Lab 7 – $A \times B$ Factorial Designs

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Situation

There are 2 factors thought to influence the response variable

The effect of each factor might depend on the other factor

We have replicates for each combination of factors

Example: effects of food and predators on voles

```
voleData <- read.csv("microtus_data.csv")
head(voleData, 7)

##   voles food predators
## 1    10    0   Present
## 2    12    0   Present
## 3     8    0   Present
## 4    14    0   Present
## 5    18    1   Present
## 6    20    1   Present
## 7    21    1   Present

str(voleData)

## 'data.frame': 24 obs. of  3 variables:
##  $ voles    : int  10 12 8 14 18 20 21 24 20 18 ...
##  $ food     : int  0 0 0 0 1 1 1 1 2 2 ...
##  $ predators: Factor w/ 2 levels "Absent","Present": 2 2 2 2 2 2 2 2 2 2 ...
```


Must convert food to a factor

```
voleData$food <- factor(voleData$food)
str(voleData)

## 'data.frame': 24 obs. of  3 variables:
##  $ voles    : int  10 12 8 14 18 20 21 24 20 18 ...
##  $ food     : Factor w/ 3 levels "0","1","2": 1 1 1 1 2 2 2 2
##  $ predators: Factor w/ 2 levels "Absent","Present": 2 2 2 2 2
```

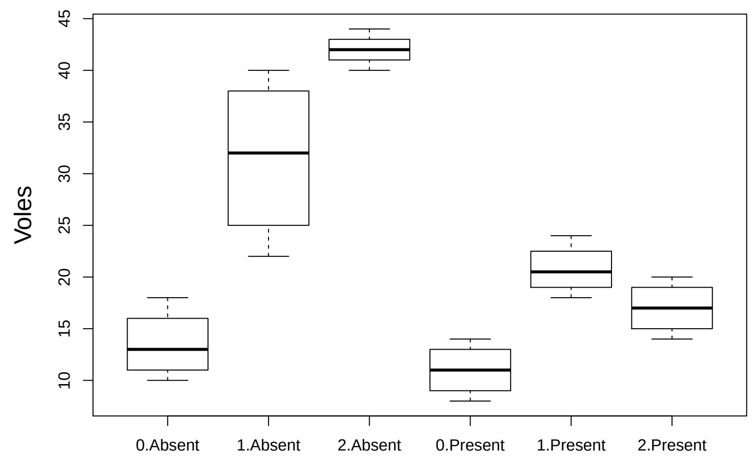
See how many replicates you have

```
table(voleData$predators, voleData$food)

##
##            0 1 2
##   Absent  4 4 4
##   Present 4 4 4
```


Boxplot with 2 factors

```
boxplot(voles ~ food + predators, data=voleData, ylab="Voles", cex.lab=1.5)
```



$A \times B$ interaction

```
aov1 <- aov(voles ~ food * predators, data=voleData)
summary(aov1)

##                Df Sum Sq Mean Sq F value   Pr(>F)
## food            2 1337.3   668.6   40.56 2.15e-07 ***
## predators       1  975.4   975.4   59.16 4.27e-07 ***
## food:predators  2  518.2   259.1   15.72 0.000112 ***
## Residuals      18  296.8    16.5
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```


No interaction

```
aov2 <- aov(voles ~ food + predators, data=voleData)
summary(aov2)

##             Df Sum Sq Mean Sq F value   Pr(>F)
## food         2 1337.3   668.6   16.41 6.06e-05 ***
## predators    1  975.4   975.4   23.94 8.81e-05 ***
## Residuals   20  815.0    40.8
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Follow-up

Effect of food when predators are present

```
summary(aov(voles ~ food, data=voleData, subset=predators=="Present"))

##             Df Sum Sq Mean Sq F value  Pr(>F)
## food         2 193.50   96.75   14.82 0.00142 **
## Residuals    9  58.75    6.53
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Effect of food when predators are absent

```
summary(aov(voles ~ food, data=voleData, subset=predators=="Absent"))

##             Df Sum Sq Mean Sq F value   Pr(>F)
## food         2   1662   831.0   31.42 8.71e-05 ***
## Residuals    9    238    26.4
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```


Tukey's HSD

```
TukeyHSD(aov1)

##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = voles ~ food * predators, data = voleData)
##
## $food
##       diff       lwr       upr     p adj
## 1-0 13.875  8.693714 19.056286 0.0000061
## 2-0 17.250 12.068714 22.431286 0.0000003
## 2-1  3.375 -1.806286  8.556286 0.2464315
##
## $predators
##                  diff       lwr       upr p adj
## Present-Absent -12.75 -16.23252 -9.267482 4e-07
##
## $`food:predators`
##                       diff         lwr        upr     p adj
## 1:Absent-0:Absent    18.00   8.8756323  27.124368 0.0000827
## 2:Absent-0:Absent    28.50  19.3756323  37.624368 0.0000001
## 0:Present-0:Absent   -2.50 -11.6243677   6.624368 0.9487798
## 1:Present-0:Absent    7.25  -1.8743677  16.374368 0.1684043
## 2:Present-0:Absent    3.50  -5.6243677  12.624368 0.8221335
## 2:Absent-1:Absent    10.50   1.3756323  19.624368 0.0189039
## 0:Present-1:Absent  -20.50 -29.6243677 -11.375632 0.0000154
## 1:Present-1:Absent  -10.75 -19.8743677  -1.625632 0.0157740
## 2:Present-1:Absent  -14.50 -23.6243677  -5.375632 0.0010013
## 0:Present-2:Absent  -31.00 -40.1243677 -21.875632 0.0000000
## 1:Present-2:Absent  -21.25 -30.3743677 -12.125632 0.0000095
## 2:Present-2:Absent  -25.00 -34.1243677 -15.875632 0.0000010
## 1:Present-0:Present   9.75   0.6256323  18.874368 0.0323125
## 2:Present-0:Present   6.00  -3.1243677  15.124368 0.3351103
```


Compute group means and SEs

```
ybar_ij.SE <- model.tables(aov1, type="means", se=TRUE)
ybar_ij.SE

## Tables of means
## Grand mean
##
## 22.625
##
##  food
## food
##      0      1      2
## 12.250 26.125 29.500
##
##  predators
## predators
##  Absent Present
##   29.00   16.25
##
##  food:predators
##     predators
## food Absent Present
##    0 13.50  11.00
##    1 31.50  20.75
##    2 42.00  17.00
##
## Standard errors for differences of means
##          food predators food:predators
##         2.030     1.658          2.871
## replic.     8        12              4
```


Extract group means and SEs

Group means

```
ybar_ij. <- ybar_ij.SE$tables$"food:predators"
ybar_ij.

##     predators
## food Absent Present
##    0 13.50   11.00
##    1 31.50   20.75
##    2 42.00   17.00
```

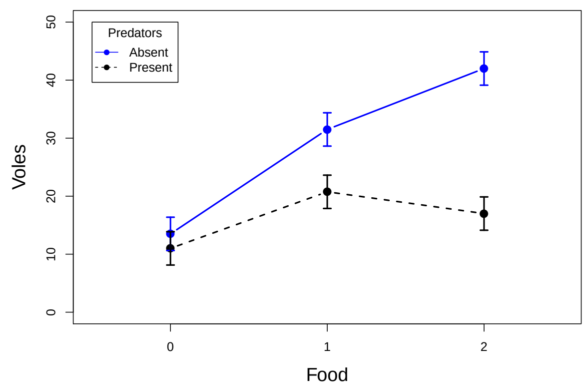
Standard error

```
SE_ij. <- as.numeric(ybar_ij.SE$se$"food:predators")
SE_ij.

## [1] 2.871072
```

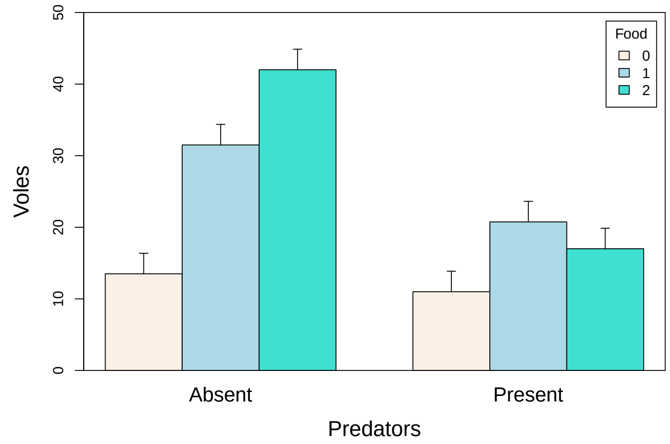
Plot group means and SEs

```
plot(1:3, ybar_ij.[,1], xaxt="n", xlim=c(0.5, 3.5), ylim=c(0, 50), type="b",
     pch=16, col="blue", xlab="Food", ylab="Voles", cex=1.5, cex.lab=1.5, lwd=2)
lines(1:3, ybar_ij.[,2], pch=16, col="black", type="b", cex=1.5, lty=2, lwd=2)
axis(1, 1:3, labels=c("0", "1", "2"))
arrows(1:3, ybar_ij.[,1]-SE_ij., 1:3, ybar_ij.[,1]+SE_ij., code=3, angle=90,
       length=0.05, lwd=2, col="blue")
arrows(1:3, ybar_ij.[,2]-SE_ij., 1:3, ybar_ij.[,2]+SE_ij., code=3, angle=90,
       length=0.05, lwd=2)
legend(0.5, 50, c("Absent", "Present"), col=c("blue", "black"), lty=c(1,2), title="Predators", pch=16)
```



Plot group means and SEs

```
bp <- barplot(ybar_ij., xlab="Predators", args.legend=list(title="Food"),
              cex.lab=1.5, cex.names=1.4, col=c("linen", "lightblue", "turquoise"),
              ylab="Voles", beside=TRUE, legend=TRUE, ylim=c(0, 50)); box()
arrows(bp, ybar_ij., bp, ybar_ij.+SE_ij., code=2, angle=90, length=0.05, lwd=1)
```



In-class exercise

Fictitious Scenario

Acid rain has lowered the pH of many lakes in the northeastern United States, and as a result, fish populations have declined. Managers have resorted to aerial applications of lime (powdered calcium carbonate) in hopes of increasing pH. To determine if lime applications result in increased pH, they applied equal amounts of lime to 15 lakes, and as a control, they applied the same amount of inert white powder to an additional 15 lakes. Researchers suspected that the effect of lime might depend upon the buffering effects of the underlying bedrock. To assess this hypothesis, the 30 lakes were chosen such that 10 had limestone bedrock, 10 had granite bedrock, and 10 had shist bedrock. pH was measured before and after each application, and the difference in pH is recorded in the file "acidityData.csv."

Questions

1. What are the null and alternative hypotheses?
2. Test the null hypotheses using an $A \times B$ factorial ANOVA implemented with `aov`. Create an ANOVA table using `summary`.
3. Does the effect of lime depend upon the bedrock type? If so, how? Answer this question by plotting the estimates of the effect of lime on pH change. Include 95% confidence intervals.

Put your answers in a self-contained **R** script, and upload the script to ELC at least one day before your next lab.