Bayesian analysis tutorial

Experimental syntax lab meeting

1/26/24

Link to slides: https://matakahas.github.io/code/R/

Outline

- Frequentist vs Bayesian frameworks
- Why should we do Bayesian data analysis?
- Example from Fukuda et al. (2022)
- Bayesian analysis with R

Review: Frequentist framework

- Examples: *t*-test, ANOVA, linear mixed models
- We typically calculate ***p*-value**, which informs us how likely we would obtain results that are (at least) as extreme as the observed results, given that the null hypothesis (H0) is correct
- Conventionally, *p*-value under 0.05 -> rejecting H0

What *p*-value does NOT tell us

❌ Smaller *p*-value = stronger evidence for a particular alternative hypothesis (H1)

❌ Larger *p*-value = stronger evidence for H0

> and before the verb of the matrix (main) clause. For the first critical region there was no main effect of type of RC, $F_1(1, 47) < 1$, $MSE = 6{,}395$, $p = .38$; $F_2(1, 23) < 1$, $MSE = 13{,}494$, $p = .09$. Reading times were significantly longer in the description

Gordon et al. (2001)

Bayesian framework

- In the Bayesian framework, we take what we already know about the probability for a hypothesis (**prior**) and update them (**posterior**) given obtained data (**evidence**/**likelihood**)

$$P(\text{Hypothesis}|\text{Data}) = \frac{P(\text{Data}|\text{Hypothesis}) \times P(\text{Hypothesis})}{P(\text{Data})}$$

Some advantages of Bayesian framework

- Answering the question we’re actually interested in (“how likely is our H0/H1 given the data?”)
    - Bayesian framework allows us to talk about possible values of a parameter given the data
- We can fit complex mixed-effects models
- More precise estimation by incorporating priors

Fukuda et al. (2022): An experimental reassessment of complex NP islands with NP-scrambling in Japanese.

- They investigated the island status of complex NPs in Japanese (wrt scrambling) given mixed findings from previous studies, by means of both frequentist and Bayesian frameworks

?Bill-o$_i$	John-ga	[$_{NC}$	Mary-ga	t_i	saketei-ru	toyuu	uwasa]-o	kii-ta.
B-ACC	J-NOM		M-NOM		avoid-NPST	that.say	rumor-ACC	hear-PST

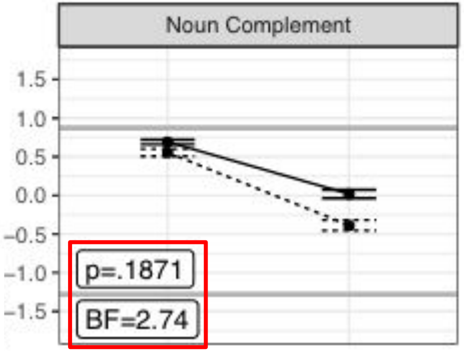
'John heard a rumor that Mary is avoiding Bill.' (Saito 1985: 246; (146b))

- Experimental design: Structure (island|non-island) x scrambling (+|-)

Fukuda et al. (2022): An experimental reassessment of complex NP islands with NP-scrambling in Japanese.

Frequentist analysis

- Calculated *p*-values of interaction, which was higher than 0.05



Bayesian analysis

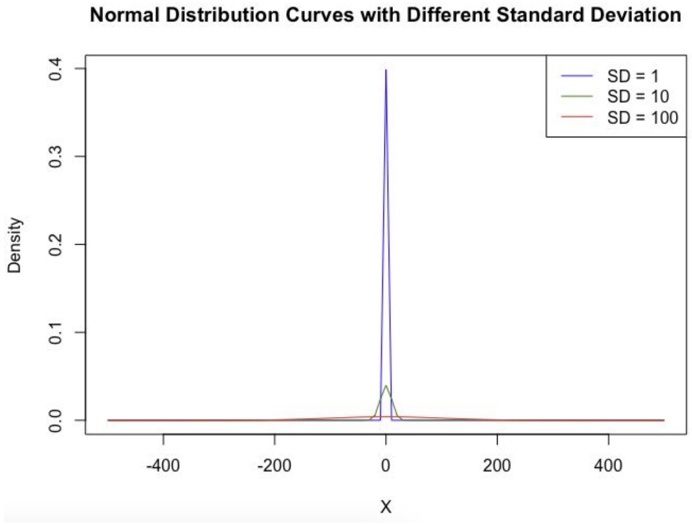
- Calculated **Bayes Factor** of interaction, which assesses the strength of evidence for one hypothesis over another
- A common threshold (for BF_{10})
  - BF > 3: In support of H1
  - BF < 0.33: In support of H0
  - 0.33 < BF < 3: Inconclusive

Bayesian analysis with R

- R packages for Bayesian analysis (R interface to Stan)
    - brms
    - RStanArm
- R packages for calculating Bayes Factor
    - bayestestR
    - BayesFactor
- Syntax of Bayesian models is identical to the one for frequentist models (e.g., lmer), with additional specification of **priors**
- We can set priors for the intercept, standard deviations, regression coefficients, etc.

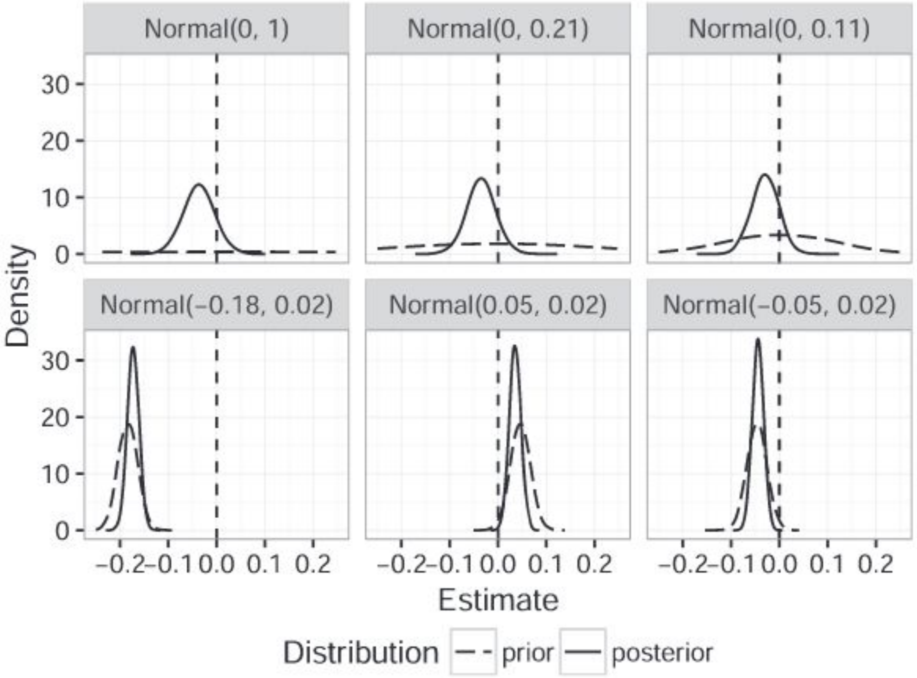
Specifying priors

- **Uninformative (flat) priors**: No existing belief about parameter values; a wide range of them is considered plausible
    - Example: Normal distribution with mean=0, sd=100
- **Weakly informative (regularizing) priors**: Some information about the expected variability, while allowing for a certain amount of uncertainty
    - Example: Normal distribution with a smaller sd (e.g., sd=10 or 1 instead of 100)
- **Informative priors**: Incorporates belief about parameter values based on prior studies



How different priors change posteriors

- **Sensitivity analysis** (changing up priors to see how that affects posteriors) is a good idea



Nicenboim & Vasishth (2016)

Tutorial

Further readings

Arunachalam, S. (2013). Experimental methods for linguists. *Language and Linguistics Compass*, 7(4):221–232.

Nicenboim, B., & Vasishth, S. (2016). Statistical methods for linguistic research: Foundational Ideas—Part II. *Language and Linguistics Compass*, 10(11), 591-613.

Sorensen, T., & Vasishth, S. (2015). Bayesian linear mixed models using Stan: A tutorial for psychologists, linguists, and cognitive scientists. *arXiv preprint arXiv:1506.06201*.

Vasishth, S., & Nicenboim, B. (2016). Statistical methods for linguistic research: Foundational ideas–Part I. *Language and Linguistics Compass*, 10(8), 349-369.

Vasishth, S., Nicenboim, B., Beckman, M. E., Li, F., & Kong, E. J. (2018). Bayesian data analysis in the phonetic sciences: A tutorial introduction. *Journal of phonetics*, 71, 147-161.