```r
knitr::opts_chunk$set(echo = TRUE)
nsims <- 100000 #set number of simulations
library(mvtnorm)
library(afex)
library(emmeans)
library(ggplot2)
library(gridExtra)
library(reshape2)
```

Validation of Power in Repeated Measures ANOVA

We first repeat the simulation by Brysbaert:

```r
# give sample size
N = 75

# give effect size d
d1 = .4 #difference between the extremes
d2 = .4 #third condition goes with the highest extreme

# give the correlation between the conditions
r = .5

# give number of simulations
nSim = nsims

# give alpha levels
alpha1 = .05 #alpha level for the omnibus ANOVA
alpha2 = .05 #also adjusted from original by DL

# create progress bar in case it takes a while
#pb <- winProgressBar(title = "progress bar", min = 0, max = nSim, width = 300)

# create vectors to store p-values
p1 <-numeric(nSim) #p-value omnibus ANOVA
p2 <-numeric(nSim) #p-value first post hoc test
p3 <-numeric(nSim) #p-value second post hoc test
p4 <-numeric(nSim) #p-value third post hoc test

# open library MASS
library('MASS')

# define correlation matrix
rho <- cbind(c(1, r, r), c(r, 1, r), c(r, r, 1))

# define participant codes
part <- paste("part",seq(1:N))

for(i in 1:nSim){ #for each simulated experiment
 # setWinProgressBar(pb, i, title=paste(round(i/nSim*100, 1), "% done"))
  data = mvrnorm(n=N, mu=c(0, 0, 0), Sigma=rho)
  data[,2] = data[,2]+d1
  data[,3] = data[,3]+d2
```

```r
  datalong = c(data[,1],data[,2],data[,3])
  conds= factor(rep(letters[24:26], each = N))
  partID = factor(rep(part, times = 3))
  output <-data.frame(partID,conds,datalong)
  test <- aov(datalong~conds + Error(partID/conds), data=output)
  tests <- (summary(test))
  p1[i] <- tests$'Error: partID:conds'[[1]]$'Pr(>F)'[[1]]
  p2[i] <- t.test(data[,1],data[,2], paired=TRUE)$p.value
  p3[i] <- t.test(data[,1],data[,3], paired=TRUE)$p.value
  p4[i] <- t.test(data[,2],data[,3], paired=TRUE)$p.value
  }
#close(pb)#close progress bar

#printing all unique tests (adjusted code by DL)
sum(p1<alpha1)/nSim
```

```
## [1] 0.95236
```

```r
sum(p2<alpha2)/nSim
```

```
## [1] 0.92702
```

```r
sum(p3<alpha2)/nSim
```

```
## [1] 0.92803
```

```r
sum(p4<alpha2)/nSim
```

```
## [1] 0.04996
```

Installation

We install the functions:

```r
# Install the two functions from GitHub by running the code below:

source("https://raw.githubusercontent.com/Lakens/ANOVA_power_simulation/master/ANOVA_design.R")
source("https://raw.githubusercontent.com/Lakens/ANOVA_power_simulation/master/ANOVA_power.R")
```

Reproducing Brysbaert

We can reproduce the same results as Brysbaert finds with his code:

```r
string <- "3w"
n <- 75
mu <- c(0, 0.4, 0.4)
sd <- 1
r <- 0.5
p_adjust = "none"
labelnames <- c("speed", "fast", "medium", "slow")
```

We create the within design, and run the simulation

```r
design_result <- ANOVA_design(string = string,
                   n = n,
                   mu = mu,
```

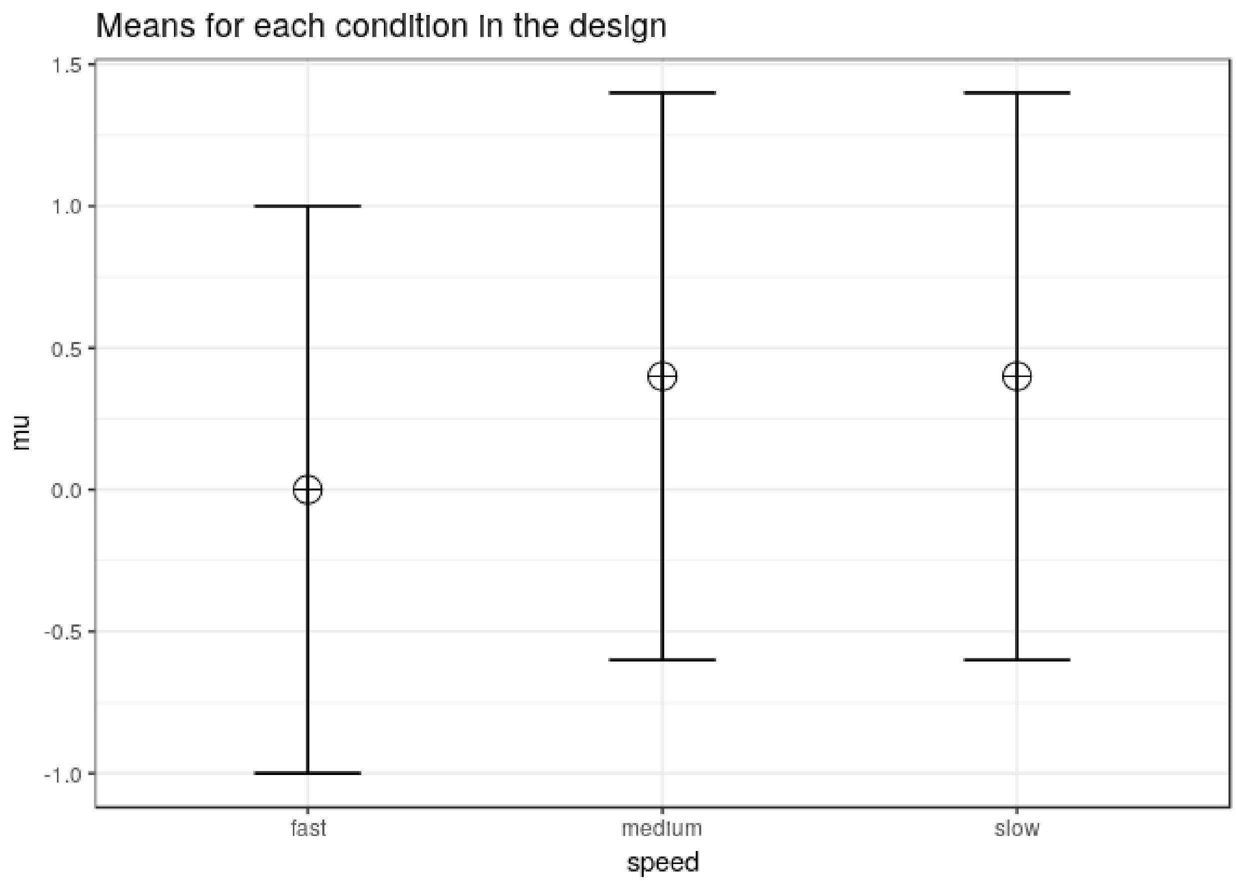


Figure 1:

```
                    sd = sd,
                    r = r,
                    p_adjust = "none",

                                       labelnames = labelnames)
```

```
ANOVA_power(design_result, nsims = nsims)
```

```
## Power and Effect sizes for ANOVA tests
##             power effect size
## anova_speed 95.09      0.1033
##
## Power and Effect sizes for contrasts
##                              power effect size
## p_speed_fast_speed_medium 92.653      0.4035
## p_speed_fast_speed_slow   92.699      0.4036
## p_speed_medium_speed_slow  4.957      0.0002
```

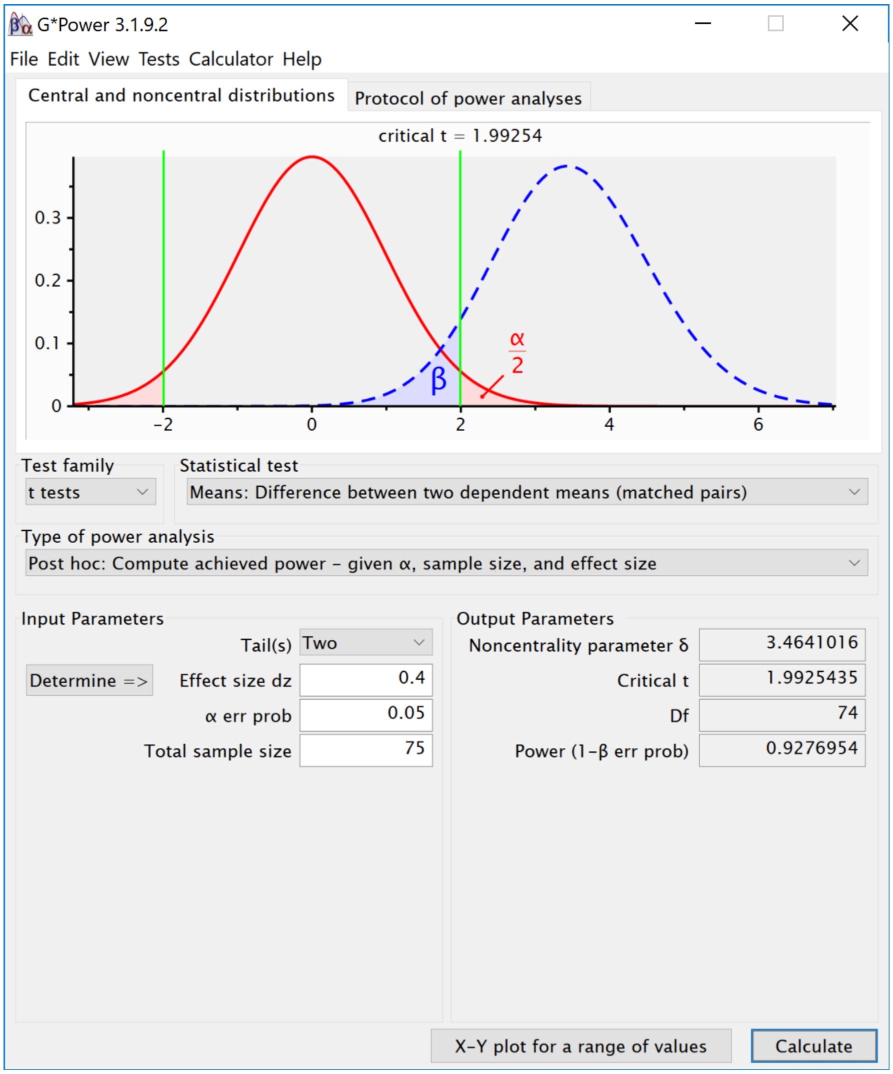


Figure 2:

Results

The results of the simulation are very similar. Power for the ANOVA F-test is around 95.2%. For the three paired t-tests, power is around 92.7. This is in line with the a-priori power analysis when using g*power:

We can perform an post-hoc power analysis in G*power. We can calculate Cohen´s f based on the means and sd, using our own custom formula.

```
# Our simulation is based onthe following means and sd:
# mu <- c(0, 0.4, 0.4)
# sd <- 1

f <- sqrt(sum((mu-mean(mu))^2)/length(mu))/sd #Cohen, 1988, formula 8.2.1 and 8.2.2
# We can see why f = 0.5*d.
# Imagine 2 group, mu = 1 and 2
# Grand mean is 1.5, we have sqrt(sum(0.5^2 + 0.5^2)/2), or sqrt(0.5/2), = 0.5.
# For Cohen's d we use the difference, 2-1 = 1.
```

The Cohen´s f is 0.1885618. We can enter the f (using the default 'as in G*Power 3.0' in the option window) and enter a sample size of 75, number of groups as 1, number of measurements as 3, correlation as 0.5. This yields:

Reproducing Brysbaert Variation 1 Changing Correlation

```
# give sample size
N = 75

# give effect size d
d1 = .4 #difference between the extremes
d2 = .4 #third condition goes with the highest extreme

# give the correlation between the conditions
r = .6 #increased correlation

# give number of simulations
nSim = nsims

# give alpha levels
alpha1 = .05 #alpha level for the omnibus ANOVA
alpha2 = .05 #also adjusted from original by DL

# create progress bar in case it takes a while
#pb <- winProgressBar(title = "progress bar", min = 0, max = nSim, width = 300)

# create vectors to store p-values
p1 <-numeric(nSim) #p-value omnibus ANOVA
p2 <-numeric(nSim) #p-value first post hoc test
p3 <-numeric(nSim) #p-value second post hoc test
p4 <-numeric(nSim) #p-value third post hoc test

# open library MASS
library('MASS')

# define correlation matrix
rho <- cbind(c(1, r, r), c(r, 1, r), c(r, r, 1))

# define participant codes
part <- paste("part",seq(1:N))

for(i in 1:nSim){ #for each simulated experiment
 # setWinProgressBar(pb, i, title=paste(round(i/nSim*100, 1), "% done"))
  data = mvrnorm(n=N, mu=c(0, 0, 0), Sigma=rho)
  data[,2] = data[,2]+d1
  data[,3] = data[,3]+d2
  datalong = c(data[,1],data[,2],data[,3])
  conds= factor(rep(letters[24:26], each = N))
  partID = factor(rep(part, times = 3))
  output <-data.frame(partID,conds,datalong)
  test <- aov(datalong~conds + Error(partID/conds), data=output)
  tests <- (summary(test))
  p1[i] <- tests$'Error: partID:conds'[[1]]$'Pr(>F)'[[1]]
```

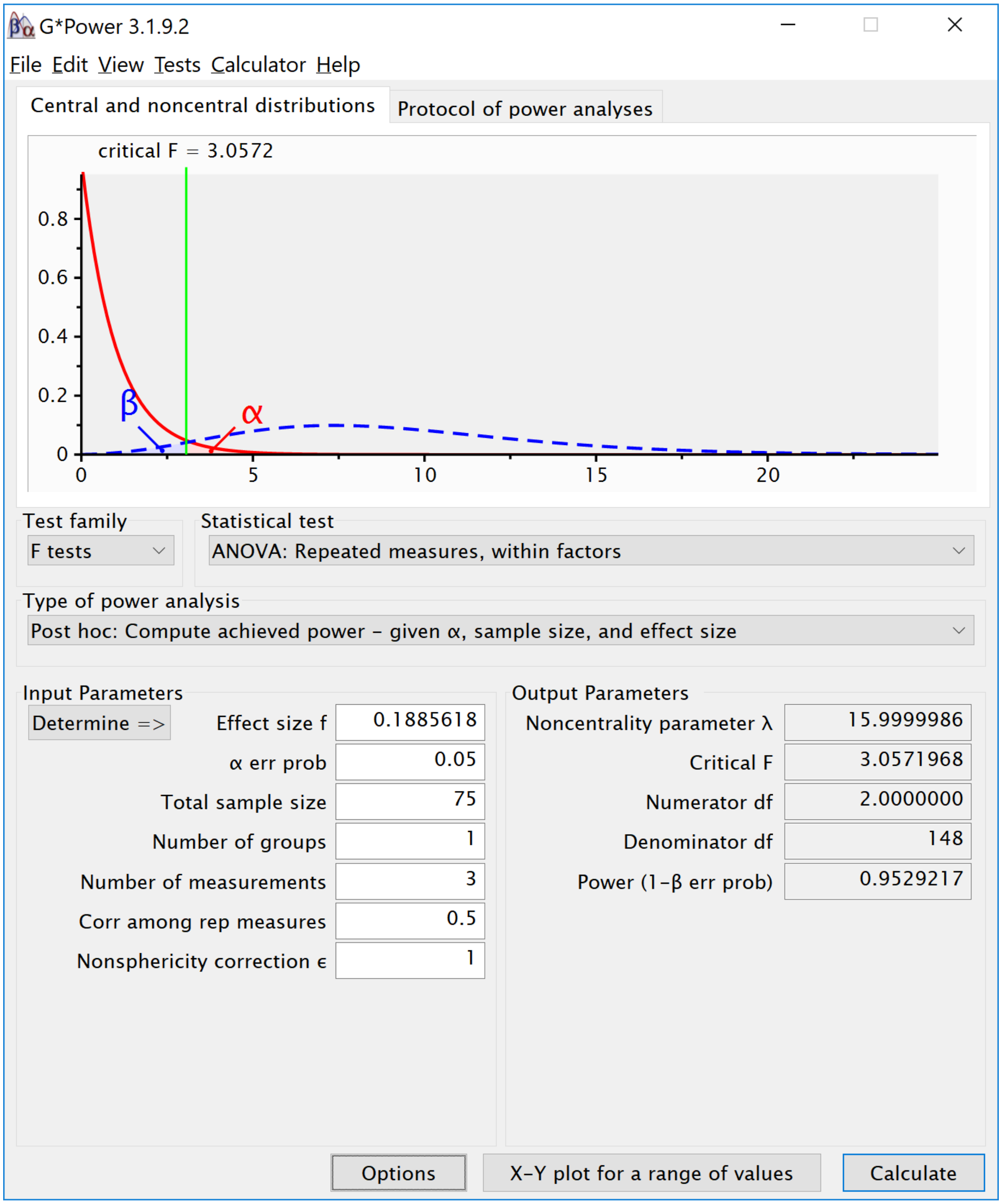

G*Power 3.1.9.2
File Edit View Tests Calculator Help
Central and noncentral distributions
Protocol of power analyses
critical F = 3.0572
Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power – given α, sample size, and effect size
Input Parameters
Determine =>
Effect size f 0.1885618
α err prob 0.05
Total sample size 75
Number of groups 1
Number of measurements 3
Corr among rep measures 0.5
Nonsphericity correction ϵ 1
Output Parameters
Noncentrality parameter λ 15.9999986
Critical F 3.0571968
Numerator df 2.0000000
Denominator df 148
Power (1–β err prob) 0.9529217
Options
X–Y plot for a range of values
Calculate

Figure 3:

```r
  p2[i] <- t.test(data[,1],data[,2], paired=TRUE)$p.value
  p3[i] <- t.test(data[,1],data[,3], paired=TRUE)$p.value
  p4[i] <- t.test(data[,2],data[,3], paired=TRUE)$p.value
  }
#close(pb)#close progress bar

#printing all unique tests (adjusted code by DL)
sum(p1<alpha1)/nSim
```

```
## [1] 0.9834
```

```r
sum(p2<alpha2)/nSim
```

```
## [1] 0.96852
```

```r
sum(p3<alpha2)/nSim
```

```
## [1] 0.96786
```

```r
sum(p4<alpha2)/nSim
```

```
## [1] 0.04983
```

```r
string <- "3w"
n <- 75
mu <- c(0, 0.4, 0.4)
sd <- 1
r <- 0.6
p_adjust = "none"
labelnames <- c("speed", "fast", "medium", "slow")
```

We create the within design, and run the simulation

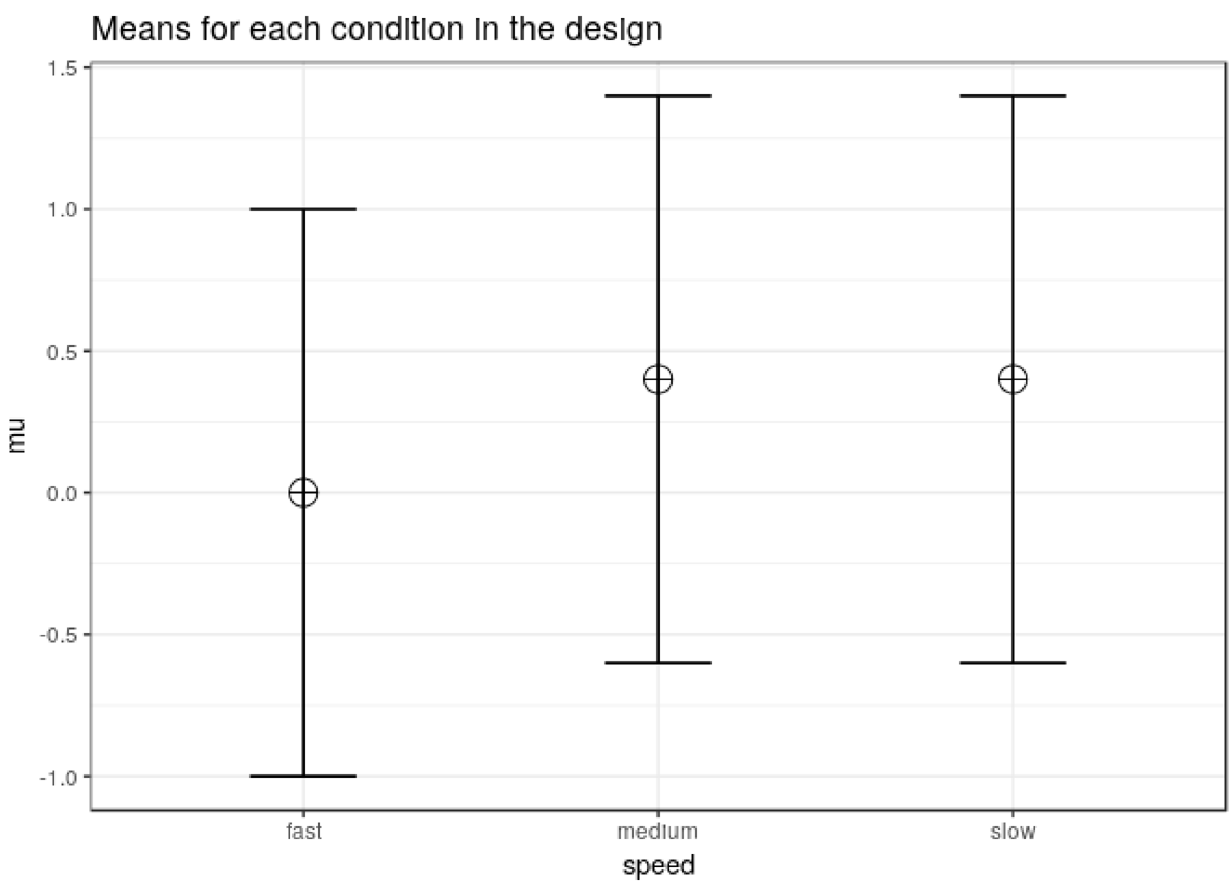
```r
design_result <- ANOVA_design(string = string,
                   n = n,
                   mu = mu,
                   sd = sd,
                   r = r,
                   p_adjust = "none",

                                     labelnames = labelnames)
```

```r
ANOVA_power(design_result, nsims = nsims)
```

```
## Power and Effect sizes for ANOVA tests
##              power effect size
## anova_speed 98.368      0.1247
##
## Power and Effect sizes for contrasts
##                           power effect size
## p_speed_fast_speed_medium 96.853      0.4516
## p_speed_fast_speed_slow   96.962      0.4521
## p_speed_medium_speed_slow  5.119      0.0005
```

Again, this is similar to g*power for the ANOVA:



Means for each condition in the design
1.5
1.0
0.5
0.0
-0.5
-1.0
mu
fast
medium
slow
speed

Figure 4:

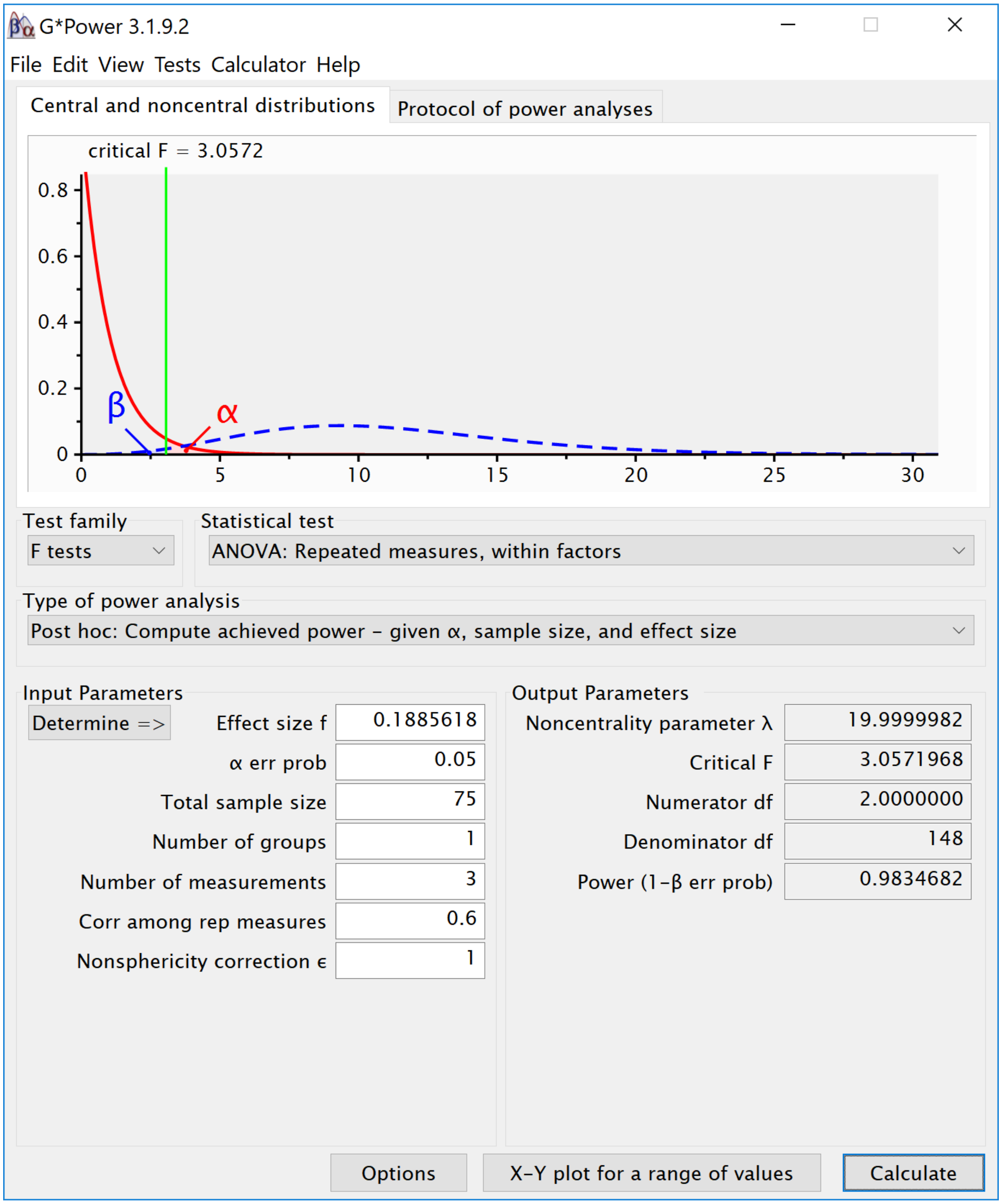

G*Power 3.1.9.2
File Edit View Tests Calculator Help
Central and noncentral distributions
Protocol of power analyses
critical F = 3.0572
0.8
0.6
0.4
0.2
0
β
α
0
5
10
15
20
25
30
Test family
F tests
Statistical test
ANOVA: Repeated measures, within factors
Type of power analysis
Post hoc: Compute achieved power – given α, sample size, and effect size
Input Parameters
Determine =>
Effect size f
0.1885618
α err prob
0.05
Total sample size
75
Number of groups
1
Number of measurements
3
Corr among rep measures
0.6
Nonsphericity correction ϵ
1
Output Parameters
Noncentrality parameter λ
19.9999982
Critical F
3.0571968
Numerator df
2.0000000
Denominator df
148
Power (1–β err prob)
0.9834682
Options
X–Y plot for a range of values
Calculate

Figure 5: