

## ASSIGNMENT SIX

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### PLEASE NOTE – Computationally intensive lab

Be careful with compiling this report! It will take a very long time. Please make sure to run your code interactively before compiling and make sure your code is correct. Then compile it. I would also recommend setting the argument, `cache = TRUE` at the top of each chunk once you're sure you have the code correct. You can do this between by doing the following ```{r, cache = TRUE}`

Do not wait till the last minute to complete this lab!!!

### Purpose

The purpose of this lab is to gain experience running a power analysis using simulation. We'll generate data using the `simulateData` function available in the *Lavaan* package. **Please note this lab could take a while to complete just because the simulations can take a while!**

When we do power analyses we generally want to determine either the sample size or the minimum detectable effect size (MDES) for a given test that has a power of at least .80. Typically in power analyses we set alpha (our type I error rate) to .05 (our de facto threshold for determining statistical significance).

For the simulation-based power analyses we'll do in this lab, you will run 1000 replicates (i.e., you will generate data, fit a model, and save a p-value 1000 times and then you will pool your findings over these replicates). Note, if you were doing this for real, you should probably use 2000 or 5000 replicates. We are using 1000 replicates because anymore will take an extremely long time to run!

The number of replicates out of the 1000 replicates where the p-value is less than alpha (i.e., .05) is an empirical estimate of power. So, if we're running a power analysis for a given test and 900 of the 1000 replicates for a certain test have a p-value less than .05, then our power is .90. Please keep in mind that power is always specific to a certain test. In our simulations, we'll investigate z-tests and the chi-square test of model fit.

Before getting started, please read the help page for `simulateData` and make sure you pay attention to the Examples section and the `#specify population model` part in particular.

`?simulateData`

Note, that the `simulateData` function assumes the data are multivariate normal.

The population model is always our true model. Or if you're doing this for a grant proposal or a dissertation prospectus, this would be your assumed model. You would derive this model based on research or content expertise.

In the lab, we'll run three set of power analyses.

## Correlation

For the first power analysis, we'll figure out the power of a z-test for determining whether the correlation between two variables, X and Y, is significant. The first thing we need to specify is the population model (again this is our our true model, which we'll call *pop.mod* below). Let's say in the population you believe the correlation between X and Y is .2. To set this up in *Lavaan*, you would do the following:

```
library(lavaan)

## Warning: package 'lavaan' was built under R version 3.5.3

## This is lavaan 0.6-3

## lavaan is BETA software! Please report any bugs.

pop.mod <- '
Y ~~ .2*X # set correlation to .2

# fix variance of X and Y to one
# so they are standardized
Y ~~ 1*Y
X ~~ 1*X
'
```

Now, what we want to do is find out the minimum sample size necessary to have a power of at least .80 of detecting a correlation of .2 between X and Y. Imagine, we're applying for a grant and we need to justify our sample size. Well that's exactly what the power analysis would do!

So, what we'll do is pass a range of sample size from 100 - 200 by 20 (so 100, 120, ..., 180, 200) and then we'll plot the empirical power as a function of the sample size. To do this you'll use the code below and modify it shortly. The comments within the code should help.

```
# the range of sample size we want to investigate
N <- seq(100, 200, 20)

# The lavaan model we'll fit
mod <- '
Y ~~ X

# again, these are just to make sure our est. is
# a correlation NOT a covariance
```

```

Y ~~ 1*Y
X ~~ 1*X
'

# we've always got to set a seed
set.seed(1235)

# this is our simulation function
# it looks tricky but it really isn't
# It says for the range of sample sizes do the following ...
run.sim <- sapply(N, function(N) {

  # repeat a function 1,000 times
  replicate(n = 1000, expr = {

    # generate our data with the sample size set to N
    tmp.data <- simulateData(pop.mod, sample.nobs = N)

    # estimate the model (this should look very familiar)
    fit <- sem(mod, tmp.data)

    # extract the parameter estimates
    params <- parameterEstimates(fit)

    # return just the p-value from the z-test of the correlation between Y and X
    subset(params, lhs == "Y" & rhs == "X", "pvalue", drop = TRUE)
  })
})

# you can print
run.sim

##           [,1]           [,2]           [,3]           [,4]
## [1,] 1.391382e-01 1.830643e-02 1.450206e-02 1.563783e-02 7.57454
## 9e-03
## [2,] 1.027322e-02 7.386291e-06 4.475715e-01 1.527909e-02 2.31643
## 0e-01
## [3,] 5.584140e-01 1.390898e-02 5.920854e-05 3.612952e-04 1.45842
## 0e-07
## [4,] 4.313940e-01 9.408179e-02 3.339040e-01 5.357175e-02 7.02748
## 9e-02
## [5,] 1.295046e-02 2.230918e-04 6.903485e-02 4.356969e-01 5.60955
## 7e-03
## [6,] 2.439630e-02 1.846107e-02 1.743817e-02 4.840756e-05 2.48102
## 2e-02

```

```
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## [8,] 9.775493e-01 3.389069e-01 2.531265e-02 3.443857e-04 1.31751  
4e-05  
## [9,] 2.209583e-02 2.765479e-01 2.371250e-02 8.890302e-04 4.28957  
2e-01  
## [10,] 6.021574e-03 1.071462e-06 4.699021e-02 1.899773e-01 1.43479  
9e-05  
## [11,] 7.554629e-01 1.996026e-02 1.068843e-03 4.998267e-06 6.48505  
4e-08  
## [12,] 5.210506e-01 9.920353e-11 2.522722e-01 2.254006e-05 1.86716  
7e-01  
## [13,] 4.172833e-02 1.093261e-02 2.835615e-03 5.296685e-03 3.01434  
9e-03  
## [14,] 1.346904e-02 3.828432e-01 3.873799e-01 3.550527e-03 4.29089  
0e-04  
## [15,] 2.682295e-01 7.821044e-03 1.050980e-02 7.690413e-03 5.61533  
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## [16,] 1.358232e-08 1.577379e-05 4.435342e-04 1.065095e-02 2.98127  
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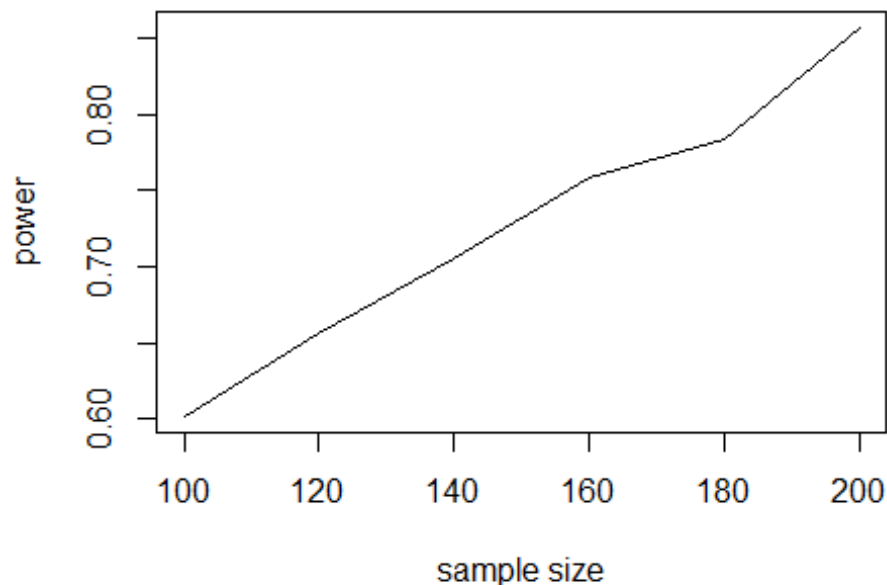
```

# to see what it contains.

# Now calculate the correlation by the sample size
calc.power <- data.frame(sample.size = N,
                          # for each column (level of sample size) find
                          the proportion of p-values < .05
                          power = apply(run.sim, 2, function(x) mean(x
< .05))))
# what does this look like
calc.power

##   sample.size power
## 1         100 0.602
## 2         120 0.656
## 3         140 0.706
## 4         160 0.759
## 5         180 0.784
## 6         200 0.857

# now lets plot it
plot(power ~ sample.size, calc.power, type = "l", xlab = "sample size"
)
```



Note, that the power curve won't necessarily be smooth and because of simulation error, larger sample sizes could potentially result in smaller power, which wouldn't happen if you increased the number of replicates. All simulations introduce error.

Question 1: Based on the plot, what is the minimum sample size you need to have a power of at least .80 to detect a correlation of .2 between X and Y? (1 pt)

For the power of 0.784, the minimum sample size is 180. Therefore, for the power of at least 0.80, the minimum estimated and assumed sample size I need to detect a correlation of 0.2 between X and Y is 184 based on the plot.

Question 2: Now copy all the code above and paste it below and adapt the `pop.mod` code to determine the sample size you need to get a power of .8 to detect a correlation of .4 between X and Y and change the sample sizes you'll investigate to be 10 to 100 by 10. Hint, this requires you to change two things in the code! Run the simulation below and then report the minimum sample size needed to have a power of .80. (3 pts)

```
library(lavaan)
pop.mod <- '
Y ~~ .4*X # set correlation to .4

# fix variance of X and Y to one
# so they are standardized
Y ~~ 1*Y
X ~~ 1*X
'

# the range of sample size we want to investigate
N <- seq(10, 100, 10)

# The lavaan model we'll fit
mod <- '
Y ~~ X

# again, these are just to make sure our est. is
# a correlation NOT a covariance
Y ~~ 1*Y
X ~~ 1*X
'

# we've always got to set a seed
set.seed(1235)

# this is our simulation function
# it looks tricky but it really isn't
```

```

# It says for the range of sample sizes do the following ...
run.sim <- sapply(N, function(N) {

  # repeat a function 1,000 times
  replicate(n = 1000, expr = {

    # generate our data with the sample size set to N
    tmp.data <- simulateData(pop.mod, sample.nobs = N)

    # estimate the model (this should look very familiar)
    fit <- sem(mod, tmp.data)

    # extract the parameter estimates
    params <- parameterEstimates(fit)

    # return just the p-value from the z-test of the correlation between Y and X
    subset(params, lhs == "Y" & rhs == "X", "pvalue", drop = TRUE)
  })
})

# you can print
run.sim

##           [,1]           [,2]           [,3]           [,4]
## [1,] 2.986383e-08 1.373643e-03 3.373431e-03 3.889895e-09 9.20259
0e-09
## [2,] 6.676306e-01 0.000000e+00 2.768158e-05 3.903203e-07 9.32965
0e-05
## [3,] 7.601002e-02 1.659696e-01 5.487371e-05 7.093748e-11 1.85544
4e-01
## [4,] 0.000000e+00 1.139775e-01 2.669762e-01 5.034900e-03 1.20597
5e-10
## [5,] 5.925765e-01 4.593179e-05 1.170646e-02 4.996004e-14 5.64169
8e-04
## [6,] 5.184948e-03 4.663914e-02 1.033913e-02 6.683076e-04 6.11634
2e-02
## [7,] 6.285253e-01 4.509653e-02 1.436333e-10 6.229578e-02 3.27380
5e-03
## [8,] 7.498002e-12 9.861414e-01 2.833521e-06 1.910464e-07 6.66136
7e-04
## [9,] 4.007140e-01 8.762933e-01 3.255180e-06 6.781957e-04 6.55871
1e-03
## [10,] 2.396882e-02 5.988627e-08 2.240191e-05 3.766747e-04 5.35706
0e-04

```

```
## [11,] 5.844853e-10 0.000000e+00 5.251124e-01 2.294541e-01 1.39236
1e-06
## [12,] 7.764429e-07 1.323709e-01 6.520356e-02 1.293568e-03 3.60267
6e-03
## [13,] 2.119420e-01 3.605710e-01 2.783775e-01 1.072479e-01 1.55619
2e-06
## [14,] 5.838116e-02 1.079671e-01 1.033815e-02 8.008302e-02 3.46643
0e-06
## [15,] 1.641578e-01 3.682165e-04 6.191841e-02 1.514426e-03 2.66151
0e-07
## [16,] 3.967532e-01 6.825858e-01 4.264271e-09 2.384829e-01 9.32224
5e-03
## [17,] 1.000191e-02 2.220446e-16 4.019040e-05 4.179749e-01 1.62292
5e-09
## [18,] 3.484142e-02 5.546775e-02 2.048125e-02 2.922390e-02 2.35327
4e-06
## [19,] 2.151725e-02 2.277432e-04 8.094417e-05 1.738778e-06 6.62389
6e-03
## [20,] 3.678580e-06 5.586404e-01 8.460075e-01 9.104414e-05 7.59262
9e-02
## [21,] 1.314033e-01 6.204470e-02 0.000000e+00 2.476560e-04 6.38888
1e-02
## [22,] 8.015044e-06 4.153005e-01 1.194688e-01 1.333019e-07 3.26757
4e-06
## [23,] 2.220446e-15 1.133333e-03 6.352718e-11 3.267594e-01 3.24464
9e-11
## [24,] 3.498310e-02 7.060192e-01 4.754780e-08 4.528040e-05 3.33066
9e-15
## [25,] 1.007784e-01 4.341562e-01 2.899347e-03 1.037605e-02 8.38542
8e-08
## [26,] 6.410491e-01 4.539566e-02 2.597922e-14 9.500950e-04 1.23356
3e-03
## [27,] 5.358134e-04 1.808144e-03 6.027927e-02 2.559915e-03 1.55967
8e-02
## [28,] 2.901130e-05 1.907723e-04 2.377039e-04 2.295852e-02 4.44089
2e-16
## [29,] 1.700184e-03 2.044997e-01 2.417519e-05 4.733644e-08 3.44094
0e-04
## [30,] 7.696858e-07 7.182216e-03 8.662382e-03 1.552828e-02 1.57168
8e-01
## [31,] 2.540559e-06 2.444076e-02 8.648526e-04 9.342571e-11 1.59297
3e-05
## [32,] 2.397086e-01 4.837825e-03 3.635298e-02 1.181872e-10 5.01438
9e-11
## [33,] 5.838280e-05 1.859790e-05 4.308155e-04 1.403964e-01 7.01869
8e-04
```



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## [34,] 1.445917e-04 6.650680e-12 4.178498e-02 1.914567e-02 4.32885
1e-07
## [35,] 6.190130e-02 1.224423e-10 9.279000e-02 4.825931e-04 1.62091
1e-04
## [36,] 2.222794e-01 6.613551e-05 1.308290e-03 2.774866e-03 1.30174
2e-09
## [37,] 4.781735e-10 6.549566e-01 9.883425e-03 2.574161e-05 9.29976
3e-04
## [38,] 5.510004e-01 5.228238e-04 6.661338e-16 2.864519e-02 6.98259
4e-06
## [39,] 1.014917e-03 2.175075e-01 5.167939e-02 6.149712e-03 1.35025
1e-01
## [40,] 1.753654e-04 6.426958e-02 3.258066e-02 6.172589e-04 5.71796
9e-02
## [41,] 5.614987e-01 1.698642e-01 5.658874e-07 1.244774e-03 9.08036
5e-01
## [42,] 0.000000e+00 1.005382e-06 1.805885e-02 1.032781e-09 6.48120
3e-04
## [43,] 5.045851e-01 5.119947e-03 3.467863e-02 1.174043e-01 1.82314
7e-01
## [44,] 1.325044e-01 1.357627e-04 3.576112e-04 1.652818e-03 1.22197
4e-02
## [45,] 3.160758e-01 2.534207e-02 1.196672e-02 1.129108e-02 2.45799
7e-05
## [46,] 1.284863e-04 5.096092e-04 2.695627e-02 1.001173e-08 1.85138
7e-02
## [47,] 4.078844e-02 5.551234e-09 1.115260e-01 3.946965e-03 8.68204
3e-02
## [48,] 8.268719e-12 6.632365e-06 1.819654e-05 2.718335e-01 2.17781
3e-11
## [49,] 7.052769e-01 1.555438e-01 3.741406e-03 1.972702e-06 8.22264
7e-04
## [50,] 1.591571e-01 1.167337e-10 7.893548e-02 4.540476e-03 6.80824
5e-03
## [51,] 3.930188e-01 4.735490e-03 1.731334e-02 3.678884e-03 5.79527
8e-06
## [52,] 1.658759e-01 3.465137e-02 1.734667e-03 4.094765e-05 6.81488
2e-06
## [53,] 1.314043e-01 2.160294e-11 4.805773e-05 2.387886e-04 2.42288
8e-05
## [54,] 2.418311e-01 5.115923e-01 1.447512e-03 2.253042e-05 0.00000
0e+00
## [55,] 6.742298e-10 8.826021e-01 8.498587e-06 4.487637e-05 1.12744
2e-03
## [56,] 4.931358e-07 2.672118e-04 1.433831e-11 4.436602e-05 3.44224
7e-06
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## [57,] 1.492046e-02 9.440687e-06 4.747960e-01 5.609815e-02 1.86829
4e-01
## [58,] 1.359969e-02 1.022269e-01 6.701835e-02 4.519897e-05 2.04553
7e-05
## [59,] 4.040197e-05 1.488633e-03 2.220446e-16 2.036748e-02 4.33728
8e-04
## [60,] 1.459222e-01 2.907952e-01 2.087338e-03 7.115767e-02 8.31093
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## [61,] 1.055527e-06 2.703223e-02 4.672182e-03 3.378010e-03 6.42226
6e-03
## [62,] 0.000000e+00 2.021683e-01 1.097455e-01 1.571897e-07 1.63466
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## [63,] 3.958274e-01 0.000000e+00 2.357782e-06 3.479883e-12 3.78007
8e-07
## [64,] 3.925422e-02 3.663672e-03 4.897315e-05 1.386316e-02 6.52949
6e-05
## [65,] 5.343264e-09 9.289603e-03 5.163496e-04 2.171954e-05 1.26960
5e-07
## [66,] 2.209324e-04 1.593461e-01 2.215975e-07 3.961773e-04 2.09427
9e-08
## [67,] 4.258944e-03 7.310013e-02 4.150680e-03 7.586923e-03 0.00000
0e+00
## [68,] 9.521167e-01 1.541761e-01 9.391380e-05 4.396483e-14 2.71994
3e-05
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3e-02
## [70,] 1.901368e-12 2.835673e-04 1.689341e-02 5.412476e-05 7.09360
4e-04
## [71,] 3.412380e-09 5.417888e-14 6.909902e-04 1.136157e-04 9.18274
9e-03
## [72,] 1.414522e-01 2.835564e-01 1.969786e-04 7.426002e-02 2.71774
4e-05
## [73,] 4.702635e-04 9.246337e-02 9.710980e-04 6.694542e-04 5.69048
1e-03
## [74,] 6.661338e-16 6.021707e-01 3.963140e-02 6.707495e-02 1.26427
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## [75,] 2.120718e-06 2.363489e-05 8.901519e-02 7.666536e-02 9.71268
0e-03
## [76,] 3.928546e-01 3.697305e-07 1.384084e-02 5.780644e-09 1.35304
2e-02
## [77,] 4.514516e-01 6.149786e-01 1.091238e-07 5.861286e-01 1.00643
8e-02
## [78,] 3.600582e-01 1.262233e-01 2.144298e-02 5.217035e-04 3.75475
3e-05
## [79,] 3.310538e-03 2.037863e-01 3.881900e-05 5.465415e-04 2.11597
6e-07
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## [80,] 2.872147e-12 5.387053e-10 1.117109e-01 9.741225e-07 0.000000e+00
## [81,] 2.317169e-11 7.259426e-05 1.429880e-07 1.309011e-03 2.489318e-04
## [82,] 0.000000e+00 4.929340e-06 1.711605e-03 2.182949e-03 1.031610e-03
## [83,] 3.840999e-01 2.244168e-08 3.152948e-03 5.504319e-01 2.679115e-03
## [84,] 2.220446e-16 7.420176e-03 3.332083e-04 3.933149e-02 1.291283e-02
## [85,] 2.577159e-01 1.089796e-03 7.585172e-01 2.667074e-03 2.880723e-09
## [86,] 9.134840e-01 2.582864e-01 3.996803e-15 6.664291e-01 2.891140e-03
## [87,] 3.178637e-01 4.190270e-01 2.154045e-04 1.373816e-01 2.667625e-03
## [88,] 0.000000e+00 3.648993e-04 1.938105e-05 1.020228e-01 2.193955e-05
## [89,] 5.815755e-05 2.582442e-02 1.080001e-03 1.827848e-04 1.604865e-04
## [90,] 3.301427e-05 1.892436e-01 5.439692e-08 2.610933e-02 1.870312e-08
## [91,] 5.006799e-01 1.314040e-04 2.659264e-08 6.345664e-03 2.235495e-06
## [92,] 5.045495e-01 1.281232e-05 5.355638e-03 6.935388e-03 1.706290e-04
## [93,] 4.289739e-01 8.792617e-06 0.000000e+00 3.345990e-12 4.045631e-03
## [94,] 1.645054e-01 8.810774e-01 6.736804e-10 5.402526e-03 7.587930e-12
## [95,] 1.537144e-04 1.933872e-09 4.094280e-02 4.933342e-06 1.120460e-05
## [96,] 4.097239e-02 7.547878e-04 5.195844e-14 3.336924e-03 3.214507e-07
## [97,] 3.108624e-14 3.672881e-01 5.556164e-01 2.999749e-02 4.620326e-08
## [98,] 7.253105e-02 2.821045e-01 1.195267e-01 2.700699e-05 2.545423e-02
## [99,] 4.370523e-07 2.261901e-03 2.476493e-01 5.456891e-03 2.643568e-02
## [100,] 3.484262e-01 5.187580e-02 2.510157e-06 1.227775e-01 1.345293e-02
## [101,] 1.058193e-02 6.471601e-11 8.031099e-03 5.811842e-03 6.555102e-02
## [102,] 1.889471e-02 2.335828e-04 2.429355e-01 1.798730e-02 6.460765e-11
```

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## [103,] 1.949074e-03 2.827933e-02 3.137369e-03 5.615709e-03 1.03501
8e-02
## [104,] 6.089126e-01 7.042779e-01 1.382735e-01 2.019083e-07 1.17759
6e-02
## [105,] 4.461518e-01 3.765848e-02 1.176706e-07 3.642735e-04 1.24481
6e-03
## [106,] 5.648763e-01 1.840750e-13 3.722086e-01 6.111494e-04 2.29082
1e-01
## [107,] 1.021695e-01 1.506536e-02 1.789302e-02 5.996490e-02 6.28701
2e-05
## [108,] 2.687586e-01 7.248414e-04 5.588925e-05 5.596779e-04 2.50098
1e-04
## [109,] 4.241503e-01 5.647784e-03 1.221648e-09 2.673501e-03 2.64971
7e-02
## [110,] 7.446746e-01 7.726426e-04 9.465548e-02 3.647929e-10 8.64488
2e-04
## [111,] 4.241818e-01 5.226727e-08 1.296052e-06 4.629770e-04 1.09061
9e-03
## [112,] 6.512901e-11 5.061206e-03 5.216896e-04 1.281087e-02 9.68333
7e-03
## [113,] 2.979839e-13 9.165765e-01 1.019103e-01 1.382760e-03 1.03293
0e-08
## [114,] 3.684942e-08 7.418805e-01 5.058791e-01 3.970039e-01 4.19406
8e-04
## [115,] 5.929261e-03 9.861905e-10 6.455252e-03 2.720359e-03 1.05793
7e-08
## [116,] 0.000000e+00 1.363576e-04 6.817035e-04 1.330013e-01 1.57021
2e-03
## [117,] 2.763015e-01 4.925304e-07 1.446886e-01 2.752916e-07 3.48010
8e-02
## [118,] 1.706865e-04 2.253378e-06 4.225450e-03 1.254161e-02 1.65810
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## [119,] 9.500593e-01 2.092894e-04 0.000000e+00 3.195714e-04 2.72097
3e-02
## [120,] 6.468590e-01 7.531362e-03 1.077646e-01 3.403085e-02 1.15250
4e-03
## [121,] 3.683466e-03 2.694809e-01 4.581839e-08 1.854668e-01 8.01456
4e-04
## [122,] 6.114263e-01 1.287771e-01 6.884676e-04 2.131435e-04 3.68317
0e-07
## [123,] 2.925853e-07 4.571164e-03 8.258324e-02 8.060476e-04 6.99710
4e-02
## [124,] 8.692867e-04 4.325700e-04 6.161024e-02 3.490903e-02 1.32724
9e-11
## [125,] 6.343208e-01 5.307586e-08 2.023760e-02 1.256454e-02 1.95188
4e-08
```

## [126,] 3.793238e-01 2.146749e-03 1.157529e-07 5.629424e-04 9.25572  
1e-05  
## [127,] 1.978868e-03 5.326154e-02 8.870242e-02 2.569370e-03 1.05194  
2e-04  
## [128,] 3.852171e-01 5.422891e-03 9.158771e-03 1.142390e-02 3.55754  
9e-04  
## [129,] 6.503394e-01 4.095349e-08 1.725090e-07 9.875673e-08 1.82198  
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2e-08  
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2e-13  
## [133,] 1.878967e-05 4.150559e-02 3.070252e-03 1.447174e-01 4.44441  
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## [136,] 0.000000e+00 5.519530e-04 6.896990e-04 1.115261e-03 4.64092  
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## [140,] 2.603879e-01 1.076478e-02 3.153275e-01 1.642628e-03 6.96271  
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5e-04  
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## [145,] 4.421546e-01 1.876742e-01 5.029757e-03 1.595194e-08 6.66133  
8e-16  
## [146,] 8.958808e-02 1.480060e-04 2.087103e-09 2.354608e-03 1.32552  
6e-06  
## [147,] 1.388712e-02 1.829106e-01 9.467911e-10 7.954289e-04 2.36552  
6e-06  
## [148,] 9.138471e-01 1.780880e-01 1.288863e-01 4.227800e-07 2.73220  
5e-02

## [149,] 8.123043e-01 2.566184e-01 2.819539e-02 2.221764e-09 9.09360  
3e-06  
## [150,] 1.158514e-01 1.859833e-04 2.678490e-01 3.685178e-02 7.43346  
7e-04  
## [151,] 6.855395e-02 6.755167e-01 4.890430e-02 2.560511e-04 2.43212  
7e-07  
## [152,] 9.727739e-01 2.505309e-07 3.073178e-01 2.361691e-04 2.01437  
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## [153,] 6.001048e-03 2.370392e-01 1.952447e-01 0.000000e+00 1.73638  
9e-13  
## [154,] 9.335789e-09 8.665243e-02 1.936316e-03 1.817179e-04 3.08466  
0e-04  
## [155,] 5.431567e-01 9.046493e-01 6.889184e-02 2.685668e-03 9.65333  
5e-04  
## [156,] 1.665335e-14 8.366135e-01 5.033173e-03 1.143621e-10 0.00000  
0e+00  
## [157,] 2.996749e-07 1.121822e-01 4.507111e-04 2.430064e-05 2.19564  
5e-03  
## [158,] 5.710939e-04 7.761118e-05 2.425160e-06 1.189757e-02 2.00968  
3e-05  
## [159,] 1.776335e-11 5.227211e-01 1.430829e-05 1.505436e-02 1.23185  
6e-08  
## [160,] 1.232110e-01 4.279907e-03 2.475286e-02 2.687690e-03 2.02373  
6e-05  
## [161,] 3.074660e-06 7.240857e-01 2.347415e-02 7.159045e-02 0.00000  
0e+00  
## [162,] 2.316657e-03 3.960697e-03 8.935579e-01 4.696443e-07 1.09589  
2e-02  
## [163,] 5.060419e-09 6.336314e-06 3.399454e-02 8.545995e-05 1.95307  
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## [164,] 5.083395e-04 1.030916e-04 4.044562e-03 1.258777e-01 9.76050  
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## [165,] 2.535629e-01 3.046452e-13 0.000000e+00 5.105268e-02 1.16529  
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## [166,] 3.547451e-01 1.508377e-02 5.007430e-03 4.309319e-06 3.67957  
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## [853,] 2.572909e-09 1.905308e-07 1.725305e-09 1.131924e-05 7.53279  
0e-07  
## [854,] 3.342178e-04 2.933316e-05 1.693516e-02 6.065664e-05 5.80662  
5e-06  
## [855,] 7.909651e-11 1.607236e-04 2.698628e-08 9.555889e-04 3.26662  
7e-08  
## [856,] 2.103044e-06 1.032602e-03 4.685849e-06 1.176711e-07 4.50084  
4e-13  
## [857,] 7.352052e-03 2.220446e-14 3.474651e-07 0.000000e+00 2.41609  
6e-08  
## [858,] 6.661338e-16 5.173400e-03 5.333679e-05 7.949711e-04 1.28834  
4e-04  
## [859,] 1.089534e-02 3.264140e-07 2.192962e-07 7.016644e-05 3.24851  
3e-13  
## [860,] 2.077944e-06 4.935112e-10 3.122784e-09 7.776699e-08 9.81136  
6e-03  
## [861,] 3.376521e-09 4.721563e-10 4.145520e-04 7.273023e-04 5.41699  
2e-07  
## [862,] 1.850570e-09 5.909886e-05 1.526985e-03 8.366568e-08 1.21135  
3e-04  
## [863,] 3.119303e-02 1.014522e-12 2.798496e-05 2.048236e-06 2.44238  
4e-03  
## [864,] 7.221163e-08 2.124972e-01 2.976727e-04 1.397132e-06 1.03031  
1e-07  
## [865,] 1.067741e-02 0.000000e+00 4.548215e-07 3.086731e-06 7.57824  
3e-04  
## [866,] 1.776357e-15 1.370076e-09 9.616576e-07 0.000000e+00 1.81284  
3e-08  
## [867,] 9.311926e-06 3.526076e-03 1.489570e-05 6.737713e-07 1.83849  
8e-08  
## [868,] 2.886580e-14 1.571357e-02 4.333323e-03 7.142613e-09 1.08268  
9e-09  
## [869,] 7.373377e-08 1.062105e-06 5.598334e-06 0.000000e+00 4.18804  
1e-04  
## [870,] 7.965639e-04 6.775868e-02 6.486616e-03 0.000000e+00 3.93678  
0e-07  
## [871,] 2.014078e-11 7.129976e-08 1.155325e-05 3.564219e-03 0.00000  
0e+00  
## [872,] 1.086224e-04 9.701190e-09 2.708288e-06 3.671088e-06 1.51463  
7e-08
```



## [873,] 1.088271e-02 6.252884e-05 1.495782e-05 1.577314e-07 2.684517e-06  
## [874,] 2.132510e-07 4.186754e-09 1.421085e-14 3.167626e-03 9.319611e-05  
## [875,] 1.949819e-08 1.104624e-02 4.782445e-09 4.464912e-05 5.291662e-05  
## [876,] 2.094281e-06 2.537088e-06 8.414713e-11 3.305456e-05 1.459646e-06  
## [877,] 4.019377e-01 3.774758e-15 2.038344e-02 1.833493e-10 1.479593e-07  
## [878,] 1.179657e-02 6.559770e-08 1.150057e-03 2.476759e-04 1.864757e-05  
## [879,] 2.976397e-02 7.112889e-06 7.400797e-09 8.247846e-08 1.700595e-11  
## [880,] 3.361517e-04 8.878691e-04 1.252794e-06 1.385583e-06 1.366542e-10  
## [881,] 2.898570e-12 5.312471e-04 4.029143e-04 3.694271e-03 1.458377e-05  
## [882,] 8.231148e-02 3.644746e-02 1.244289e-07 5.036391e-05 8.129357e-08  
## [883,] 4.223688e-11 0.000000e+00 2.827386e-06 2.514391e-04 1.219272e-03  
## [884,] 3.157390e-04 3.659439e-07 6.439294e-15 8.558352e-09 3.708145e-14  
## [885,] 1.299501e-03 3.154896e-06 1.096501e-11 3.708536e-10 1.714228e-07  
## [886,] 1.204998e-03 1.836102e-10 1.332268e-15 4.898668e-10 7.241375e-06  
## [887,] 3.334804e-08 2.304257e-08 2.783992e-06 1.682166e-11 4.269902e-10  
## [888,] 0.000000e+00 7.703086e-09 6.430412e-13 7.016275e-09 9.766399e-09  
## [889,] 8.624645e-07 1.903913e-04 2.101043e-08 1.455439e-07 1.682637e-08  
## [890,] 5.928403e-07 1.998401e-14 3.785330e-09 2.084476e-05 5.883127e-10  
## [891,] 8.305885e-03 7.978562e-08 4.800803e-03 7.852974e-03 7.642543e-03  
## [892,] 6.861691e-05 1.261768e-05 6.656868e-04 2.775396e-02 1.350350e-03  
## [893,] 1.332155e-05 0.000000e+00 6.238600e-05 1.901797e-09 2.468336e-05  
## [894,] 1.443498e-05 1.685382e-07 6.489876e-07 3.303312e-06 5.111467e-13  
## [895,] 5.315615e-01 4.674937e-03 1.299734e-04 5.585251e-04 1.995050e-03

```
## [896,] 7.602878e-03 1.975895e-09 6.691274e-06 4.703035e-05 0.000000e+00
## [897,] 2.747917e-10 6.553103e-07 2.166883e-09 1.149567e-07 2.139901e-08
## [898,] 3.780976e-11 8.377688e-02 3.894981e-03 1.045234e-05 0.000000e+00
## [899,] 4.578459e-05 3.799729e-03 1.442065e-01 1.284957e-03 9.987372e-07
## [900,] 2.698791e-06 5.802972e-03 8.551098e-04 1.151453e-02 1.435092e-08
## [901,] 5.046424e-06 7.487804e-04 7.990814e-05 0.000000e+00 2.727809e-07
## [902,] 2.928212e-04 4.169398e-08 1.538004e-07 2.070888e-10 1.796633e-02
## [903,] 1.076291e-03 4.739502e-02 2.447279e-02 4.748024e-09 6.992919e-05
## [904,] 0.000000e+00 1.554312e-15 4.073692e-07 2.741036e-10 4.866764e-07
## [905,] 1.125566e-03 0.000000e+00 1.296507e-06 6.431634e-09 0.000000e+00
## [906,] 5.450266e-02 9.008473e-04 6.080138e-07 8.059109e-12 3.141039e-07
## [907,] 3.430801e-03 1.094014e-12 2.192858e-05 0.000000e+00 6.400818e-04
## [908,] 3.578305e-05 1.156756e-06 0.000000e+00 2.706906e-07 4.783498e-05
## [909,] 6.954428e-09 8.469130e-06 1.265323e-04 2.570296e-07 1.821181e-04
## [910,] 4.168583e-04 2.391121e-03 3.795524e-05 1.358640e-06 3.288403e-04
## [911,] 2.600616e-05 8.008231e-07 0.000000e+00 9.430812e-08 2.176037e-14
## [912,] 5.487536e-03 2.180843e-06 1.073204e-06 4.953877e-09 4.194774e-05
## [913,] 2.684646e-02 1.344364e-06 5.150088e-05 1.716281e-09 7.958101e-11
## [914,] 1.833340e-06 5.758355e-07 4.006369e-10 4.664905e-03 1.110223e-15
## [915,] 1.065814e-14 9.051072e-06 2.403767e-03 2.959785e-09 0.000000e+00
## [916,] 1.308965e-03 1.999616e-05 2.615333e-02 8.359780e-11 2.883760e-11
## [917,] 1.052735e-09 1.048079e-09 2.707152e-06 1.046550e-07 4.676208e-09
## [918,] 4.542655e-06 2.412149e-05 5.638235e-08 4.440892e-16 1.663584e-02
```

## [919,] 2.931732e-03 6.725933e-10 8.400058e-11 2.980669e-05 1.865728e-07  
## [920,] 6.352840e-04 2.578826e-03 4.271858e-03 6.661338e-16 2.035286e-09  
## [921,] 1.576258e-03 0.000000e+00 1.388529e-03 9.414691e-14 2.878441e-09  
## [922,] 2.141620e-02 5.640126e-05 5.046394e-04 3.405810e-03 1.616339e-04  
## [923,] 1.000333e-08 6.963674e-11 7.616574e-12 1.328634e-03 1.220868e-06  
## [924,] 7.482903e-14 6.660816e-04 2.536411e-09 5.158934e-03 3.735818e-09  
## [925,] 3.364123e-03 1.396167e-06 1.135037e-05 4.616028e-07 3.282799e-09  
## [926,] 0.000000e+00 3.121130e-07 2.887520e-05 5.838663e-11 5.448778e-05  
## [927,] 9.131430e-03 7.019842e-03 1.171145e-05 2.432721e-12 3.677248e-02  
## [928,] 3.492626e-03 3.378992e-03 2.042054e-03 3.280205e-04 8.189378e-06  
## [929,] 2.730605e-04 3.539270e-06 3.295206e-09 3.720727e-04 4.005771e-07  
## [930,] 2.685786e-03 1.884387e-08 9.281158e-04 1.194311e-11 4.146049e-06  
## [931,] 2.948697e-08 1.959734e-01 2.514536e-05 8.242041e-04 1.251561e-05  
## [932,] 9.812412e-02 4.440892e-15 2.359432e-02 5.711893e-10 3.145744e-07  
## [933,] 9.008414e-05 1.970841e-08 7.255544e-07 2.220446e-16 1.776357e-15  
## [934,] 1.091332e-04 1.191427e-04 4.488835e-06 0.000000e+00 2.066602e-07  
## [935,] 2.220446e-16 2.182851e-04 8.558580e-09 3.195611e-08 4.404012e-05  
## [936,] 1.772520e-05 4.159713e-04 4.146337e-04 4.908413e-08 9.339997e-05  
## [937,] 8.435475e-13 6.920930e-11 1.255923e-02 2.779609e-07 2.243741e-03  
## [938,] 9.581423e-03 5.048815e-03 3.023788e-10 5.207504e-07 1.803393e-07  
## [939,] 3.194161e-08 2.158668e-04 1.321107e-02 2.503823e-07 6.985523e-13  
## [940,] 9.823905e-06 9.724221e-12 2.703577e-07 9.095801e-08 1.334515e-04  
## [941,] 1.604337e-02 8.070376e-06 4.325331e-02 6.995571e-07 5.246068e-09

```
## [942,] 1.821144e-05 2.271200e-03 1.935705e-04 9.462539e-08 9.09830
2e-06
## [943,] 7.448440e-04 2.137806e-03 1.787502e-05 2.220446e-16 0.00000
0e+00
## [944,] 2.768912e-06 2.668219e-08 3.708145e-14 1.781494e-08 3.31966
9e-10
## [945,] 5.661312e-09 1.208375e-05 2.511499e-05 6.273182e-06 2.69519
5e-10
## [946,] 6.288698e-02 3.853984e-11 8.756369e-05 0.000000e+00 0.00000
0e+00
## [947,] 1.234945e-11 9.439506e-09 4.632785e-07 4.376364e-06 1.35833
3e-08
## [948,] 2.600125e-10 1.073434e-05 3.799633e-08 6.824205e-08 1.81927
1e-08
## [949,] 3.687842e-05 2.143728e-07 7.341159e-07 9.744641e-05 2.84554
3e-06
## [950,] 9.873520e-07 1.649791e-12 7.783626e-06 3.634576e-05 3.84122
3e-08
## [951,] 4.513953e-07 6.124150e-02 3.825042e-06 1.964517e-10 2.35463
3e-03
## [952,] 4.832582e-02 2.531308e-13 4.376043e-07 7.347813e-10 7.16297
9e-05
## [953,] 4.803475e-05 6.025458e-04 1.537373e-08 2.722211e-09 1.63894
4e-06
## [954,] 4.440892e-16 1.592060e-13 8.823502e-07 2.270357e-05 1.74115
3e-06
## [955,] 7.295622e-07 6.556879e-10 9.465789e-05 1.598166e-05 1.86018
8e-08
## [956,] 3.355163e-06 7.889654e-04 5.432868e-07 7.978109e-04 3.11557
2e-05
## [957,] 6.891216e-07 1.023559e-04 1.814050e-09 1.755248e-07 5.61510
8e-11
## [958,] 5.334738e-03 1.259222e-10 7.458478e-12 1.896772e-11 3.11825
0e-07
## [959,] 6.772686e-05 1.989043e-06 1.256205e-04 1.790500e-07 1.71776
1e-06
## [960,] 2.789126e-05 1.001641e-03 1.536276e-05 1.957940e-09 4.37555
0e-06
## [961,] 5.376452e-03 4.218847e-15 1.099387e-11 2.550561e-07 7.71106
3e-10
## [962,] 2.440926e-04 9.552473e-06 8.212543e-02 2.176702e-09 8.32759
3e-06
## [963,] 1.088482e-07 1.068123e-04 2.220446e-16 9.834524e-06 1.60478
1e-10
## [964,] 6.540340e-04 5.586674e-05 1.142094e-05 3.467648e-10 6.70296
5e-05
```

## [965,] 4.702588e-06 7.010729e-07 2.493850e-11 1.608054e-04 2.255950e-03  
## [966,] 6.338066e-05 3.370689e-05 4.899217e-07 1.090246e-06 2.220446e-15  
## [967,] 1.519307e-09 6.841800e-03 1.029722e-06 7.892340e-09 8.988460e-06  
## [968,] 5.028051e-07 2.402929e-06 5.588359e-08 0.000000e+00 2.122419e-08  
## [969,] 7.182987e-03 5.823683e-09 1.798525e-04 2.612443e-07 2.260189e-07  
## [970,] 2.344331e-01 7.940918e-03 5.974142e-04 3.375078e-14 1.685481e-05  
## [971,] 0.000000e+00 4.714198e-10 1.586351e-09 1.742244e-07 3.522693e-11  
## [972,] 2.622495e-04 6.449015e-04 4.863758e-03 4.357625e-09 1.241773e-06  
## [973,] 5.995204e-15 3.633977e-04 4.917743e-03 1.622265e-03 2.596993e-08  
## [974,] 6.125835e-03 3.508634e-09 1.530354e-11 8.364420e-13 3.255562e-09  
## [975,] 1.566469e-02 2.203268e-05 3.348482e-05 3.551419e-08 1.794324e-02  
## [976,] 1.590853e-03 3.289058e-11 3.471038e-05 9.157142e-11 2.775558e-14  
## [977,] 2.483382e-06 2.661927e-05 2.242160e-04 1.488233e-04 9.771279e-07  
## [978,] 7.011698e-10 2.987640e-07 1.351736e-04 9.430030e-09 1.828930e-10  
## [979,] 2.130936e-07 2.700243e-06 5.097973e-03 3.042011e-14 4.889470e-07  
## [980,] 1.836020e-07 9.236476e-05 3.802338e-02 9.597345e-04 1.246920e-02  
## [981,] 9.805613e-06 2.911830e-06 1.641139e-04 1.645677e-06 3.782271e-09  
## [982,] 4.393193e-04 9.551879e-07 2.389136e-06 4.008594e-06 5.847234e-10  
## [983,] 1.447182e-03 1.601844e-05 5.149241e-04 2.737684e-03 4.440892e-16  
## [984,] 2.075459e-03 1.182987e-03 5.132679e-03 1.253535e-03 6.536809e-10  
## [985,] 1.327506e-01 9.648832e-09 3.800858e-09 1.931797e-05 9.300138e-11  
## [986,] 1.042700e-09 6.285311e-05 9.202785e-06 9.681105e-10 2.463722e-03  
## [987,] 9.784217e-06 1.037951e-06 1.043610e-14 5.338901e-07 0.000000e+00

```
## [988,] 1.992393e-03 3.308778e-07 1.234568e-12 2.123578e-05 1.52394
3e-05
## [989,] 2.102570e-07 1.421308e-12 1.625946e-03 6.814771e-12 6.17130
3e-09
## [990,] 1.122956e-03 5.596695e-08 0.000000e+00 4.066485e-10 5.67384
6e-10
## [991,] 1.754916e-07 2.009795e-03 9.088952e-12 4.680229e-06 4.44222
5e-07
## [992,] 3.211645e-05 9.148696e-05 2.003953e-12 2.445597e-03 1.39657
9e-05
## [993,] 4.639280e-04 3.921133e-04 4.659755e-07 1.290079e-13 4.95048
2e-09
## [994,] 1.625367e-12 4.819445e-05 2.816029e-07 1.695957e-05 4.21395
6e-04
## [995,] 1.505215e-06 6.651048e-06 1.054171e-04 5.421019e-11 2.67080
8e-07
## [996,] 3.345305e-05 2.220446e-16 8.572249e-02 9.944160e-04 1.82664
0e-03
## [997,] 8.281791e-06 1.250932e-03 1.657645e-02 6.375508e-07 5.22063
4e-08
## [998,] 8.314970e-02 2.256633e-04 2.383153e-05 2.907769e-07 7.75349
7e-04
## [999,] 4.832475e-08 1.424713e-08 2.173493e-04 2.637668e-12 2.74246
4e-06
## [1000,] 6.020828e-11 4.276641e-07 2.981707e-01 3.190912e-02 1.36499
2e-09
```

*# to see what it contains.*

*# Now calculate the correlation by the sample size*

```
calc.power <- data.frame(sample.size = N,
                          # for each column (level of sample size) find
                          the proportion of p-values < .05
                          power = apply(run.sim, 2, function(x) mean(x
< .05))))
```

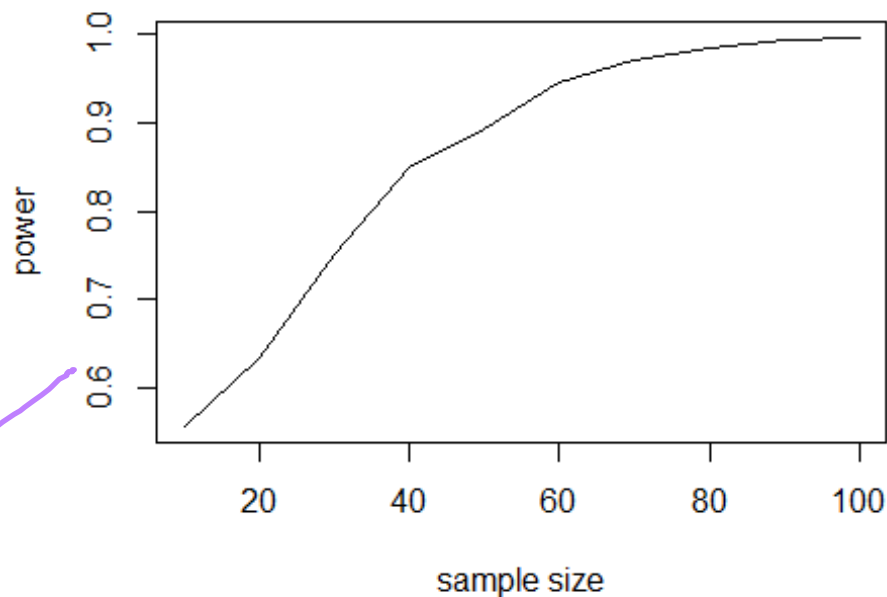
*# what does this look like*

```
calc.power

##      sample.size power
## 1             10 0.557
## 2             20 0.634
## 3             30 0.750
## 4             40 0.849
## 5             50 0.894
## 6             60 0.945
## 7             70 0.971
```

```
## 8      80 0.984
## 9      90 0.994
## 10     100 0.996

# now lets plot it
plot(power ~ sample.size, calc.power, type = "l", xlab = "sample size"
)
```



For the power of 0.750, the minimum sample size is 30. For the power of 0.849, the minimum sample size is 30. Therefore, for the power of at least 0.80, the minimum estimated and assumed sample size I need to detect a correlation of 0.4 between X and Y is 36 based on the plot.

### Question 3: If you had a sample size of 80, what would you expect your power to detect a correlation of .4 between X and Y to be using a z-test? (1 pt)

If I had a sample size of 80, I would expect my power is 0.984 based on the result and plot to detect a correlation of 0.4 between X and Y to be using a z-test.

## Mediation

Next, we will run a simulation of a simple mediation model where X causes M and X and M cause Y (i.e., M is the mediator). In the simulation below, we will determine the MDES for the indirect effect (ab) assuming a sample size of 100 again using the z-test. Note, we really

shouldn't use the z-test but instead should do **bootstrapping**, however, for the sake of your computers, your energy bill, and your time we will just do a power analysis with the z-test. The generally findings should be similar.

We'll examine the power by varying the relationship between X on M between .1 to 1 by 1 (.1, .2, ..., .9, 1), while holding the relationship between M on Y to a fixed value.

```
# set sample size
N <- 100
a <- seq(.1, 1, by = .1) # we will vary the relationship of X on M

# set the seed
set.seed(1235)

# The lavaan model we'll fit
mod <- '
M ~ a*X
Y ~ b*M + c*X
ab := a*b
'

# This time we're pass a NOT the sample size
# b/c it's fixed to 100
run.sim <- sapply(a, function(a) {
  replicate(n = 1000, expr = {

    # notice the population model is now here!
    pop.mod <- paste0("
      M ~ ", a, "*X # takes the value of a and multiples it by X
      Y ~ .3*M + .3*X") # this values correspond to "b" and "c"

    # simulate the data
    tmp.data <- simulateData(pop.mod, sample.nobs = N)

    # fit the model
    fit <- sem(mod, tmp.data)

    # save the parameter estimates
    params <- parameterEstimates(fit)

    # return the p-value from the z-test of the indirect effect
    subset(params, lhs == "ab", "pvalue", drop = TRUE)
  })
})

# calculate power
calc.power <- data.frame(indirect = a * .3,
```



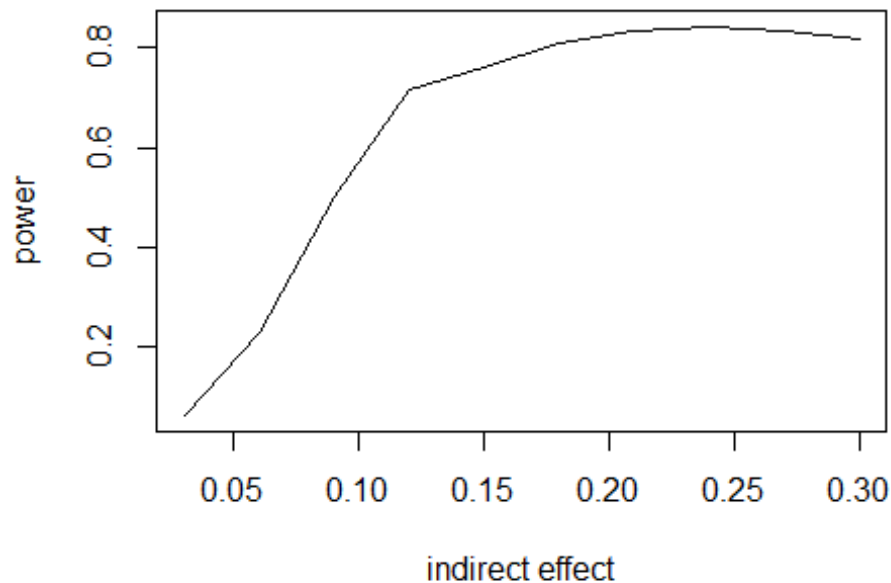
```

power = apply(run.sim, 2, function(x) mean(x
< .05)))
calc.power

##      indirect power
## 1      0.03 0.063
## 2      0.06 0.228
## 3      0.09 0.500
## 4      0.12 0.718
## 5      0.15 0.763
## 6      0.18 0.810
## 7      0.21 0.833
## 8      0.24 0.843
## 9      0.27 0.834
## 10     0.30 0.819

# plot it!
plot(power ~ indirect, calc.power, type = "l", xlab = "indirect effect
")

```



Question 4: What is the MDES that achieves a power of at least .80 based on the power analysis? (1 pt)

At the power of 0.81, the MDES is 0.18. Therefore, based on the power analysis, the assumed MDES is 0.178 that achieves a power of at least 0.80.

Question 5: Does the relationship of X on Y have an impact on this? Conduct a simulation-based power analysis by changing the relationship from .3 to .6 for X on Y. Report the MDES that achieves a power of at least .80 for the z-test of the indirect effect. (3 pts)

```
# set sample size
N <- 100
a <- seq(.1, 1, by = .1) # we will vary the relationship of X on M

# set the seed
set.seed(1235)

# The lavaan model we'll fit
mod <- '
M ~ a*X
Y ~ b*M + c*X
ab := a*b
'

# This time we're pass a NOT the sample size
# b/c it's fixed to 100
run.sim <- sapply(a, function(a) {
  replicate(n = 1000, expr = {

    # notice the population model is now here!
    pop.mod <- paste0("
M ~ ", a, "*X # takes the value of a and multiplies it by X
Y ~ .3*M + .6*X") # this values correspond to "b" and "c"

    # simulate the data
    tmp.data <- simulateData(pop.mod, sample.nobs = N)

    # fit the model
    fit <- sem(mod, tmp.data)

    # save the parameter estimates
    params <- parameterEstimates(fit)

    # return the p-value from the z-test of the indirect effect
    subset(params, lhs == "ab", "pvalue", drop = TRUE)
  })
})

# calculate power
calc.power <- data.frame(indirect = a * .3,
                          power = apply(run.sim, 2, function(x) mean(x
```

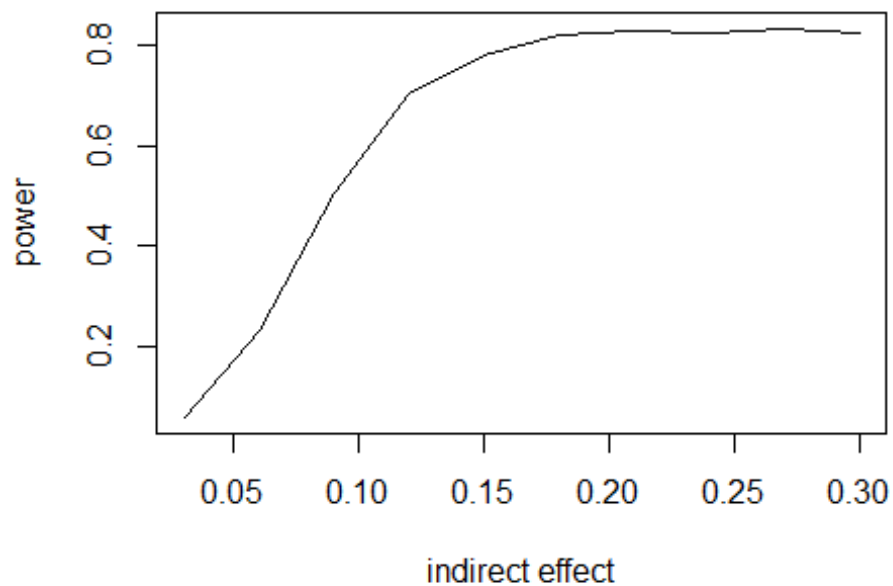
```

< .05)))
calc.power

##      indirect power
## 1      0.03 0.060
## 2      0.06 0.232
## 3      0.09 0.506
## 4      0.12 0.704
## 5      0.15 0.782
## 6      0.18 0.822
## 7      0.21 0.828
## 8      0.24 0.826
## 9      0.27 0.833
## 10     0.30 0.826

# plot it!
plot(power ~ indirect, calc.power, type = "l", xlab = "indirect effect
")

```



It's just simulation error

Yes, the relationship of X on Y has an impact on this . For example, when X is 0.3, the MDES is 0.18 for the power of 0.81. When X is 0.6, the MDES is 0.18 for the power of 0.822. However, the change is very little.

At the power of 0.822, the MDES is 0.18. Therefore, based on the power analysis, the assumed MDES is 0.175 that achieves a power of at least 0.80.

Question 6: Repeat this simulation but set the relationship from .6 to 1 for X on Y. Report the MDES that achieves a power of at least .80. (3 pts)

```
# set sample size
N <- 100
a <- seq(.1, 1, by = .1) # we will vary the relationship of X on M

# set the seed
set.seed(1235)

# The lavaan model we'll fit
mod <- '
M ~ a*X
Y ~ b*M + c*X
ab := a*b
'

# This time we're pass a NOT the sample size
# b/c it's fixed to 100
run.sim <- sapply(a, function(a) {
  replicate(n = 1000, expr = {

    # notice the population model is now here!
    pop.mod <- paste0("
      M ~ ", a, "*X # takes the value of a and multiples it by X
      Y ~ .3*M + 1*X") # this values correspond to "b" and "c"

    # simulate the data
    tmp.data <- simulateData(pop.mod, sample.nobs = N)

    # fit the model
    fit <- sem(mod, tmp.data)

    # save the parameter estimates
    params <- parameterEstimates(fit)

    # return the p-value from the z-test of the indirect effect
    subset(params, lhs == "ab", "pvalue", drop = TRUE)
  })
})

# calculate power
```

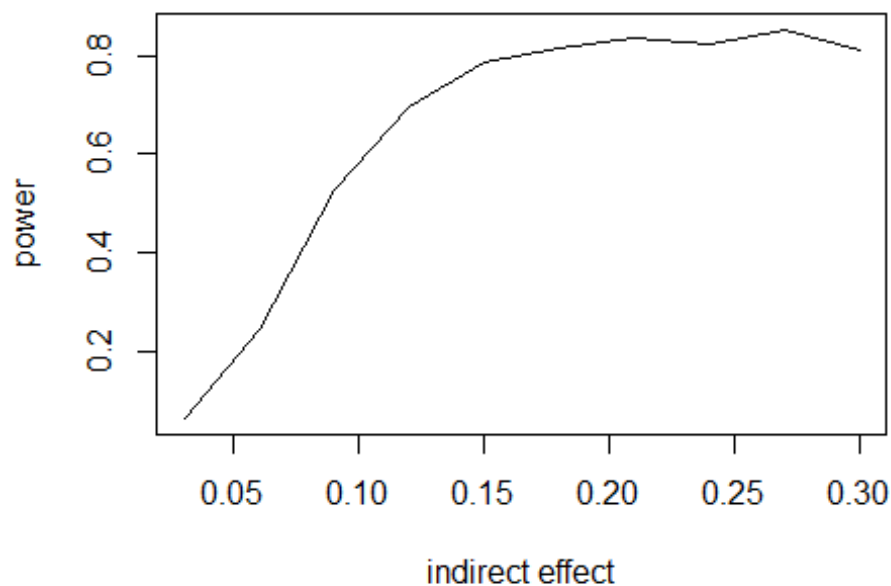
```

calc.power <- data.frame(indirect = a * .3,
                          power = apply(run.sim, 2, function(x) mean(x
< .05))))
calc.power

##      indirect power
## 1      0.03 0.064
## 2      0.06 0.243
## 3      0.09 0.528
## 4      0.12 0.697
## 5      0.15 0.785
## 6      0.18 0.815
## 7      0.21 0.838
## 8      0.24 0.822
## 9      0.27 0.853
## 10     0.30 0.813

# plot it!
plot(power ~ indirect, calc.power, type = "l", xlab = "indirect effect
")

```



✓ For the power of 0.815, the MDES is 0.18. Therefore, for the power of at least 0.8, the assumed MDES is 0.17 based on the plot and power analysis.

-1 But you got basically the same result all 3 times. Note that your power for 0.18 was slightly higher at 0.6 than 1. These differences are due to simulation error; we wouldn't theoretically expect that relationship to affect power.

### Question 7: Did changing the relationship between X and Y appear to have an impact on the z-test of the indirect effect? (1 pts)

Yes, changing the relationship between X and Y appear to have an impact on the Z-test of the indirect effect. For example, when X is 0.3, the indirect effect is 0.18 for the power of 0.81. When X is 0.6, the indirect effect is 0.18 for the power of 0.822. When X is 1, the indirect effect is 0.18 for the power of 0.815. It appears to have an impact on the z-test of the indirect effect.

## Structural Equation Modeling

For the final set of simulations, we are going to examine how the chi-square test of model fit is affected when we specify the model correctly and when we misspecify the model. And we will see if this is affected by our sample size, which we'll vary from 200 to 1000 by 50. When the **model is misspecified**, we want our power to be .80 and when the model is **correctly specified** we want to fail to reject the null hypothesis and want our type I error rate (the proportion of times that  $p < .05$ ) to be .05 because we know that the null hypothesis is true.

First, we will again define the true model, which we will save as pop.mod as we have done throughout.

```
pop.mod <- "  
  f1 =~ 1*x1 + 0.8*x2 + 1.2*x3  
  f2 =~ 1*x4 + 0.5*x5 + 1.5*x6  
  f3 =~ 1*x7 + 0.7*x8 + 0.9*x9  
  
  f3 ~ 0.5*f1 + 0.8*f2  
"
```

### Question 8: Why are there 1s in front of x1, x4, and x7? (1 pt)

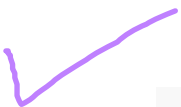
It means that here the variance of factors is not fixed to one to measure all factor loadings of indicators. For f1, the variance of one indicator that is x1 is fixed to one to measure the factor loadings of x2 and x3. Similar case is for x4 and x7. The variance of factor is not fixed to one. Here, the variance of indicator such as x1, x4, and x7 are fixed to one to measure the factor loadings of other indicators. When the variance of factor is set to one, that is standardized. Now, it is unstandardized.

### Question 9: What are the values for the structural parameters? (1 pt)

Here, the structural parameters are f3, f1, and f2. The direct effect of f1 on f3 is 0.5. Also, the direct effect of f2 on f3 is 0.8. These are the values for the structural parameters.

### Question 10: Write the syntax for the correct lavaan model that you will fit based on pop.mod and call that the model, correct.mod. (1 pt)


```
correct.mod <- "  
  f1 =~ x1 + x2 + x3
```



```
f2 =~ x4 + x5 + x6
f3 =~ x7 + x8 + x9

f3 ~ f1 + f2
"
```

Question 11: For the misspecified model rather than having x7 load onto f3 have x7 load onto f2 and keep the rest of the model the same. Write the syntax for the misspecified model below and save it as mis.mod. (1 pt)



```
mis.mod <- "
  f1 =~ x1 + x2 + x3
  f2 =~ x4 + x5 + x6 +x7
  f3 =~ x8 + x9

  f3 ~ f1 + f2
"
```

Now we will run the simulation, you do not need to modify any of this code, just interpret the output. Unfortunately, this will take a while to run. Sorry!

```
# set the sample size
N <- seq(200, 1000, by = 100)

# again set the seed
set.seed(1234)

# this is for the correct model
cor.sim <- sapply(N, function(N) {
  replicate(n = 1000, expr = {

    # generate the data
    tmp.data <- simulateData(pop.mod, sample.nobs = N)

    # fit the correct mod
    cor.fit <- sem(correct.mod, tmp.data)

    # extract the p-value from the chi-square test of model fit
    chi.p <- fitmeasures(cor.fit, "pvalue")
    chi.p
  })
})

# set the seed
set.seed(1234)
wrong.sim <- sapply(N, function(N) {
  replicate(n = 1000, expr = {
```

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## variances are negative
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## variances are negative
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## Warning in lav object post check(object): lavaan WARNING: some esti
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mated lv
## variances are negative

## Warning in lav_object_post_check(object): lavaan WARNING: some esti
mated lv
## variances are negative

## Warning in lav_object_post_check(object): lavaan WARNING: some esti
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mated lv
## variances are negative

## Warning in lav_object_post_check(object): lavaan WARNING: some esti
mated lv
## variances are negative

sim.results <- data.frame(N = N,
                           typeI.correct.model = apply(cor.sim, 2, func
tion(x) mean(x < .05)),
                           power.misspecified.model = apply(wrong.sim,
2, function(x) mean(x < .05)))
sim.results

##      N typeI.correct.model power.misspecified.model
## 1  200              0.052                1
## 2  300              0.062                1
## 3  400              0.064                1
## 4  500              0.048                1

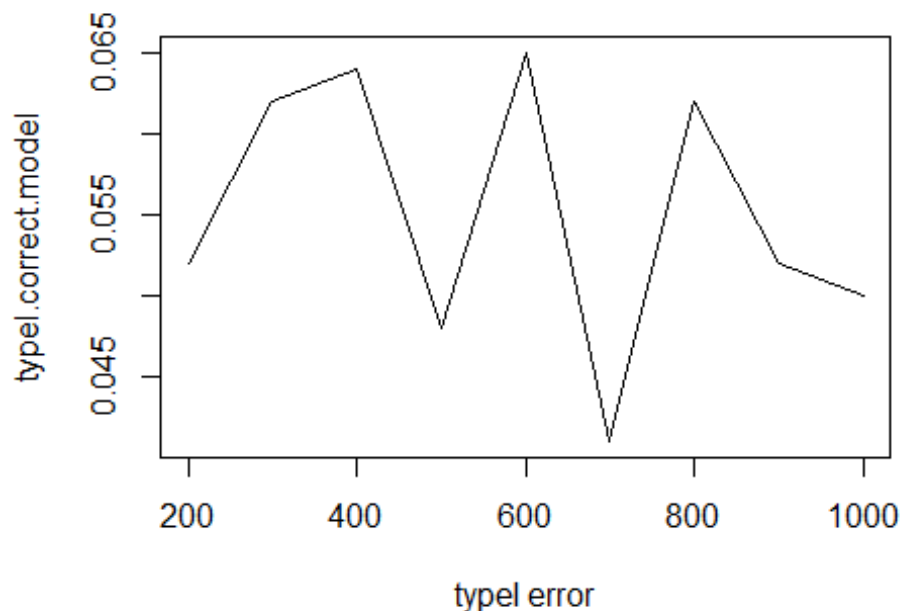
```

##	5	600	0.065	1
##	6	700	0.041	1
##	7	800	0.062	1
##	8	900	0.052	1
##	9	1000	0.050	1

For the simulation you can ignore the warning messages, but what do the warning messages indicate? If this was your study, should you ignore these messages? What might be the causes of these messages? Just food for thought ...

Question 12: How does the type I error rate of the chi-square test of model fit change as a function of the sample size for the correctly specified model? Please plot this below. Is the type I error always approximately .05? (2 pts)

```
plot(typeI.correct.model ~ N , sim.results, type = "l", xlab = "typeI error")
```



How does the type I error rate of the chi-square test of model fit change as a function of the sample size for the correctly specified model? Please plot this below. Is the type I error always approximately .05?

Yes, the type I error rate of the chi-square test of model fit changes as a function of the sample size for the correctly specified model. However, the change does not mean that the value of type I error will increase with sample size. From the plot, it is visible that the value of the type I error both increase and decrease with the higher value of sample size. For example, when the

sample size is 300 from 200, the value of type I error increase. However, when the sample size is 500, the value of type I error decrease. No, the type I error is not approximately 0.05 for some sample size the value of type I error is 0.062 and for some sample size, the value of type I error is 0.042.

OK

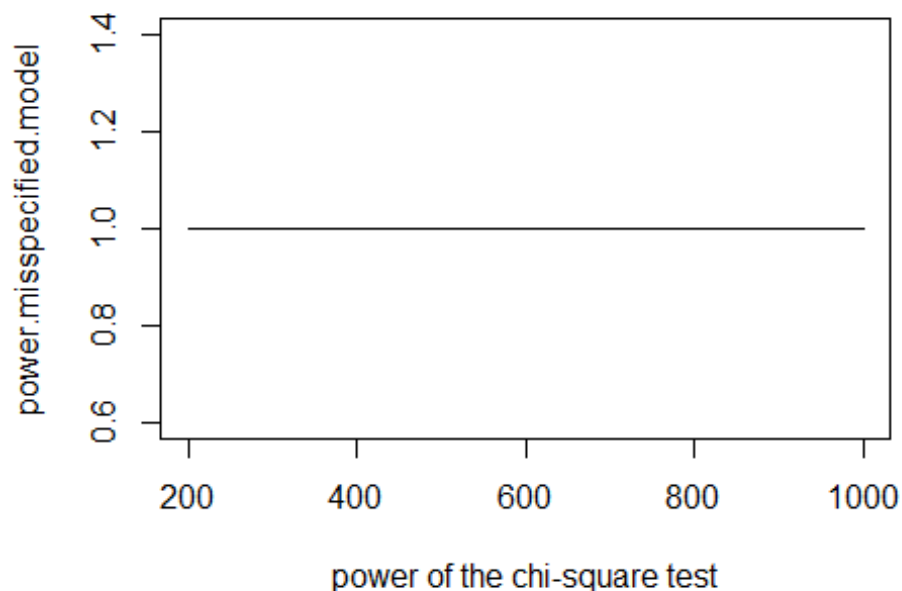
Question 13: Given what you've been taught about the relationship between power and sample size, do the results from Question 12 mirror this? What might you expect would happen to the type I error rate as sample size increases? (2 pt)

With the increase of the sample size, the power increases. It means that the power increases with the increase of the sample size. There is a change in power with the increase in the sample size. From the question 12, there is also a change in the type one error rate with the increase of sample size. However, that change is both increase and decrease with the higher value of sample size. For example, when the sample size is 300 from 200, the value of type I error increase. However, when the sample size is 500, the value of type I error decrease. No, the type I error is not approximately 0.05 for some sample size the value of type I error is 0.062 and for some sample size, the value of type I error is 0.042. Therefore, question 12 does not mirror the relationship between power and sample size. It might expect that the type I error rate may both increase and decrease as sample size increases.

Increasing sample size increases power, but the type I error rate (for a well behaved test and with nominal  $\alpha = 0.05$ ) remains the same

Question 14: How does the power of the chi-square test of model fit change as a function of the sample size for the misspecified model? Please plot this below. Is the power always approximately .80 or greater? (2 pt)

```
plot(power.misspecified.model ~ N , sim.results, type = "l", xlab = "power of the chi-square test")
```



✓ The power of the chi-square test of model fit does not change as function of the sample size for the misspecified model. It is constantly one for all sample size. Yes, the power is always greater than 0.8 and it is 1.

Question 15: What do you conclude about the chi-square test of model fit? Should you use this test for evaluating your models? Why or why not? (2 pts)

I am concluding that the chi-square test of model fit here will not use for evaluating the models. Because, the type I error rate of the chi-square test for the correctly specified model is approximately 0.05. However, we have got different type I error rate with the increase of the sample size. For example, when the sample size is 200, the type I error value is close to 0.05. However, when the sample size is 800, the value of type one error is 0.062 which is far away from 0.05. When the sample size is 1000, then the type I error value is 0.05. It indicates that the chi-square test of model fit is highly sensitive to the sample size. Also, with the increase of the sample size, the power increases. Therefore, I should not use this test for evaluating these models.

This is a reasonable conclusion given your simulation results, even if it's not what we were looking for :-). I'd say that the type I error rate is quite close to 0.05; the fluctuations are likely due to simulation error.