

Sample Size Calculation with R

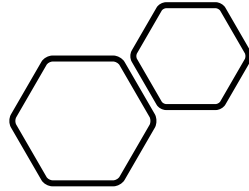
Generalized Linear Mixed Models

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Biostatistics, Epidemiology, and Research Design Core

DaCCoTA

Purpose



- This Module is a supplement to the Sample Size Calculation in R Module
- Gives the setup of Generalized Linear Mixed Models and Getting Sample Size Calculations

Background

- The Biostatistics, Epidemiology, and Research Design Core (BERDC) is a component of the DaCCoTA program
- Dakota Cancer Collaborative on Translational Activity has as its goal to bring together researchers and clinicians with diverse experience from across the region to develop unique and innovative means of combating cancer in North and South Dakota
- If you use this Module for research, please reference the DaCCoTA project

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DAKOTA CANCER COLLABORATIVE
ON TRANSLATIONAL ACTIVITY

Overview of Model Types

Level I:

- a) **General linear models (lm):** model with a normally distributed response variable (y) and predictor variables (x) with fixed effects

Level II:

- a) **Generalized linear model (glm):** model with non-normally distributed response variable (y) and predictor variables (x) with fixed effects
- b) **General linear mixed model (lmer):** model with a normally distributed response variable (y) and predictor variables (x) with fixed and/or random effects

Level III:

- a) **Generalized linear mixed model (glmer):** model with non-normally distributed response variable (y) and predictor variables (x) with fixed and/or random effects

Notes on distributions

Name	Type	Range	Explanation
Normal (Gaussian)	Continuous	$-\infty < x < \infty$	x= dispersal from a central point, or diffusion through a Gaussian filter, with variance independent of mean
Log-normal	Continuous	$x > 0$	x= probability distribution whose logarithm is normally distributed
Exponential	Continuous	$x > 0$	x= time between events that occur at rate $\lambda = 1/\beta$
Gamma	Continuous	$x > 0$	x= time it takes for k event to occur with rate $\lambda = 1/\theta$, or the sum of k exponential events
Beta	Continuous	$0 < x < 1$	x= distribution of probabilities based on a successes and b failures, when both a and b > 1
Binomial	Discrete	$x = 0, 1, 2...$	x= number of positive events out of n trials each with a probability of success p
Geometric	Discrete	$x = 1, 1, 3...$	x= number of trials, with probability of success p , that are needed to obtain one success
Negative Binomial	Discrete	$x = 0, 1, 2...$	x= number of failures before k successes occur in sequential independent trials, all with the same probability of success, p
Poisson	Discrete	$x = 0, 1, 2...$	x= count of items in a standardized unit of effort that occurs at rate λ

Notes on Effects

Terms:

Fixed effects:

- True effect size is same in all categories; summary effect is estimate of common effect size
- Categories with smaller sample size get less weight, ones with larger sample size get more weight
- Only source of uncertainty is within-study (sampling) error
- All categories {of interest} are present in the model
 - **Example:** Categories are all the state parks in a state

Random effects:

- True effect size varies across categories; effect sizes are random sample of effect sizes that could be observed; summary effect is estimate of the mean of these effects
- Categories are more balanced with weighting
- Uncertainty is within-study (sampling) error, plus between-studies variance
 - Leads to larger confidence intervals for summary effect
- Categories present in the model are subset of the total number of categories
 - **Example:** Categories are 10 state parks from states across the US

Impact of Intervention (Fixed effect)

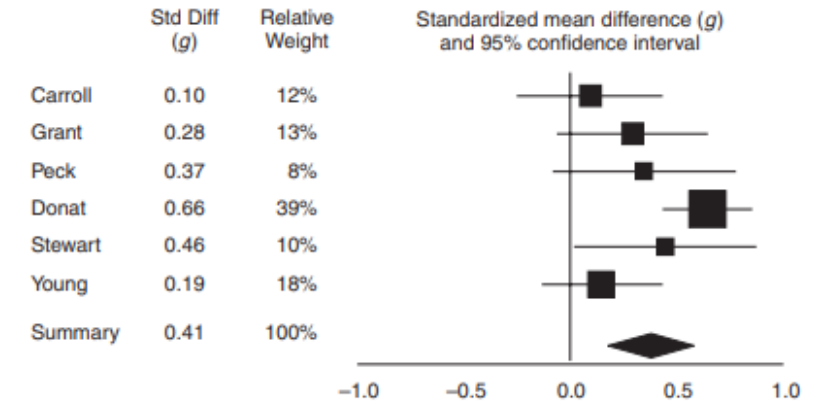


Figure 13.1 Fixed-effect model – forest plot showing relative weights.

Impact of Intervention (Random effects)

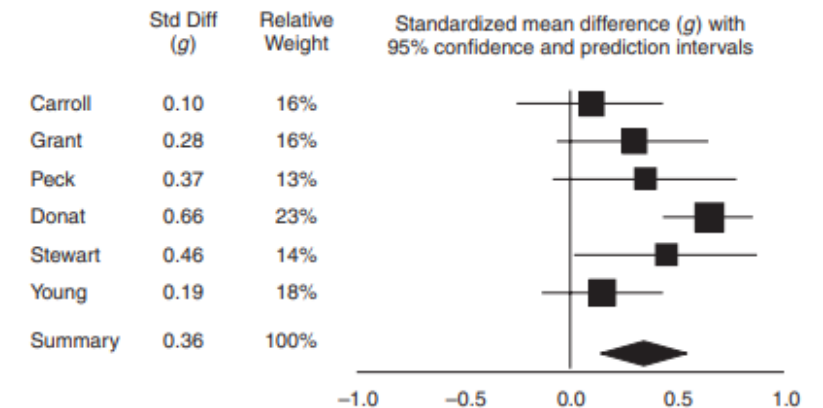


Figure 13.2 Random-effects model – forest plot showing relative weights.

Generalized Linear Mixed Models

Description:

Combination of a Generalized Linear Model (GLM) and Mixed Model

- GLM: can be used with non-normal data
- Mixed Model: include both **fixed** and **random** effects

These models can be made very sophisticated and cover a very large range of models

- Need to understand how to create model and define variables
- We will create models with **lme4**
- We will get sample sizes with **Simr**

Package lme4: Description

Description:

Provides functions to fit and analyze a variety of models, including generalized linear mixed models

<https://cran.r-project.org/web/packages/lme4/lme4.pdf>

<https://cran.r-project.org/web/packages/lme4/vignettes/lmer.pdf>

Package lme4: lmer

lmer: fits a linear mixed-effects model to data

`lmer(formula, data = NULL, REML = TRUE, control = lmerControl(), start = NULL, verbose = 0L, subset, weights, na.action, offset, contrasts = NULL, devFunOnly = FALSE, ...)`

Formula: $y \sim x_1 + x_2 + (x_1 | x_3)$

y=response, x=terms, (|)=distinguish random-effects terms, separating expression for design matrices from grouping factors

Example: `lmer(Reaction ~ Days + (Days | Subject))`

Models Reaction time as a function of Days, with the Subject as a random effect

Formula	Alternative	Meaning
<code>(1 g)</code>	<code>1 + (1 g)</code>	Random intercept with fixed mean.
<code>0 + offset(o) + (1 g)</code>	<code>-1 + offset(o) + (1 g)</code>	Random intercept with <i>a priori</i> means.
<code>(1 g1/g2)</code>	<code>(1 g1)+(1 g1:g2)</code>	Intercept varying among g1 and g2 within g1 .
<code>(1 g1) + (1 g2)</code>	<code>1 + (1 g1) + (1 g2).</code>	Intercept varying among g1 and g2 .
<code>x + (x g)</code>	<code>1 + x + (1 + x g)</code>	Correlated random intercept and slope.
<code>x + (x g)</code>	<code>1 + x + (1 g) + (0 + x g)</code>	Uncorrelated random intercept and slope.

Table 2: Examples of the right-hand-sides of mixed-effects model formulas. The names of grouping factors are denoted **g**, **g1**, and **g2**, and covariates and *a priori* known offsets as **x** and **o**.

Symbol	Size
n	Length of the response vector, \mathcal{Y}
p	Number of columns of fixed-effects model matrix, \mathbf{X}
$q = \sum_i^k q_i$	Number of columns of random-effects model matrix, \mathbf{Z}
p_i	Number of columns of the raw model matrix, \mathbf{X}_i
ℓ_i	Number of levels of the grouping factor indices, \mathbf{i}_i
$q_i = p_i \ell_i$	Number of columns of the term-wise model matrix, \mathbf{Z}_i
k	Number of random-effects terms
$m_i = \binom{p_i+1}{2}$	Number of covariance parameters for term i
$m = \sum_i^k m_i$	Total number of covariance parameters

Table 3: Dimensions of linear mixed models. The subscript $i = 1, \dots, k$ denotes a specific random-effects term.

Symbol	Size	Description
\mathbf{X}_i	$n \times p_i$	Raw random-effects model matrix
\mathbf{J}_i	$n \times \ell_i$	Indicator matrix of grouping factor indices
\mathbf{X}_{ij}	$p_i \times 1$	Column vector containing j th row of \mathbf{X}_i
\mathbf{J}_{ij}	$\ell_i \times 1$	Column vector containing j th row of \mathbf{J}_i
\mathbf{i}_i	n	Vector of grouping factor indices
\mathbf{Z}_i	$n \times q_i$	Term-wise random-effects model matrix
$\boldsymbol{\theta}$	m	Covariance parameters
\mathbf{T}_i	$p_i \times p_i$	Lower triangular template matrix
$\boldsymbol{\Lambda}_i$	$q_i \times q_i$	Term-wise relative covariance factor

Table 4: Symbols used to describe the structure of the random-effects model matrix and the relative covariance factor. The subscript $i = 1, \dots, k$ denotes a specific random-effects term.

Package lme4: lmer cont.

lmer: fits a linear mixed-effects model to data

- Consists of four modules

Module		R function	Description
Formula module	(Section 2)	<code>lFormula</code>	Accepts a mixed-model formula, data, and other user inputs, and returns a list of objects required to fit a linear mixed model.
Objective function module	(Section 3)	<code>mkLmerDevfun</code>	Accepts the results of <code>lFormula</code> and returns a function to calculate the deviance (or restricted deviance) as a function of the covariance parameters, θ .
Optimization module	(Section 4)	<code>optimizeLmer</code>	Accepts a deviance function returned by <code>mkLmerDevfun</code> and returns the results of the optimization of that deviance function.
Output module	(Section 5)	<code>mkMerMod</code>	Accepts an optimized deviance function and packages the results into a useful object.

Table 1: The high-level modular structure of `lmer`.

Package lme4: glmer

glmer: fits a generalized linear mixed-effects model to data

A generalized linear mixed model incorporates both fixed-effects parameters and random effects in a linear predictor, via maximum likelihood. The linear predictor is related to the conditional mean of the response through the inverse link function defined in the GLM family.

```
glmer(formula, data = NULL, family = gaussian, control = glmerControl(), start = NULL, verbose = 0L, nAGQ = 1L, subset, weights, na.action, offset, contrasts = NULL, mustart, etastart, devFunOnly = FALSE, ...)
```

Formula: $y \sim x_1 + x_2 + (x_1 \mid x_3)$

y=response, x=terms, (|)=distinguish random-effects terms, separating expression for design matrices from grouping factors

Family: a GLM family -> binomial(link = "logit"), gaussian(link = "identity"), Gamma(link = "inverse"), inverse.gaussian(link = "1/mu^2"), poisson(link = "log"), quasi(link = "identity", variance = "constant"), quasibinomial(link = "logit"), quasipoisson(link = "log")

Use glmer.nb to fit negative binomial GLMMs

Offset: this can be used to specify an a priori known component to be included in the linear predictor during fitting. This should be NULL or a numeric vector of length equal to the number of cases

<https://www.rdocumentation.org/packages/lme4/versions/1.1-21/topics/glmer>

Package lme4: glmer cont.

glmer: Examples (R-code)

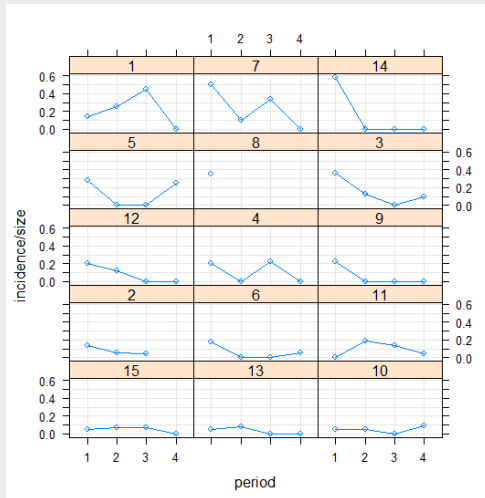
```
## generalized linear mixed model
```

```
library(lme4)
```

```
library(lattice)
```

```
str(cbpp)
```

```
xyplot(incidence/size ~ period | herd, cbpp, type=c('g','p','l'),  
       layout=c(3,5), index.cond = function(x,y)max(y))
```



```
## response as a matrix
```

```
(m1 <- glmer(cbind(incidence, size - incidence) ~ period + (1 | herd),  
            family = binomial, data = cbpp))
```

```
## response as a vector of probabilities and usage of argument "weights"
```

```
(m1p <- glmer(incidence / size ~ period + (1 | herd), weights = size,  
            family = binomial, data = cbpp))
```

```
'data.frame': 56 obs. of 4 variables:
```

```
$ herd : Factor w/ 15 levels "1","2","3","4",...: 1 1 1 1 2 2 2 3 3 3 ...
```

```
$ incidence: num 2 3 4 0 3 1 1 8 2 0 ...
```

```
$ size : num 14 12 9 5 22 18 21 22 16 16 ...
```

```
$ period : Factor w/ 4 levels "1","2","3","4": 1 2 3 4 1 2 3 1 2 3 ...
```

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
```

```
Family: binomial ( logit )
```

```
Formula: cbind(incidence, size - incidence) ~ period + (1 | herd)
```

```
Data: cbpp
```

```
AIC BIC logLik deviance df.resid  
194.0531 204.1799 -92.0266 184.0531 51
```

```
Random effects:
```

```
Groups Name Std.Dev.
```

```
herd (Intercept) 0.6421
```

```
Number of obs: 56, groups: herd, 15
```

```
Fixed Effects:
```

```
(Intercept) period2 period3 period4  
-1.3983 -0.9919 -1.1282 -1.5797
```

```
Generalized linear mixed model fit by maximum likelihood (Laplace Approximation) ['glmerMod']
```

```
Family: binomial ( logit )
```

```
Formula: incidence/size ~ period + (1 | herd)
```

```
Data: cbpp
```

```
Weights: size
```

```
AIC BIC logLik deviance df.resid  
194.0531 204.1799 -92.0266 184.0531 51
```

```
Random effects:
```

```
Groups Name Std.Dev.
```

```
herd (Intercept) 0.6421
```

```
Number of obs: 56, groups: herd, 15
```

```
Fixed Effects:
```

```
(Intercept) period2 period3 period4  
-1.3983 -0.9919 -1.1282 -1.5797
```

Package lme4: glmer cont.

glmer: Formula examples

Formula	Alternative	Meaning
<code>(1 g)</code>	<code>1 + (1 g)</code>	Random intercept with fixed mean.
<code>0 + offset(o) + (1 g)</code>	<code>-1 + offset(o) + (1 g)</code>	Random intercept with <i>a priori</i> means.
<code>(1 g1/g2)</code>	<code>(1 g1)+(1 g1:g2)</code>	Intercept varying among <code>g1</code> and <code>g2</code> within <code>g1</code> .
<code>(1 g1) + (1 g2)</code>	<code>1 + (1 g1) + (1 g2).</code>	Intercept varying among <code>g1</code> and <code>g2</code> .
<code>x + (x g)</code>	<code>1 + x + (1 + x g)</code>	Correlated random intercept and slope.
<code>x + (x g)</code>	<code>1 + x + (1 g) + (0 + x g)</code>	Uncorrelated random intercept and slope.

Table 2: Examples of the right-hand-sides of mixed-effects model formulas. The names of grouping factors are denoted `g`, `g1`, and `g2`, and covariates and *a priori* known offsets as `x` and `o`.

Package Simr: Description

Description:

Allows user to calculate power for generalized linear mixed models from lme4 using Monte Carlo simulations

<https://cran.r-project.org/web/packages/simr/simr.pdf>

<https://besjournals.onlinelibrary.wiley.com/doi/10.1111/2041-210X.12504>

Version 1.0 of SIMR is designed for any LMM or GLMM fitted using lmer or glmer in the LME4 package, and for any linear or generalized linear model using lm or glm, and is focused on calculating power for hypothesis tests. In future versions we plan to:

- Increase the number of models supported by adding interfaces to additional R packages.
- Extend the package to include precision analysis for confidence intervals.
- Improve the speed of the package by allowing simulations to run in parallel

Power analysis for mixed effects models in R

pamm, clusterPower,
longpower, nlmeU,
simr

Calculates power using simulation

YES

pamm,
clusterPower,
simr

NO

longpower,
nlmeU

Handles non-normal response variables

YES

clusterPower,
simr

NO

pamm

Accommodates a range of model specifications

YES

simr

NO

clusterPower

Package Simr: doTest

doTest: applies a hypothesis test to a fitted model

```
powerSim(object, test)
```

object=usually a fitted model

test=a test function

- `fixed(xname, method=c("z", "t", "f", "chisq", "anova", "lr", "sa", "kr", "pb"))`
- `compare(model, method=c("lr", "pb"))`
- `fcompare(model, method=c("lr", "kr", "pb"))`
- `rcompare(model, method=c("lr", "pb"))`
- `random()`

Example:

```
doTest(gm1, fixed("variable", "z"))
```

Package Sim: powerSim

powerSim: estimates power by simulation

Performs a power analysis for a mixed model

```
powerSim(fit, test = fixed(getDefaultXname(fit)), sim = fit, fitOpts = list(), testOpts = list(),  
simOpts = list(), seed, ...)
```

fit=fitted model object

test=specifies test to perform

sim=object to simulate from

Example:

```
fm1 <- lmer(y ~ x + (1|g), data=simdata)  
powerSim(fm1, nsim=10)
```


Package Simr: powerCurve

powerCurve: estimate power at a range of sample sizes

This function runs powerSim over a range of sample sizes

```
powerCurve(fit, test = fixed(getDefaultXname(fit)), sim = fit, along = getDefaultXname(fit),  
within, breaks, seed, fitOpts = list(), testOpts = list(), simOpts = list(), ...)
```

fit=fitted model object

test=specifies test to perform

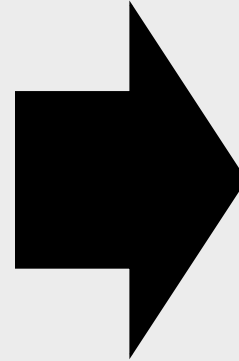
sim=object to simulate from

Example:

```
fm <- lmer(y ~ x + (1|g), data=simdata)  
pc1 <- powerCurve(fm)  
pc2 <- powerCurve(fm, breaks=c(4,6,8,10))  
print(pc2)  
plot(pc2)
```

Steps to GLMM power analysis

- 1) Get and describe data
- 2) Create model with lme4
 - confirm output and interpretation
- 3) Run model with SIMR
 - tweak/extend model as needed
- 4) Run power curve



- 1) Get data
- 2) Create model
- 3) Run model
- 4) Power curve

Examples

Each example will have three parts

- I. Introduction
- II. R-code
- III. Results

Examples

- 1) Basic Poisson
- 2) Binomial
- 3) Simulation 1
- 4) Simulation 2
- 5) Environmental

In R, make sure to install the lme4 and simr packages first and call them with the library function

```
>library(lme4)  
>library(simr)
```

Example 1: Basic Poisson Introduction

- Adapted from *SIMR: an R package for power analysis of generalized linear mixed models by simulation*
- <https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/2041-210X.12504>
- **Research Question: Do prescription rates at a certain hospital differ by day, controlling for doctor?**
- **Modeling prescription counts for ten days each across three doctors**
- **`glmer(Pr_rate ~ Day + (1 | doctor), family="poisson", data=simdata)`**
- **Random intercept model where each group (doctor) has own intercept, but the doctors share a common trend**
- **Doctor is a random effect, while Day is a fixed effect**

- 1) Get data
- 2) Create model
- 3) Run model
- 4) Power curve

Example 1: Basic Poisson R-Code

#1) GET DATA

```
> simdata2<-read.csv("SIMR_RW_example.csv") #download csv first  
> https://med.und.edu/daccota/files/docs/simr\_rw\_example.csv or  
at end of slides
```

```
> head(simdata2)
```

#2) CREATE MODEL

```
> model1 <- glmer(Pr_rate ~ Day + (1 | Doctor), family="poisson",  
data=simdata2)
```

```
> summary(model1)
```

change size of fixed effect

```
> fixef(model1)["Day"] #view effect
```

```
> fixef(model1)["Day"] <- -0.06 #change effect to about half
```

#3) SIMULATE POWER

simulate power (given sample size of 10 per group)

```
> powerSim(model1)
```

extend the model to increase sample size (20 per group) and simulate power

```
> model2 <- extend(model1, along="Day", n=20)
```

```
> powerSim(model2)
```

#4) POWER CURVE

id minimum sample size required

```
> pc2 <- powerCurve(model2)
```

```
> print(pc2)
```

```
> plot(pc2)
```

varying the number and size of groups

adding more groups

```
> model3 <- extend(model1, along="Doctor", n=15)
```

```
> pc3 <- powerCurve(model3, along="Doctor")
```

```
> plot(pc3)
```

increase size within group

```
> model4 <- extend(model1, within="Day+Doctor", n=5)
```

```
> pc4 <- powerCurve(model4, within="Day+Doctor", breaks=1:5)
```

```
> print(pc4)
```

```
> plot(pc4)
```

Example 1: Basic Poisson Results*

- Power for first model=42.70% <- **not enough**
- Power for second model=98.30% <- **overkill**
- Minimum sample size found to be about 14 Days (*for 3 Doctors*) for a power of 80% (figure 1)
- Minimum group size found to be about 8 Doctors (*each with 10 Days*) for a power of 80% (figure 2)
- Need 3 repeats (*3 Doctors X 10 Days*) to get a power of 80% (figure 3)

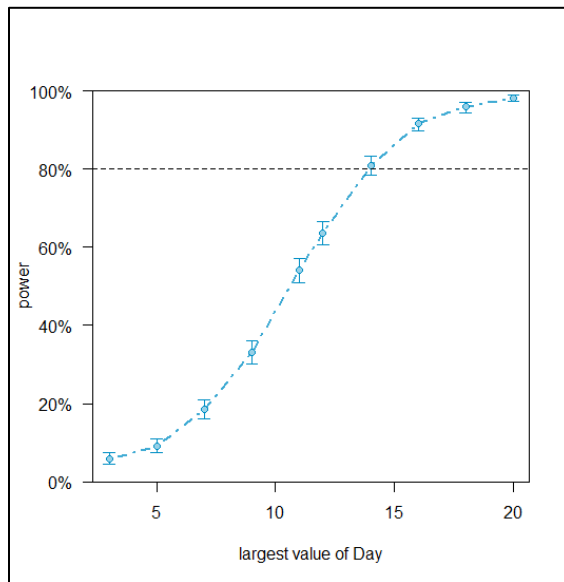


Figure 1: Power Curve 1

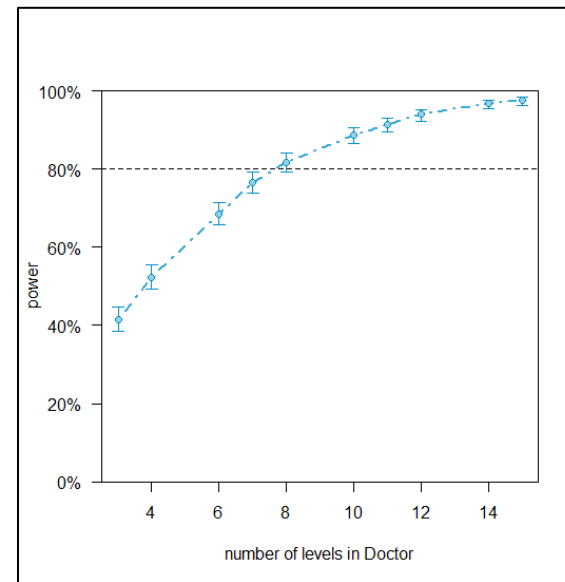


Figure 2: Power Curve 2

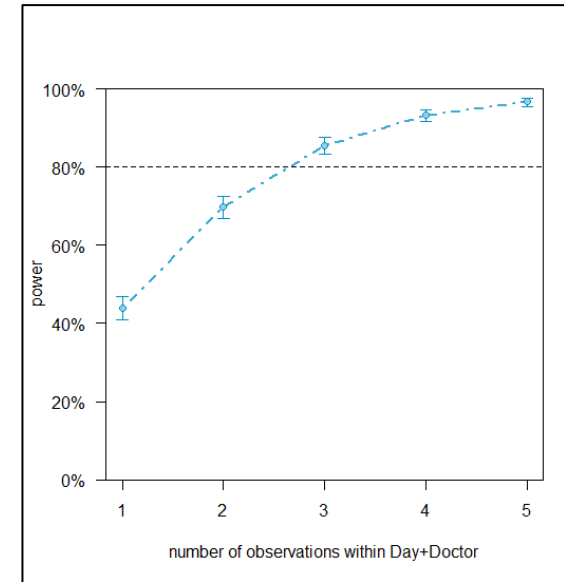


Figure 3: Power Curve 3

*will be mildly different each run based on simulation seed

Example 2: Binomial Introduction

- Taken from *SIMR: an R package for power analysis of generalized linear mixed models by simulation: Appendix 1*
- <https://besjournals.onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2F2041-210X.12504&file=mee312504-sup-0001-AppendixS1.html>
- **Research Question: Is the incidence of cbpp (contagious bovine pleuropneumonia) different across period or size?**
- **Modeling Incidence across periods and size while controlling for herds**
- **`glmer(cbind(incidence, size - incidence) ~ period + size + (1 | herd), data=cbpp, family=binomial)`**
- **Size is a continuous predictor (effect), period is a fixed effect, and herd is a random effect**

- 1) Get data
- 2) Create model
- 3) Run model
- 4) Power curve

Example 2: Binomial R Code

#1) GET DATA

```
> head(cbpp) #dataset found in lme4
```

#2) CREATE MODEL

Period only

```
> gm1 <- glmer(cbind(incidence, size -  
incidence) ~ period + (1 | herd),  
data=cbpp, family=binomial)
```

```
> doTest(gm1, fixed("period", "lr"))
```

Add size to model

```
> gm2 <- glmer(cbind(incidence, size -  
incidence) ~ period + size + (1 | herd),  
data=cbpp, family=binomial)
```

```
> doTest(gm2, fixed("size", "z"))
```

#3) SIMULATE POWER

Period model

```
> powerSim(gm1, fixed("period", "lr"),  
nsim=50)
```

Size model

```
> powerSim(gm2, fixed("size", "z"),  
nsim=50)
```

change size of fixed effect (bigger)

```
> fixef(gm2)["size"] <- 0.05
```

```
> powerSim(gm2, fixed("size", "z"),  
nsim=50)
```

#4) POWER CURVE

Double the number of herds

```
> gm3 <- extend(gm2, along="herd", n=30)
```

```
> powerSim(gm3, fixed("size", "z"),  
nsim=50)
```

Power curve not applicable here

Example 2: Binomial Results*

- Power for period model=92.00% <- **more than enough power**
- Power for size model with original effect size=10.00% <- **need more power**
- Power for size model with larger effect size=58%^ <-**still need more power, try extending herds**
- Power for size model with larger effect size and double the number of herds=80.00% <- **good enough**

* will be mildly different each run based on simulation seed
^was significantly higher than the appendix example, despite all the other numbers similar, so not sure why

Example 3: Simulation w/o Data Introduction

- Taken from https://humburg.github.io/Power-Analysis/simr_power_analysis.html
- **You can simulate without real data**
- **Research Question: Is there a difference between a treatment and control for schoolchildren across classes**
- **Model- $\rightarrow y \sim \text{treatment} + \text{time} + \text{treatment} \times \text{time} + (1 \mid \text{class/id}) + \epsilon$**
- **Testing the effect of treatment, time, the interaction of treatment and time on our y variable, with class and id as random effects and id nested inside class**

- 1) Get data
- 2) Create model
- 3) Run model
- 4) Power curve

Example 3: Simulation w/o Data R Code

#1) GET DATA

```
create covariates
> subj <- factor(1:10)
> class_id <- letters[1:5]
> time <- 0:2
> group <- c("control", "intervention")
> subj_full <- rep(subj, 15)
> class_full <- rep(rep(class_id, each=10), 3)
> time_full <- rep(time, each=50)
> group_full <- rep(rep(group, each=5), 15)
> covars <- data.frame(id=subj_full, class=class_full, treat=group_full,
  time=factor(time_full))
> covars

Intercept and slopes for intervention, time1, time2, intervention:time1, intervention:time2
> fixed <- c(5, 0, 0.1, 0.2, 1, 0.9)

Random intercepts for participants clustered by class
> rand <- list(0.5, 0.1)

residual variance
> res <- 2
```

#2) CREATE MODEL

```
> model <- makeLmer(y ~ treat*time + (1|class/id), fixef=fixed, VarCorr=rand, sigma=res,
  data=covars)
> model
```

#3) SIMULATE POWER

```
> sim_treat <- powerSim(model, nsim=100, test = fcompare(y~time))
> sim_treat
> sim_time <- powerSim(model, nsim=100, test = fcompare(y~treat))
> sim_time
```

#4) POWER CURVE

```
changing effect size
> model_large <- model
> fixef(model_large)['treatintervention:time1'] <- 2
> sim_treat_large <- powerSim(model_large, nsim=100, test = fcompare(y~time))
> sim_treat_large

changing number of classes
> model_ext_class <- extend(model, along="class", n=20)
> model_ext_class
> sim_treat_class <- powerSim(model_ext_class, nsim=100, test = fcompare(y~time))
> sim_treat_class
> p_curve_treat <- powerCurve(model_ext_class, test=fcompare(y~time), along="class")
> plot(p_curve_treat)

changing number within classes
> model_ext_subj <- extend(model, within="class+treat+time", n=20)
> model_ext_subj
> sim_treat_subj <- powerSim(model_ext_subj, nsim=100, test = fcompare(y~time))
> sim_treat_subj
> p_curve_treat <- powerCurve(model_ext_subj, test=fcompare(y~time),
  within="class+treat+time", breaks=c(5,10,15,20))
> plot(p_curve_treat)

changing both
> model_final <- extend(model, along="class", n=8)
> model_final <- extend(model_final, within="class+treat+time", n=10)
> sim_final <- powerSim(model_final, nsim=100, test = fcompare(y~time))
> sim_final
```

Example 3: Simulation w/o Data Results*

- Power for base treatment model=33.00% <-not enough power
- Power for base time model=37.00% <-not enough power
- Power for treatment model (> effect size)=95.00% <-enough power
- Power for treatment model (more classes)=94.00% <-enough power
 - Would need 13 classes to have 80% power (figure 1)
- Power for treatment model (more within class)=89.00% <-enough power
 - Would need 15 students within each class to have 80% power (figure 2)
- Power for treatment model (more + more w/i classes)=88.00% <-enough power

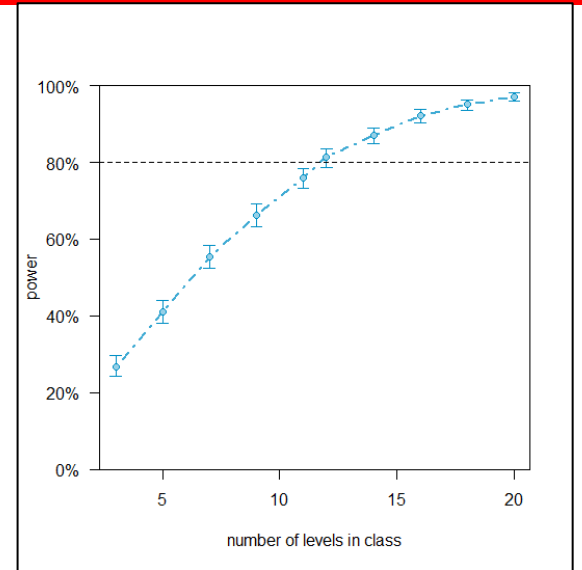


Figure 1: Power Curve 1

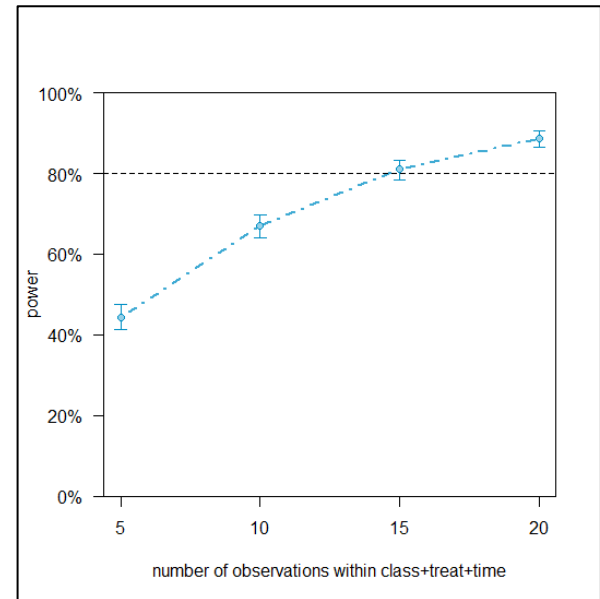


Figure 2: Power Curve 2

*will be mildly different each run based on simulation seed

Example 4: Simulation w/o Data 2 Introduction

- Taken from <http://www.alexanderdemos.org/Mixed9.html>
- **You can simulate data that is similar to real data**
- **Research Question: Is there a difference in the dependent variable (DV) across Conditions, controlling for Subject and Item?**
- **Model-> $\text{lmer}(\text{DV} \sim \text{Condition1} + (\text{Condition1} | \text{Subject}) + (\text{Condition1} | \text{Item}))$**
- **Condition is a fixed effect, while Subject and Item are random effects**

- 1) Get data
- 2) Create model
- 3) Run model
- 4) Power curve

Example 4: Simulation w/o Data 2 R Code

#1) GET DATA

```
> Item <- as.factor(rep(1:10))
> Subject <- as.factor(rep(1:30))
> Condition1 <- rep(-.5:.5)
> X <- expand.grid(Subject=Subject, Item=Item, Condition1=Condition1) #creates a 'frame'
```

fixed intercept and slope

```
> b <- c(10.1912, 4.7773)
```

random intercept and slope variance-covariance matrix

For Subject

```
> SubVC <- matrix(c(23.471, 0, 0, 3.98), 2)
```

For Items

```
> ItemVC <- matrix(c(2.197, 0, 0, 5.009), 2)
```

Extract the residual sd

```
> s <- 7.13.5
```

#2) CREATE MODEL

next, make a lmer object (feed in fixed effects, random effects, residual, and the frame of the data)

```
> SimModel <- makeLmer(DV ~ Condition1 + (Condition1|Subject)+(Condition1|Item),
                      fixef=b, VarCorr=list(SubVC, ItemVC), sigma=s, data=X)
> summary(SimModel)
```

#3) SIMULATE POWER

```
> SimPower1 <- powerSim(SimModel, fixed("Condition1", "lr"), nsim=100, alpha=.045,
                       progress=FALSE)
```

```
> SimPower1
```

#4) POWER CURVE

Test the number of subjects needed

```
> Item <- as.factor(rep(1:20))
> Subject <- as.factor(rep(1:80))
> Condition1 <- rep(-.5:.5)
> X <- expand.grid(Subject=Subject, Item=Item, Condition1=Condition1)
```

```
> b2 <- c(0, .112)
> SubVC2 <- matrix(c(.368, 0, 0, .004), 2)
> ItemVC2 <- matrix(c(.068, 0, 0, .001), 2)
> s2 <- (.559).5 # residual sd
> SimCurve <- makeLmer(DV ~ Condition1 + (Condition1|Subject)+(Condition1|Item),
                    fixef=b2, VarCorr=list(SubVC2, ItemVC2), sigma=s2, data=X)
> summary(SimCurve)
> SCurve1 <- powerCurve(SimCurve, fixed("Condition1", "lr"),
                      along = "Subject",
                      breaks = c(20, 40, 60, 80),
                      nsim=100, alpha=.045, progress=FALSE)
> plot(SCurve1)
```

Test across number of Items

```
> SCurve2 <- powerCurve(SimCurve, fixed("Condition1", "lr"),
                      along = "Item",
                      breaks = c(5, 10, 15),
                      nsim=100, alpha=.045, progress=FALSE)
> plot(SCurve2)
```

Higher order interactions

```
> Item <- as.factor(rep(1:20))
> Subject <- as.factor(rep(1:20))
> C1 <- rep(-.5:.5)
> C2 <- rep(-.5:.5)
> # creates "frame" for our data
> X <- expand.grid(Subject=Subject, Item=Item, C1=C1, C2=C2)
> b3 <- c(0, .05, -.05, .1) # fixed intercept and slope
> SubVC3 <- diag(c(.35, .005, .005, .005))
> ItemVC3 <- diag(c(.1, .005, .005, .005)) # random intercept and slope variance-covariance matrix
> s3 <- (1 - (sum(SubVC3) + sum(ItemVC3))).5 # residual sd
> SimInter <- makeLmer(DV ~ C1*C2 + (C1*C2|Subject)+(C1*C2|Item),
                    fixef=b3, VarCorr=list(SubVC3, ItemVC3), sigma=s3, data=X)
> summary(SimInter)
> SimPower.Inter <- powerSim(SimInter, fixed("C1:C2", "lr"),
                          nsim=100, alpha=.045, progress=FALSE)
> SimPower.Inter
```

Example 4: Simulation w/o Data 2 Results*

- Power for base model=100.0% <- based on observed power, so not surprising
- The number of subjects needed was over 55 (figure 1)
- The number of items needed was 14 (figure 2)
- Power for the Interaction term=19.00% <-weak interaction

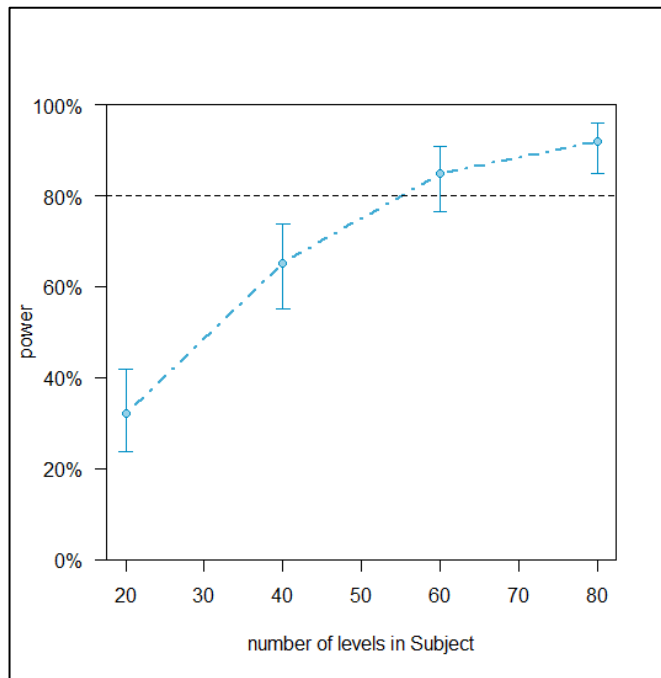


Figure 1: Power Curve 1

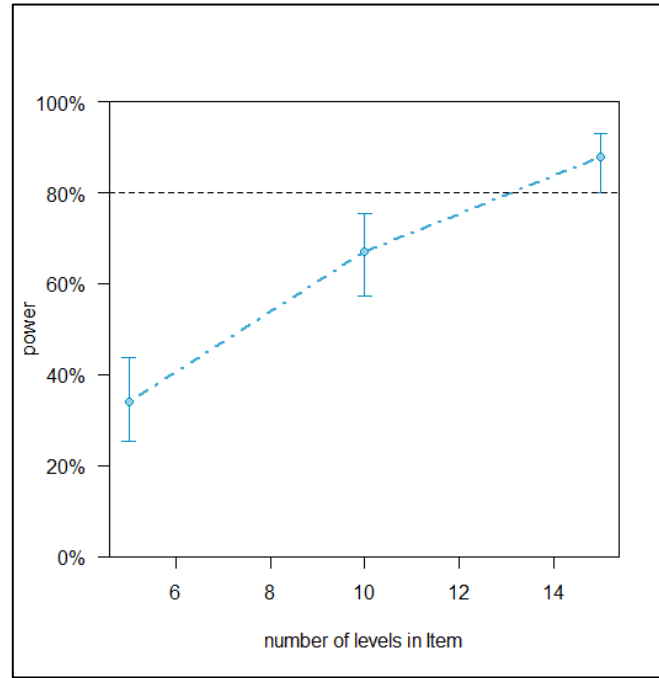


Figure 2: Power Curve 2

*will be mildly different each run based on simulation seed

Example 5: Environmental Data Introduction

- Taken from <http://environmentalcomputing.net/power-analysis/>
- **Research Question: Is there an effect of estuary modification on the abundance of a marine species?**
- **Model-> `glmer(abundance ~ temperature + modification + (1|site)`**
- **Temperature is a continuous fixed effect, modification is a fixed effect, and site is a random effect (nested in modification)**

- 1) Get data
- 2) Create model
- 3) Run model
- 4) Power curve

Example 5: Environmental Data R Code

#1) GET DATA

```
> Pilot <- read.csv(file = "Pilot.csv", header = TRUE) #get csv
Change modification into factor
> Pilot$modification <- factor(Pilot$modification)
> par(mfrow=c(1,2))
> boxplot(abundance~modification,data=Pilot,main="modification")
> boxplot(abundance~site,data=Pilot,main="site")
> par(mfrow=c(1,1))
```

#2) CREATE MODEL

```
> Pilot.mod <- glmer(abundance ~ temperature +
  modification + (1|site), family="poisson", data=Pilot)
> summary(Pilot.mod)
> fixef(Pilot.mod)["modification2"] <- 0.1 #lowers from 1.14
> fixef(Pilot.mod)["modification3"] <- 0.2 #lowers from 1.24
```

#3) SIMULATE POWER

Pilot study model

```
> powerSim(Pilot.mod, fixed("modification", "lr"), nsim=50)
> xtabs(~modification+site,data=Pilot)
```

#4) POWER CURVE

Full model (extend by increasing number of sites)

```
> full1 <- extend(Pilot.mod, along="site", n=24)
> xtabs(~site,data=attributes(full1)$newData)
> powerSim(full1, fixed("modification", "lr"), nsim=50)
```

Full model 2 (extend by increasing observations w/i sites)

```
> full2 <- extend(Pilot.mod,within="site",n=12)
> xtabs(~site,data=attributes(full2)$newData)
> powerSim(full2, fixed("modification", "lr"), nsim=50)
```

Full model 3 (extend both number of sites and obs. w/i sites)

```
> full3 <- extend(Pilot.mod,within="site",n=6)
> full3 <- extend(full3,along="site",n=12)
> xtabs(~site,data=attributes(full3)$newData)
> powerSim(full3, fixed("modification", "lr"), nsim=50)
```

Example 5: Environmental Data Results*

- Power for pilot model=52.00% <- **low, but pilot studies are designed to be underpowered**
- Power for full model 1 (increase in sites) = 78.00% <-**good, close to needed power**
- Power for full model 2 (increase within)= 68.00% <-**not as good**
- Power for full model 3 (increase in and within sites)= 74.00% <-**better, but not as good as first**
- **In summary, these results showed that it was better to increase the number of sites used rather than the number of observations within sites for the full study**

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References

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- https://humburg.github.io/Power-Analysis/simr_power_analysis.html
- <http://www.alexanderdemos.org/Mixed9.html>
- <http://environmentalcomputing.net/power-analysis/>

Data for Example 1

Cancer,Day,Doctor,Pr_rate

8.139081,1,a,3
7.947861,2,a,3
9.283638,3,a,3
7.779489,4,a,2
5.803512,5,a,3
6.13172,6,a,2
6.122911,7,a,3
7.542655,8,a,0
6.428387,9,a,2
6.219345,10,a,1
9.17015,1,b,2
8.253626,2,b,3
10.346381,3,b,2
8.807318,4,b,1
6.09285,5,b,1
8.510823,6,b,3
7.086676,7,b,2
6.241644,8,b,3
6.841493,9,b,0
5.783463,10,b,2
13.697234,1,c,9
13.551086,2,c,7
12.239432,3,c,6
14.513912,4,c,2
13.579498,5,c,2
12.037988,6,c,4
14.17994,7,c,3
13.102589,8,c,4
12.131053,9,c,2
13.071251,10,c,2