 0*G2 + 1*G3 = 0
# -1*(I) + 0*(I + D1) + 1*(I + D2) = 0
# -I + I + D2 = 0
# D2 = 0
H1.1 <- c(0, 1, 0)
# quadratic contrast: 1*G1 + -2*G2 + 1*G3 = 0
# 1*(I) + -2*(I + D1) + 1*(I + D2) = 0
# I -2*I -2*D1 + I + D2 = 0
# -2*D1 + D2 = 0
H1.2 <- c(0, -2, 1)
# group 1 differs from 2 + 3: G1 = G2 + G3
# (I) = (I + D1 + I + D2)
# 0 = I + D1 + D2
H2.1 <- c(1, 1, 1)
# group 2 and 3 don't differ: G2 = G3
# (I + D1) = (I + D2)
# D1 - D2 = 0
H2.2 <- c(0, -1, 1)

# H3: G2 performance best: G1 + G3 = G2
# I + I + D2 = I + D1
# I - D1 + D2 = 0
H3.1 <- c(1, -1, 1)
# H3: G3 < G2 performance: G3 = G2
# (I + D2) = (I + D1)
# D2 - D1 = 0
H3.2 <- c(0, 1, -1)

H.1 <- rbind(H1.1, H1.2, H2.1, H2.2, H3.1, H3.2)
rownames(H.1) <- c("H1 linear", "H1 quadratic",
                   "H2: G1 = G2 + G3", "H2: G2 - G3 = 0",
                   "H3: G2 = G1 + G3", "H3: G2 = G3")

tab_fun <- function(x){
  x$confint %>% data.frame %>%
    mutate(Group = rownames(x$confint)) %>%
    select(Group, everything())
}

nested1 <- nested1 %>%
  mutate(comp = map(lm, ~glht(., linfct=H.1, alternative="two.sided",rhs=0)),
         summ = map(comp, ~confint(., adjusted("holm"), calpha = univariate_calpha())),
         tab = map(summ, tab_fun))

nested1 %>% unnest(tab) %>%
  filter((outcome == "Anxiety" & Group == "H1 linear") | # H1 linear contrast
         (outcome == "Anxiety" & Group == "H1 quadratic") | # H1 quadratic
         (outcome == "Persist" & Group == "H2: G1 = G2 + G3") |
         (outcome == "Persist" & Group == "H2: G2 - G3 = 0") |
         (outcome == "Perform" & Group == "H3: G2 = G1 + G3") |
         (outcome == "Perform" & Group == "H3: G2 = G3") |
         (outcome == "Anxiety" & Group == "H3: G2 = G3")) %>%
  arrange(Group)
```

```
## # A tibble: 7 x 5
##   outcome Group            Estimate     lwr     upr
##   <chr>   <chr>               <dbl>   <dbl>   <dbl>
## 1 Anxiety H1 linear          4.29     0.946   7.63
## 2 Anxiety H1 quadratic      -0.0687  -5.86    5.72
## 3 Persist H2: G1 = G2 + G3  60.5     53.8    67.3
## 4 Persist H2: G2 - G3 = 0   -1.41    -6.91    4.09
## 5 Perform H3: G2 = G1 + G3  39.5     29.2    49.8
## 6 Perform H3: G2 = G3       10.4      2.00   18.8
## 7 Anxiety H3: G2 = G3       -4.22    -7.53   -0.909
```

Hypothesis 1: A linear contrast supports the hypothesis that the increasingly challenging instructions should lead to increasing levels of anxiety. This is further supported by the non-significant quadratic contrast.

Hypothesis 2: On average, Groups 2 and 3 persisted longer than group 1, which is further supported by the non-significant difference between groups 2 and 3.

Hypothesis 3: Group 2 performed the best of the of the other groups on average and better than Group 3 specifically but Group 2 appears to have had lower anxiety than Group 3.

3 Question 2

Then conduct a multivariate analysis and indicate if this approach adds any additional insight or qualification to the univariate analyses.

```
# ombinus test
dat$Group.sum <- dat$Group
contrasts(dat$Group.sum) <- contr.sum(3)
manova1 <- manova(cbind(Perform, Persist, Anxiety) ~ Group.sum, data = dat)
m1 <- lm(cbind(Anxiety, Persist, Perform) ~ Group, data = dat)
id <- data.frame(measure = factor(c("Anxiety", "Persist", "Perform")))
manova2 <- Anova(m1, data = dat, idesign = ~measure, idata = id, multivariate = T)

summary(manova2)

##
## Type II Repeated Measures MANOVA Tests:
##
## ------------------------------------------
##
## Term: (Intercept)
##
##  Response transformation matrix:
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
## Sum of squares and products for the hypothesis:
##             (Intercept)
## (Intercept)    911905.3
##
## Multivariate Tests: (Intercept)
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1   0.96988 2318.506      1     72 < 2.22e-16 ***
```

```
## Wilks              1   0.03012 2318.506      1     72 < 2.22e-16 ***
## Hotelling-Lawley  1  32.20147 2318.506      1     72 < 2.22e-16 ***
## Roy               1  32.20147 2318.506      1     72 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: Group
##
##  Response transformation matrix:
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
## Sum of squares and products for the hypothesis:
##             (Intercept)
## (Intercept)    16983.92
##
## Multivariate Tests: Group
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            2 0.3748989 21.59069      2     72 4.5103e-08 ***
## Wilks             2 0.6251011 21.59069      2     72 4.5103e-08 ***
## Hotelling-Lawley  2 0.5997412 21.59069      2     72 4.5103e-08 ***
## Roy               2 0.5997412 21.59069      2     72 4.5103e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##           measure1  measure2
## measure1  37587.21 -28363.91
## measure2 -28363.91  21403.85
##
## Multivariate Tests: measure
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1  0.825154 167.5359      2     71 < 2.22e-16 ***
## Wilks             1  0.174846 167.5359      2     71 < 2.22e-16 ***
## Hotelling-Lawley  1  4.719320 167.5359      2     71 < 2.22e-16 ***
## Roy               1  4.719320 167.5359      2     71 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## ------------------------------------------
##
## Term: Group:measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##           measure1  measure2
## measure1 2041.6017  707.4617
## measure2  707.4617 2096.8278
##
## Multivariate Tests: Group:measure
##                  Df test stat  approx F num Df den Df     Pr(>F)
## Pillai            2 0.4072735  9.205501      4    144 1.1881e-06 ***
## Wilks             2 0.6206264  9.562287      4    142 7.1021e-07 ***
## Hotelling-Lawley  2 0.5663209  9.910616      4    140 4.3294e-07 ***
## Roy               2 0.4708449 16.950416      2     72 9.2810e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Univariate Type II Repeated-Measures ANOVA Assuming Sphericity
##
##               Sum Sq num Df Error SS den Df   F value    Pr(>F)
## (Intercept)   303968      1   9439.6     72 2318.5060 < 2.2e-16 ***
## Group           5661      2   9439.6     72   21.5907  4.51e-08 ***
## measure        58237      2  15832.7    144  264.8340 < 2.2e-16 ***
## Group:measure   2287      4  15832.7    144    5.2008 0.0006087 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## Mauchly Tests for Sphericity
##
##               Test statistic    p-value
## measure              0.44729 3.9448e-13
## Group:measure        0.44729 3.9448e-13
##
##
## Greenhouse-Geisser and Huynh-Feldt Corrections
##  for Departure from Sphericity
##
##                GG eps Pr(>F[GG])
## measure       0.64404  < 2.2e-16 ***
## Group:measure 0.64404   0.003697 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##                  HF eps   Pr(>F[HF])
## measure       0.6507342 8.217931e-33
```

```
## Group:measure 0.6507342 3.572024e-03
```

3.1 Hypothesis 1

```r
dat <- dat %>%
  mutate(H1.1 = as.numeric(mapvalues(Group, 1:3, c(-1,0,1))), # linear cntrast
         H1.2 = as.numeric(mapvalues(Group, 1:3, c(1,-2,1)))) # quadratic contrast
```

Linear change

```r
m2 <- lm(cbind(Anxiety, Persist, Perform) ~ H1.1, data = dat)
manova.H1.1 <- Anova(m2, data = dat, idesign = ~measure, idata = id, multivariate = T)
summary(manova.H1.1)
```

```
##
## Type II Repeated Measures MANOVA Tests:
##
## ------------------------------------------
##
## Term: (Intercept)
##
##  Response transformation matrix:
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
## Sum of squares and products for the hypothesis:
##             (Intercept)
## (Intercept)    911905.3
##
## Multivariate Tests: (Intercept)
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1  0.962243 1860.418      1     73 < 2.22e-16 ***
## Wilks             1  0.037757 1860.418      1     73 < 2.22e-16 ***
## Hotelling-Lawley  1 25.485173 1860.418      1     73 < 2.22e-16 ***
## Roy               1 25.485173 1860.418      1     73 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: H1.1
##
##  Response transformation matrix:
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
## Sum of squares and products for the hypothesis:
##             (Intercept)
```

```
## (Intercept)    9520.868
##
## Multivariate Tests: H1.1
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1 0.2101613 19.42394      1     73 3.5324e-05 ***
## Wilks             1 0.7898387 19.42394      1     73 3.5324e-05 ***
## Hotelling-Lawley  1 0.2660813 19.42394      1     73 3.5324e-05 ***
## Roy               1 0.2660813 19.42394      1     73 3.5324e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##           measure1  measure2
## measure1  37587.21 -28363.91
## measure2 -28363.91  21403.85
##
## Multivariate Tests: measure
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1  0.815442 159.0609      2     72 < 2.22e-16 ***
## Wilks             1  0.184558 159.0609      2     72 < 2.22e-16 ***
## Hotelling-Lawley  1  4.418358 159.0609      2     72 < 2.22e-16 ***
## Roy               1  4.418358 159.0609      2     72 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: H1.1:measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##           measure1 measure2
## measure1  646.9025 1128.767
## measure2 1128.7668 1969.562
##
## Multivariate Tests: H1.1:measure
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1 0.3191665 16.87636      2     72 9.7605e-07 ***
```

```
## Wilks             1 0.6808335 16.87636      2     72 9.7605e-07 ***
## Hotelling-Lawley  1 0.4687878 16.87636      2     72 9.7605e-07 ***
## Roy               1 0.4687878 16.87636      2     72 9.7605e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Univariate Type II Repeated-Measures ANOVA Assuming Sphericity
##
##              Sum Sq num Df Error SS den Df  F value    Pr(>F)
## (Intercept)  303968      1    11927     73 1860.418 < 2.2e-16 ***
## H1.1           3174      1    11927     73   19.424 3.532e-05 ***
## measure       58237      2    17128    146  248.203 < 2.2e-16 ***
## H1.1:measure    992      2    17128    146    4.227   0.01642 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## Mauchly Tests for Sphericity
##
##              Test statistic   p-value
## measure             0.41927 2.568e-14
## H1.1:measure        0.41927 2.568e-14
##
##
## Greenhouse-Geisser and Huynh-Feldt Corrections
##  for Departure from Sphericity
##
##               GG eps Pr(>F[GG])
## measure      0.63262     <2e-16 ***
## H1.1:measure 0.63262     0.0336 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##                 HF eps   Pr(>F[HF])
## measure      0.6386537 1.941780e-31
## H1.1:measure 0.6386537 3.320521e-02
```

```
m3 <- lm(cbind(Anxiety, Persist, Perform) ~ H1.2, data = dat)
manova.H1.2 <- Anova(m3, data = dat, idesign = ~measure, idata = id, multivariate = T)
summary(manova.H1.2)
```

```
##
## Type II Repeated Measures MANOVA Tests:
##
## ------------------------------------------
##
## Term: (Intercept)
##
##  Response transformation matrix:
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
```

```
## Sum of squares and products for the hypothesis:
##             (Intercept)
## (Intercept)    911905.3
##
## Multivariate Tests: (Intercept)
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1  0.959969 1750.603      1     73 < 2.22e-16 ***
## Wilks             1  0.040031 1750.603      1     73 < 2.22e-16 ***
## Hotelling-Lawley  1 23.980867 1750.603      1     73 < 2.22e-16 ***
## Roy               1 23.980867 1750.603      1     73 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: H1.2
##
##  Response transformation matrix:
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
## Sum of squares and products for the hypothesis:
##             (Intercept)
## (Intercept)    7276.297
##
## Multivariate Tests: H1.2
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1 0.1606152 13.96846      1     73 0.00036657 ***
## Wilks             1 0.8393848 13.96846      1     73 0.00036657 ***
## Hotelling-Lawley  1 0.1913487 13.96846      1     73 0.00036657 ***
## Roy               1 0.1913487 13.96846      1     73 0.00036657 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##           measure1  measure2
## measure1  37587.21 -28363.91
## measure2 -28363.91  21403.85
##
## Multivariate Tests: measure
##                  Df test stat approx F num Df den Df     Pr(>F)
```

```
## Pillai            1  0.816413 160.0922      2     72 < 2.22e-16 ***
## Wilks             1  0.183587 160.0922      2     72 < 2.22e-16 ***
## Hotelling-Lawley  1  4.447005 160.0922      2     72 < 2.22e-16 ***
## Roy               1  4.447005 160.0922      2     72 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: H1.2:measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##           measure1  measure2
## measure1 1373.5342 -436.3164
## measure2 -436.3164  138.6001
##
## Multivariate Tests: H1.2:measure
##                  Df test stat approx F num Df den Df   Pr(>F)
## Pillai            1 0.0878057 3.465277      2     72 0.036572 *
## Wilks             1 0.9121943 3.465277      2     72 0.036572 *
## Hotelling-Lawley  1 0.0962577 3.465277      2     72 0.036572 *
## Roy               1 0.0962577 3.465277      2     72 0.036572 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Univariate Type II Repeated-Measures ANOVA Assuming Sphericity
##
##              Sum Sq num Df Error SS den Df   F value    Pr(>F)
## (Intercept)  303968      1    12676     73 1750.6033 < 2.2e-16 ***
## H1.2           2425      1    12676     73   13.9685 0.0003666 ***
## measure       58237      2    16821    146  252.7354 < 2.2e-16 ***
## H1.2:measure   1299      2    16821    146    5.6373 0.0043823 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## Mauchly Tests for Sphericity
##
##              Test statistic   p-value
## measure             0.58244 3.541e-09
## H1.2:measure        0.58244 3.541e-09
##
##
## Greenhouse-Geisser and Huynh-Feldt Corrections
##  for Departure from Sphericity
##
##               GG eps Pr(>F[GG])
```

```
## measure      0.70544    < 2e-16 ***
## H1.2:measure 0.70544    0.01077 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##                 HF eps   Pr(>F[HF])
## measure      0.7152272 3.324336e-35
## H1.2:measure 0.7152272 1.045538e-02
```

Groups have different linear and quad trends

```
# simple effects, controlling for other outcomes
broom::tidy(aov(Anxiety ~ H1.1 + Persist + Perform, data = dat))

## # A tibble: 4 x 6
##   term         df  sumsq meansq statistic  p.value
##   <chr>     <dbl>  <dbl>  <dbl>     <dbl>    <dbl>
## 1 H1.1          1  922.   922.      44.5   4.64e-9
## 2 Persist       1  958.   958.      46.3   2.70e-9
## 3 Perform       1   48.5   48.5      2.34  1.30e-1
## 4 Residuals    71 1470.    20.7     NA    NA

broom::tidy(aov(Anxiety ~ H1.2 + Persist + Perform, data = dat))

## # A tibble: 4 x 6
##   term         df     sumsq   meansq statistic     p.value
##   <chr>     <dbl>     <dbl>    <dbl>     <dbl>       <dbl>
## 1 H1.2          1    0.0392   0.0392   0.00116  0.973
## 2 Persist       1  123.     123.       3.64     0.0606
## 3 Perform       1  875.     875.      25.9      0.00000285
## 4 Residuals    71 2400.      33.8     NA        NA
```

evidence for linear, not quadratic trend for anxiety, in accordance with the hypothesis

3.2 Hypothesis 2

Groups 2 and 3 should exert more persistence than Group 1 but should not differ from each other because there is an upper limit to the number of anagrams that can reasonably be attempted in 30 minutes.

```
dat <- dat %>%
  mutate(H2.1 = as.numeric(mapvalues(Group, 1:3, c(-2, 1, 1))), # G1 v. G2 + G3
         H2.2 = as.numeric(mapvalues(Group, 1:3, c(0, -1, 1)))) # G2 v. G3
# ombnius test
m4 <- lm(cbind(Anxiety, Persist, Perform) ~ H2.1 + H2.2, data = dat)
manova.H2.1 <- Anova(m4, data = dat, idesign = ~measure, idata = id, multivariate = T)
summary(manova.H2.1)

##
## Type II Repeated Measures MANOVA Tests:
##
## ------------------------------------------
##
## Term: (Intercept)
##
##  Response transformation matrix:
```

```
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
## Sum of squares and products for the hypothesis:
##             (Intercept)
## (Intercept)    911905.3
##
## Multivariate Tests: (Intercept)
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1   0.96988 2318.506      1     72 < 2.22e-16 ***
## Wilks             1   0.03012 2318.506      1     72 < 2.22e-16 ***
## Hotelling-Lawley  1  32.20147 2318.506      1     72 < 2.22e-16 ***
## Roy               1  32.20147 2318.506      1     72 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: H2.1
##
##  Response transformation matrix:
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
## Sum of squares and products for the hypothesis:
##             (Intercept)
## (Intercept)    7463.052
##
## Multivariate Tests: H2.1
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1 0.2085712  18.9747      1     72 4.3148e-05 ***
## Wilks             1 0.7914288  18.9747      1     72 4.3148e-05 ***
## Hotelling-Lawley  1 0.2635375  18.9747      1     72 4.3148e-05 ***
## Roy               1 0.2635375  18.9747      1     72 4.3148e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: H2.2
##
##  Response transformation matrix:
##         (Intercept)
## Anxiety           1
## Persist           1
## Perform           1
##
## Sum of squares and products for the hypothesis:
##             (Intercept)
```

```
## (Intercept)    718.2935
##
## Multivariate Tests: H2.2
##                  Df test stat approx F num Df den Df Pr(>F)
## Pillai            1 0.0247371 1.826251      1     72 0.1808
## Wilks             1 0.9752629 1.826251      1     72 0.1808
## Hotelling-Lawley  1 0.0253646 1.826251      1     72 0.1808
## Roy               1 0.0253646 1.826251      1     72 0.1808
##
## ------------------------------------------
##
## Term: measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##           measure1  measure2
## measure1  37587.21 -28363.91
## measure2 -28363.91  21403.85
##
## Multivariate Tests: measure
##                  Df test stat approx F num Df den Df     Pr(>F)
## Pillai            1  0.825154 167.5359      2     71 < 2.22e-16 ***
## Wilks             1  0.174846 167.5359      2     71 < 2.22e-16 ***
## Hotelling-Lawley  1  4.719320 167.5359      2     71 < 2.22e-16 ***
## Roy               1  4.719320 167.5359      2     71 < 2.22e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: H2.1:measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##           measure1  measure2
## measure1 1394.6992 -421.3051
## measure2 -421.3051  127.2661
##
## Multivariate Tests: H2.1:measure
##                  Df test stat approx F num Df den Df  Pr(>F)
## Pillai            1 0.0884315 3.443865      2     71 0.03737 *
## Wilks             1 0.9115685 3.443865      2     71 0.03737 *
## Hotelling-Lawley  1 0.0970103 3.443865      2     71 0.03737 *
```

```
## Roy               1 0.0970103 3.443865      2     71 0.03737 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## ------------------------------------------
##
## Term: H2.2:measure
##
##  Response transformation matrix:
##         measure1 measure2
## Anxiety        1        0
## Persist       -1       -1
## Perform        0        1
##
## Sum of squares and products for the hypothesis:
##          measure1 measure2
## measure1  394.875 -631.125
## measure2 -631.125 1008.721
##
## Multivariate Tests: H2.2:measure
##                  Df test stat approx F num Df den Df    Pr(>F)
## Pillai            1 0.1435015 5.947826      2     71 0.0040907 **
## Wilks             1 0.8564985 5.947826      2     71 0.0040907 **
## Hotelling-Lawley  1 0.1675444 5.947826      2     71 0.0040907 **
## Roy               1 0.1675444 5.947826      2     71 0.0040907 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Univariate Type II Repeated-Measures ANOVA Assuming Sphericity
##
##              Sum Sq num Df Error SS den Df   F value    Pr(>F)
## (Intercept)  303968      1   9439.6     72 2318.5060 < 2.2e-16 ***
## H2.1           2488      1   9439.6     72   18.9747 4.315e-05 ***
## H2.2            239      1   9439.6     72    1.8263  0.180802
## measure       58237      2  15832.7    144  264.8340 < 2.2e-16 ***
## H2.1:measure   1296      2  15832.7    144    5.8914  0.003473 **
## H2.2:measure   1356      2  15832.7    144    6.1687  0.002689 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##
## Mauchly Tests for Sphericity
##
##              Test statistic    p-value
## measure             0.44729 3.9448e-13
## H2.1:measure        0.44729 3.9448e-13
## H2.2:measure        0.44729 3.9448e-13
##
##
## Greenhouse-Geisser and Huynh-Feldt Corrections
##  for Departure from Sphericity
##
##               GG eps Pr(>F[GG])
```

```
## measure      0.64404  < 2.2e-16 ***
## H2.1:measure 0.64404   0.011069 *
## H2.2:measure 0.64404   0.009272 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##                 HF eps   Pr(>F[HF])
## measure      0.6507342 8.217931e-33
## H2.1:measure 0.6507342 1.082916e-02
## H2.2:measure 0.6507342 9.057900e-03
```

across the different measures, the groups differed, but we really just need a univariate test

```
broom::tidy(aov(Persist ~ H2.1, data = dat))

## # A tibble: 2 x 6
##   term         df sumsq meansq statistic  p.value
##   <chr>     <dbl> <dbl>  <dbl>     <dbl>    <dbl>
## 1 H2.1          1 4494. 4494.       47.8  1.50e-9
## 2 Residuals    73 6863.   94.0      NA   NA

broom::tidy(aov(Persist ~ H2.1 + Anxiety + Perform, data = dat))

## # A tibble: 4 x 6
##   term         df sumsq meansq statistic   p.value
##   <chr>     <dbl> <dbl>  <dbl>     <dbl>     <dbl>
## 1 H2.1          1 4494. 4494.      134.   5.40e-18
## 2 Anxiety       1 3094. 3094.       92.1  1.87e-14
## 3 Perform       1 1384. 1384.       41.2  1.33e- 8
## 4 Residuals    71 2385.   33.6      NA   NA
```

Groups 2 + 3 differ from 1 on persistence

```
broom::tidy(aov(Persist ~ H2.2, data = dat))

## # A tibble: 2 x 6
##   term         df sumsq meansq statistic     p.value
##   <chr>     <dbl> <dbl>  <dbl>     <dbl>       <dbl>
## 1 H2.2          1 3113.  3113.      27.6  0.00000143
## 2 Residuals    73 8243.   113.      NA   NA

broom::tidy(aov(Persist ~ H2.2 + Anxiety + Perform, data = dat))

## # A tibble: 4 x 6
##   term         df sumsq meansq statistic   p.value
##   <chr>     <dbl> <dbl>  <dbl>     <dbl>     <dbl>
## 1 H2.2          1 3113. 3113.       92.7  1.62e-14
## 2 Anxiety       1 3189. 3189.       95.0  9.96e-15
## 3 Perform       1 2671. 2671.       79.6  3.29e-13
## 4 Residuals    71 2383.   33.6      NA   NA
```

But groups 1 and 2 also differ from one another, not in accordance with teh hypothesis

3.3 Hypothesis 3

Performance should be greatest in Group 2. Group 1 should have lower performance than Group 2 because of lower motivation. Group 3 should have lower performance than Group 2 because of the incapacitating effects of high anxiety.

```
dat <- dat %>%
  mutate(H3.1 = as.numeric(mapvalues(Group, 1:3,  c(-1, 2, -1))), # G2 v. G1 + G3
         H3.2 = as.numeric(mapvalues(Group, 1:3, c(-1, 1, 0))), # G1 v. G2, perf, mod, mot
         H3.3 = as.numeric(mapvalues(Group, 1:3, c(0, 1, -1)))) # G2 v. G3, perf, mod anx
```

Performance should be greatest in Group 2.

```
mH3.1 <- lm(Perform ~ H3.1 + Anxiety + Persist, data = dat)
anova(mH3.1)

## Analysis of Variance Table
##
## Response: Perform
##           Df Sum Sq Mean Sq F value    Pr(>F)
## H3.1       1 2365.5  2365.5  28.739 9.803e-07 ***
## Anxiety    1 3900.5  3900.5  47.388 1.916e-09 ***
## Persist    1 6356.8  6356.8  77.230 5.787e-13 ***
## Residuals 71 5844.0    82.3
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

broom::tidy(mH3.1)

## # A tibble: 4 x 5
##   term        estimate std.error statistic  p.value
##   <chr>          <dbl>     <dbl>     <dbl>    <dbl>
## 1 (Intercept)   31.1      5.00        6.23 2.87e- 8
## 2 H3.1           4.59     2.40        1.91 5.98e- 2
## 3 Anxiety       -0.806    0.159      -5.09 2.85e- 6
## 4 Persist        0.812    0.0924      8.79 5.79e-13
```

Group 2's performance was better than the other groups, on average.
Group 1 should have lower performance than Group 2 because of lower motivation.

```
mH3.2 <- lm(Perform ~ H3.2*Persist + Anxiety, data = dat)
anova(mH3.2)

## Analysis of Variance Table
##
## Response: Perform
##              Df  Sum Sq Mean Sq  F value Pr(>F)
## H3.2          1   130.3   130.3   1.6282 0.2062
## Persist       1 12547.2 12547.2 156.7402 <2e-16 ***
## Anxiety       1   185.1   185.1   2.3119 0.1329
## H3.2:Persist  1     0.5     0.5   0.0060 0.9384
## Residuals    70  5603.6    80.1
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

broom::tidy(mH3.2)

## # A tibble: 5 x 5
##   term         estimate std.error statistic  p.value
```

```
##   <chr>           <dbl>     <dbl>     <dbl>    <dbl>
## 1 (Intercept)   30.0        9.19      3.27   0.00168
## 2 H3.2          -6.03       5.68     -1.06   0.292
## 3 Persist        1.10       0.275     3.98   0.000167
## 4 Anxiety       -0.343      0.241    -1.42   0.160
## 5 H3.2:Persist   0.0104     0.134     0.0776 0.938
```

Groups 1 and 2 don't differ as a function of persistence.

Group 3 should have lower performance than Group 2 because of the incapacitating effects of high anxiety.

```
mH3.3 <- lm(Perform ~ H3.3*Anxiety + Persist, data = dat)
anova(mH3.3)

## Analysis of Variance Table
##
## Response: Perform
##              Df Sum Sq Mean Sq F value    Pr(>F)
## H3.3          1  130.3   130.3  1.6532    0.2028
## Anxiety       1 6451.4  6451.4 81.8313 2.177e-13 ***
## Persist       1 6280.9  6280.9 79.6683 3.618e-13 ***
## H3.3:Anxiety  1   85.4    85.4  1.0833    0.3015
## Residuals    70 5518.7    78.8
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

broom::tidy(mH3.3)

## # A tibble: 5 x 5
##   term         estimate std.error statistic  p.value
##   <chr>           <dbl>     <dbl>     <dbl>    <dbl>
## 1 (Intercept)    36.1       8.06       4.47 2.90e- 5
## 2 H3.3           -9.60      4.38      -2.19 3.17e- 2
## 3 Anxiety        -0.866     0.547     -1.58 1.18e- 1
## 4 Persist         1.15      0.129      8.91 3.84e-13
## 5 H3.3:Anxiety    0.240     0.231      1.04 3.02e- 1
```

Groups 2 and 3 don't differ in performance as a function of anxiety.

On the whole, the multivariate approach seems to add little to tests of these hypotheses, which largely specify univariate questions with predetermined group structures, with the partial exception of the third question, which, even then, can also be answered with a univariate approach.