Project planning: From design to paper and data release

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Research/teaching interests in my lab

- Experimental psycholinguistics
- Computational modeling (sentence processing)
- Disseminating statistical methods (principally, Bayesian) in psycholinguistics (courses and tutorial articles)
- Open and transparent science

Materials from this workshop are available on github

Github source: https://github.com/vasishth/MPILeipzig2019

Web page: https://vasishth.github.io/MPILeipzig2019/

Motivation

Important problems in all areas of science

Too often, "findings" in published papers are:

- **non-replicable**
  Replication attempt of Dillon et al 2013 (JML): https://osf.io/reavs/
  Replication attempt of Levy and Keller 2013 (JML):
  https://osf.io/eyphj/
- **non-reproducible**
  https://royalsocietypublishing.org/doi/full/10.1098/rsos.180448
  "*...suboptimal data curation, unclear analysis specification and reporting errors can impede analytic reproducibility, undermining the utility of data sharing and the credibility of scientific findings*."
- **contain (serious) mistakes**
  https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02210/full
- **impossible to use for meta-analysis**
  https://osf.io/dcbfz/
  https://osf.io/g5ndw/

Motivation

The underlying causes of these problems

- lack of statistical training in psych/ling
- experiments are run without checks or planning
- the result is a chaotic research process
- there is a culture of not releasing data with the paper

  Actual data release statements:

  > "*Aggregate measures are available to qualified researchers upon written request*"
  >
  > "*The raw data supporting the conclusions of this manuscript will be made available to any qualified researcher upon request.*"
- errors in analyses and coding waste researcher's time and energy

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

- The research question is whether object relatives (ORs) are easier to process than subject relatives (SRs), in Mandarin Chinese.
- In English, SRs are **easier** to process than ORs:

SR: The senator who interviewed the journalist resigned.

OR: The senator who the journalist interviewed resigned.

- Gibson and Wu 2013, and Hsiao and Gibson 2003, have argued that Chinese shows the opposite pattern (ORs easier). (Some background here: https://tinyurl.com/y69nqnyt).

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

Existing data on Chinese relative clauses: Gibson and Wu 2013.

```
## load and preprocess data:
chineseRC<-read.table("data/gibsonwu2012data.txt")
crit<-subset(chineseRC,region=="headnoun")
crit$region<-factor(crit$region)
crit<-crit[,c(1,2,3,7)]
```

Example: Subject and object relatives in Mandarin Chinese

```
## the data frame:
head(crit)
```

```
##     subj item     type   rt
## 94     1   13  obj-ext 1561
## 221    1    6 subj-ext  959
## 341    1    5  obj-ext  582
## 461    1    9  obj-ext  294
## 621    1   14 subj-ext  438
## 753    1    4 subj-ext  286
```

```
## slight imbalance in design:
head(xtabs(~subj+type,crit),n=2)
```

```
##     type
## subj obj-ext subj-ext
##    1       8        7
##    2       7        8
```

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

```
## partially crossed, Latin square:
head(xtabs(~subj+item,crit),n=2)
```

```
##     item
## subj 1 2 3 4 5 6 7 8 9 10 11 13 14 15 16
##    1 1 1 1 1 1 1 1 1 1  1  1  1  1  1  1
##    2 1 1 1 1 1 1 1 1 1  1  1  1  1  1  1
```

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

```
## sum contrasts:
crit$so<-ifelse(crit$type=="obj-ext",1,-1)
library(lme4)
```

```
## Loading required package: Matrix
```

```
## "maximal" LMM (ignores convergence issues):
m<-lmer(log(rt)~so+(1+so|subj)+
          (1+so|item),
        crit,control=lmerControl(calc.derivs=FALSE))
```

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

Results:

```
Random effects:
 Groups   Name        Variance Std.Dev. Corr
 subj     (Intercept) 5.99e-02 0.244814
          so          3.54e-03 0.059512 -1.00
 item     (Intercept) 3.32e-02 0.182104
          so          4.74e-08 0.000218 0.85
 Residual             2.65e-01 0.514322
Number of obs: 547, groups:  subj, 37; item, 15

Fixed effects:
            Estimate Std. Error t value
(Intercept)   6.0618     0.0657    92.2
so           -0.0362     0.0242    -1.5
```

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

Underlying model:

$$y_{kj} \sim LogNormal(\alpha + u_{0j} + w_{0k} + (\beta + u_{1j} + w_{1k}) * so_{kj}, \sigma) \qquad (1)$$

where we have variance components: σ and

$$\Sigma_u = \begin{pmatrix} \sigma_{u0}^2 & \rho_u \sigma_{u0} \sigma_{u1} \\ \rho_u \sigma_{u0} \sigma_{u1} & \sigma_{u1}^2 \end{pmatrix} \quad \Sigma_w = \begin{pmatrix} \sigma_{w0}^2 & \rho_w \sigma_{w0} \sigma_{w1} \\ \rho_w \sigma_{w0} \sigma_{w1} & \sigma_{w1}^2 \end{pmatrix} \qquad (2)$$

$$\begin{pmatrix} u_0 \\ u_1 \end{pmatrix} \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma_u \right), \quad \begin{pmatrix} w_0 \\ w_1 \end{pmatrix} \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \Sigma_w \right) \qquad (3)$$

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

Generate fake data to compute power:

```
## load fake data simulation code:
source("R/gen_fake_lnorm.R")
```

Experiment design and planning

Example: power calculation

```
## extract estimates of fixed-effects parameters:
beta<-summary(m)$coefficients[,1]
## extract standard deviation estimate:
sigma_e<-attr(VarCorr(m),"sc")
## assemble variance covariance matrix for subjects:
subj_ranefsd<-attr(VarCorr(m)$subj,"stddev")
subj_ranefcorr<-attr(VarCorr(m)$subj,"corr")
## choose some intermediate values for correlations:
corr_matrix<-(diag(2) + matrix(rep(1,4),ncol=2))/2
Sigma_u<-SIN::sdcor2cov(stddev=subj_ranefsd,
                        corr=corr_matrix)
```

Experiment design and planning

Example: power calculation

```r
## assemble variance covariance matrix for items:
item_ranefsd<-attr(VarCorr(m)$item,"stddev")
Sigma_w<-SIN::sdcor2cov(stddev=item_ranefsd,
                        corr=corr_matrix)
```

Experiment design and planning

Example: power calculation

```
nsim<-100
tvals<-c()
for(i in 1:nsim){
fakedat<-gen_fake_lnorm(nitem=16,nsubj=40,
                        alpha=beta[1],beta=beta[2],
                        Sigma_u=Sigma_u,Sigma_w=Sigma_w,
                        sigma_e=sigma_e)
m<-lmer(log(rt)~so+(1+so|subj)+(1+so|item),
            fakedat,
            control=lmerControl(calc.derivs=FALSE))
tvals[i]<-summary(m)$coefficients[2,3]
}
```

Experiment design and planning

Example: power calculation

```r
## prospective power for nsubj=40, nitem=16:
mean(abs(tvals)>2)
```

```
## [1] 0.25
```

Experiment design and planning

Example: power calculation

Write a function for computing power:

```
compute_power<-function(nsim=100,b=-0.03625,
                        nsubj=40,nitem=16){
  tvals<-c()
for(i in 1:nsim){
fakedat<-gen_fake_lnorm(nitem=nitem,nsubj=nsubj,
               alpha=beta[1],beta=b,
               Sigma_u=Sigma_u,Sigma_w=Sigma_w,sigma_e=sigma_e
m<-lmer(log(rt)~so+(1+so|subj)+(1+so|item),
        fakedat,
        control=lmerControl(calc.derivs=FALSE))
tvals[i]<-summary(m)$coefficients[2,3]
}
mean(abs(tvals)>2)
}
```

Experiment design and planning

Example: power calculation

- Conclusion: If we were to run a new experiment on Chinese RCs with 40 subjects and 16 items, our prospective power is approximately 30%.
- This assumes that the parameter estimates from the original data are the true values.
- Note that we are uncertain about the effect estimate (and also the variance components).

Experiment design and planning

Example: power calculation

Statistical power depends on

- sample size (subjects and items)
- standard deviations (of residual and of random effects)
- true effect size

For a full analysis, we should take these uncertainties into account. See appendix in Jäger et al., 2017 (in the folder readings).

Experiment design and planning

Example: power calculation

How to take uncertainty about the effect into account? An example:
If we have ± 1 sum coding, with OR coded $+1$ and SR -1, then:

- Mean SR processing time (log ms): $\mu_1 = \beta_0 - \beta_1$
- Mean OR processing time (log ms): $\mu_2 = \beta_0 + \beta_1$
- Since the model is on the log scale, we can go back to the ms scale by exponentiating:

Mean difference in ms in OR vs SR: $\exp(\mu_2) - \exp(\mu_1)$

Experiment design and planning

Example: power calculation

Here is the model again:

```
m<-lmer(log(rt)~so+(1+so|subj)+(1+so|item),
          crit,control=lmerControl(calc.derivs=FALSE))
```

Experiment design and planning

Example: power calculation

```
## estimated OR-SR difference in ms:
exp(beta[1]+beta[2])-exp(beta[1]-beta[2])
```

```
## (Intercept)
##      -31.12
```

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

```
## what is the slope for an effect of 20 ms?
exp(beta[1]+(-0.024))-exp(beta[1]-(-0.024))
```

```
## (Intercept)
##     -20.601
```

```
## what is the slope for an effect of 50 ms?
exp(beta[1]+(-0.06))-exp(beta[1]-(-0.06))
```

```
## (Intercept)
##     -51.528
```

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

Minimum power:

```
## there will be random fluctuation
compute_power(b=-0.024)
```

```
## [1] 0.12
```

```
compute_power(b=-0.024)
```

```
## [1] 0.14
```

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

Maximum power:

```
## there will be random fluctuation
compute_power(b=-0.06)
```

```
## [1] 0.72
```

```
compute_power(b=-0.06)
```

```
## [1] 0.73
```

Experiment design and planning

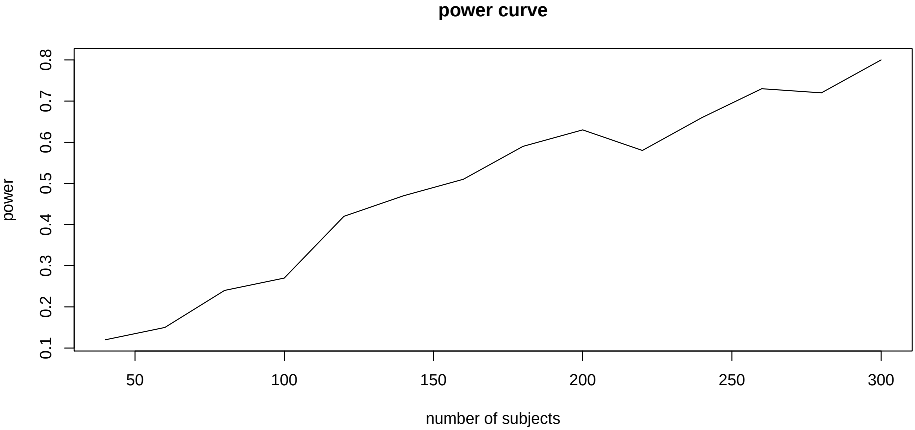
Example: Subject and object relatives in Mandarin Chinese

We are now in a position to figure out, for a given effect size, what sample size we need (number of subjects/items) to obtain 80% power or higher. Let's take the minimum effect size to compute a power curve.

```
n<-seq(40,300,by=20)
pow<-rep(NA,length(n))
for(i in 1:length(n)){
#print(n[i])
pow[i]<-compute_power(b=-0.024,
                      nsubj=n[i])
}
```

Experiment design and planning

Example: Subject and object relatives in Mandarin Chinese

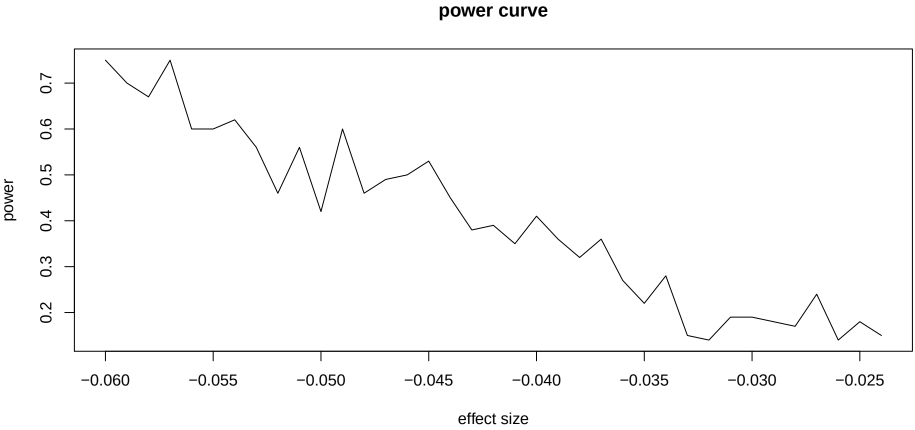


Exercise

Compute power curve as a function of different effect sizes

Exercise

Compute power curve as a function of different effect sizes



Defining the analysis plan using simulated data

Pre-registering the analysis

In 2000, ClinicalTrials.gov made it mandatory to pre-register primary outcomes.
"17 of 30 studies (57%) published prior to 2000 showed a significant benefit of intervention on the primary outcome in comparison to only 2 among the 25 (8%) trials published after 2000 (χ^2=12.2,df= 1, p=0.0005).
Pre-registration in clinical trials.gov was strongly associated with the trend toward null findings."
See readings: https://doi.org/10.1371/journal.pone.0132382

Defining the analysis plan using simulated data

Pre-registering the analysis

What is a pre-registration for?
[See: https://www.bayesianspectacles.org/a-breakdown-of-preregistration-is-redundant-at-best/]

Defining the analysis plan using simulated data

Pre-registering the analysis

What a pre-registration is for (based on a twitter thread by Christina Bergmann):

- It allows the **researcher**, to clearly specify their research hypothesis in advance
- It creates documentation of the steps to be taken
- It can improve data management
- Makes a clear distinction between exploratory and confirmatory analyses
- Allows for improvements in design before the experiment is run

Defining the analysis plan using simulated data

Pre-registering the analysis

What a pre-registration is **not** for (again echoing Bergmann):

- It doesn't improve theory (the Garbage-in-garbage-out, GIGO, principle)
- It doesn't guarantee that the study was of a high quality
- It doesn't prevent exploration or p-hacking

Defining the analysis plan using simulated data

Pre-registering the analysis

Confirmatory analysis: Define the following in advance:

- the dependent variable(s) (in eyetracking, we have many choices)
- the region of interest/time window
- exclusion criteria
- the statistical model
- expected results using fake-data simulation

None of this prevents you from doing an exploratory analysis. See: - https://osf.io/mmr7s/ - https://psyarxiv.com/2atrh/

Defining the analysis plan using simulated data

Pre-registering the analysis

Example pre-registration: Expt 7 in
https://osf.io/eyphj/
One can also submit one's pre-registration at: aspredicted.org

Defining the analysis plan using simulated data

Pre-registering the analysis

Switch to slides on pre-registration.

Check that your experiment software actually collects the data you need and back-up your data

- Many people do not check whether their experimental software is actually collecting data.
- The software repeatedly crashes during live experimental runs
- They only find out after the experiment was done.
- *Solution*: Before running the experiment for real, run the study once with one subject per group (in a Latin square design), and analyze the data fully.

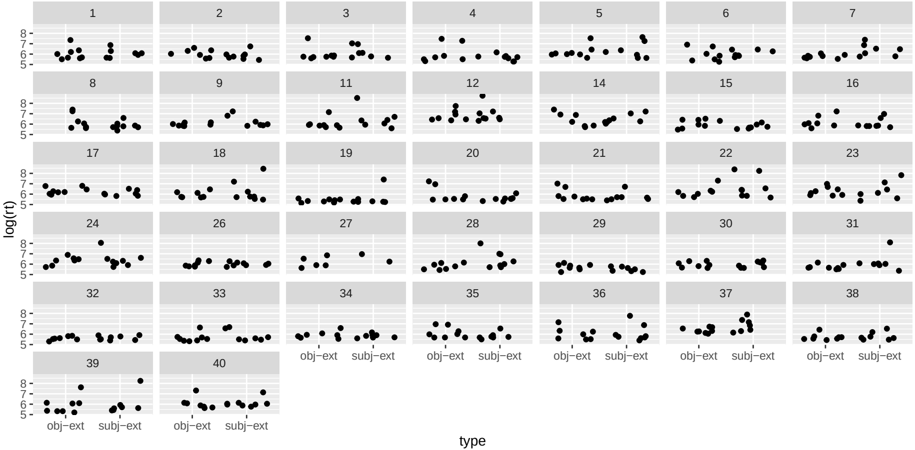
Once data are collected, visualize and summarize the data before doing any analysis

Example: Chinese RCs data

```
library(ggplot2)
p <- ggplot(crit, aes(x=type,
                      y=log(rt))) +
  geom_point(position="jitter")+
  facet_wrap( ~ subj, nrow=6)
```

Once data are collected, visualize the data before doing any analysis

Example: Chinese RCs data



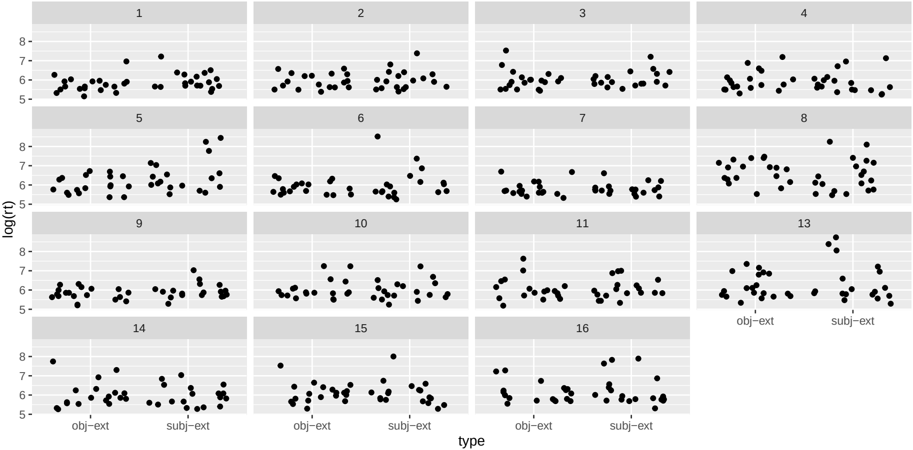
Once data are collected, visualize the data before doing any analysis

Example: Chinese RCs data

```
p2 <- ggplot(crit, aes(x=type,
                       y=log(rt))) + geom_point(position="jitte
  facet_wrap( ~ item, nrow=4)
```

Once data are collected, visualize the data before doing any analysis

Example: Chinese RCs data



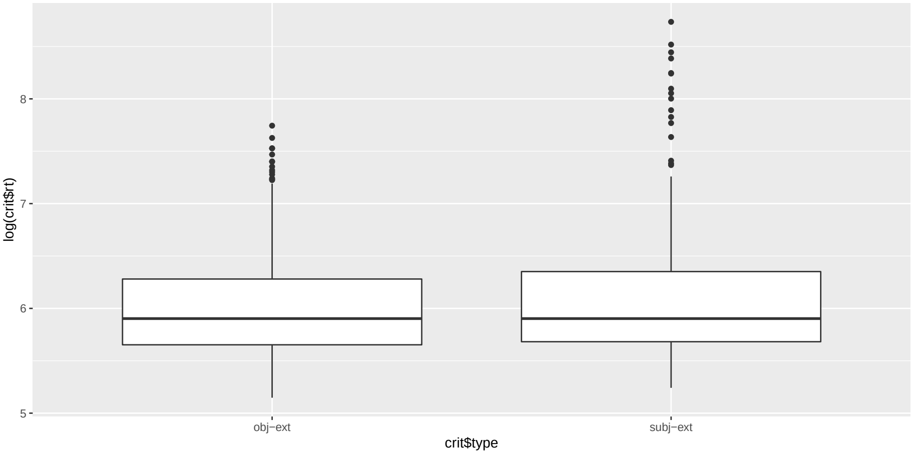
Once data are collected, visualize the data before doing any analysis

Example: Chinese RCs data

```
p3 <- qplot(crit$type,log(crit$rt),geom="boxplot")
```

Once data are collected, visualize the data before doing any analysis

Example: Chinese RCs data



Integrating the data analysis into the manuscript

Workflow checklist

Before collecting any data:

- conduct power analysis using simulated data
- pre-register an analysis plan and time-stamp it (on osf.io or aspredicted.org)
- run the entire experiment at least once per group and analyze data to check for software errors

After collecting data:

- create a data repository (using github/bitbucket/osf)
- data analysis:
    - visualize the data first
    - present the pre-registered analysis first
    - then do a separate exploratory analysis
- write code using R Markdown
- release all code and data during review and after publication
- ideally: the paper itself should be the documentation (Rmd or Rnw).

Integrating the data analysis into the manuscript

some high-level coding suggestions

- write functions for common tasks and figure types
- never hard-code variables, this will make code non-robust to changes (e.g., don't write `num_rows<-500`)
- take the time to document code
- refactor code (simplify, write modular code using customized functions)

Integrating the data analysis into the manuscript

Using R Markdown for writing papers

From RMarkdown directory, open:

- apatemplatepapaja.Rmd
- apatemplate.Rmd

Integrating the data analysis into the manuscript

Creating an R package or vignette

Read this short book: http://r-pkgs.had.co.nz/

Creating a package:

```
usethis::create_package("VasishthEtAl2019")
```

Package structure

- DESCRIPTION
- R/
- man/
- docs/
- vignettes/
- data/
- NAMESPACE

Data repositories: osf and github

- osf.io
- github.com