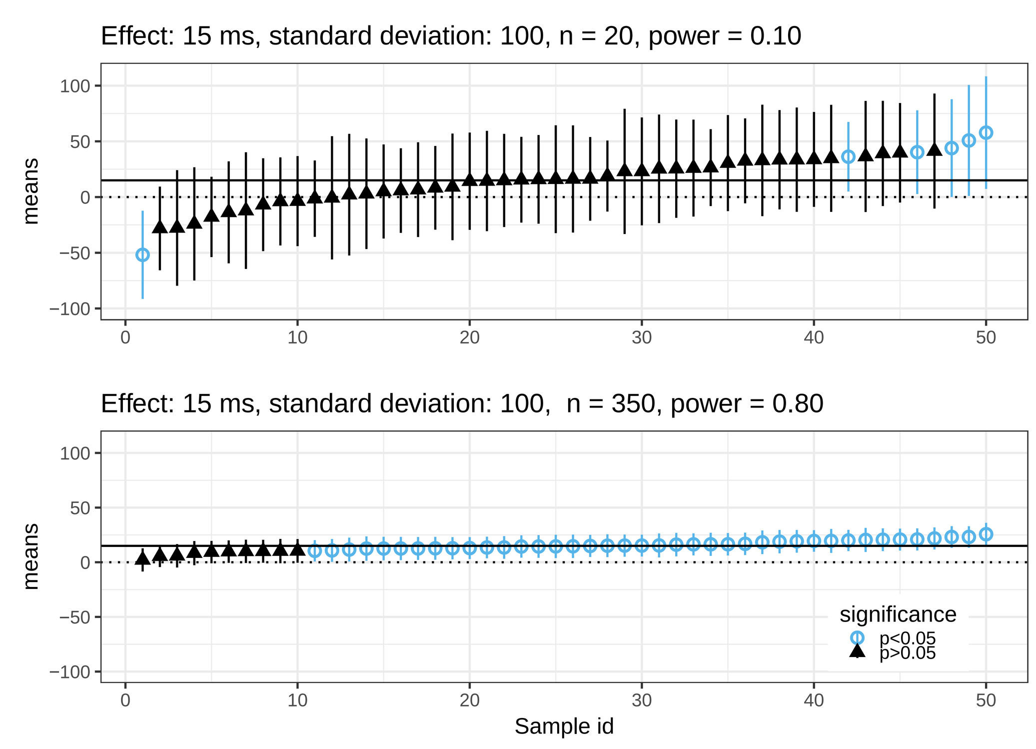
TYPE M ERRORS IN PRACTICE: A CASE STUDY

Shravan Vasishth[1], Daniela Mertzen[1], Lena A. Jäger[1] & Andrew Gelman[2]
[1]University of Potsdam, [2]Columbia University
vasishth@uni-potsdam.de

1. Motivation

- Power is relatively low in psycholinguistic studies.
  - E.g., in Jäger et al., 2017 (Appendix B): for effects (reading studies) ranging from -16 to -41 ms (sd = 150 ms, N = 40), power estimates ranged from 15% to 45%.
- Low power leads to exaggerated estimates
- Published claims will not be replicable
- Our paper (*Journal of Memory & Language*, in press) demonstrates this through direct replication of a published result (Levy & Keller, 2013).

2. The Problem: Demonstration of Type M error (simulated data)



If the estimated effect is statistically significant given that the true effect is not 0, under repeated sampling, low power leads to:

(i) **Type M** (= *magnitude*) error, i.e. an *overestimation* of the effect

(ii) **Type S** (= *sign*) error, i.e. effect in the *wrong direction*

(Gelman & Carlin, 2014)

When power is high, significant and non-significant effects will be tightly clustered near the true mean.

3. Investigating Type M error in published data: Levy & Keller, 2013

Levy & Keller (2013) study:
Two eye-tracking reading experiments: each had 28 subjects and 24 items presented in a Latin Square

Design: 2 × 2 repeated measures fully-crossed factorial design

- Two main effects and one interaction

Dependent measure:

- reading time in milliseconds (*rt*)

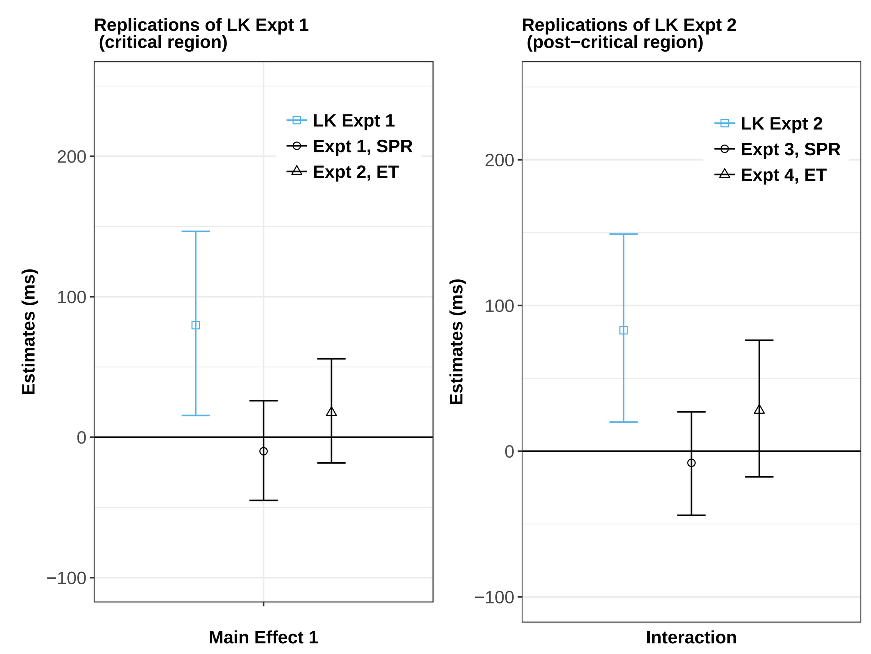
We conducted seven replication attempts of Levy & Keller, 2013

Our Replication Attempts:

Our Expt	Original Expt	Subj	Items
Expt 1 (SPR)	LK 1	28	24
Expt 2 (ET)	LK 1	28	24
Expt 3 (SPR)	LK 2	28	24
Expt 4 (ET)	LK 2	28	24
Expt 5 (SPR)	LK 1, 2 (c,d)	28	24
Expt 6 (ET)	LK 1, 2 (c,d)	28	24
Expt 7 (ET)	LK 1, 2 (c,d)	100	24

ET: eye-tracking while reading; SPR: self-paced reading

4. Results of our Expts 1–4



Posterior means with 95% credible intervals computed from a Bayesian maximal linear mixed model using Stan. Shown are mean reading time at the critical or at the post-critical region of the original studies vs. our replication attempts.

5. Hierarchical linear mixed models in Stan

$i = 1,\ldots,I$ subjects; $j = 1,\ldots,J$ items; n data points; p predictors

$$log(rt) = \underbrace{X\beta}_{\text{fixed effects}} + \underbrace{Z_u b_u}_{\text{subjects random effects}} + \underbrace{Z_w b_w}_{\text{items random effects}} + \epsilon$$

$$X_{n\times p} = \begin{bmatrix} 1 & -1 & -1 & +1 \\ 1 & +1 & +1 & +1 \\ \vdots & \vdots & \vdots & \vdots \end{bmatrix} \qquad \beta_{p\times 1} = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix}$$

$$= Z_u = Z_w$$

β_1 = Main Effect 1; β_2 = Main Effect 2; β_3 = Interaction

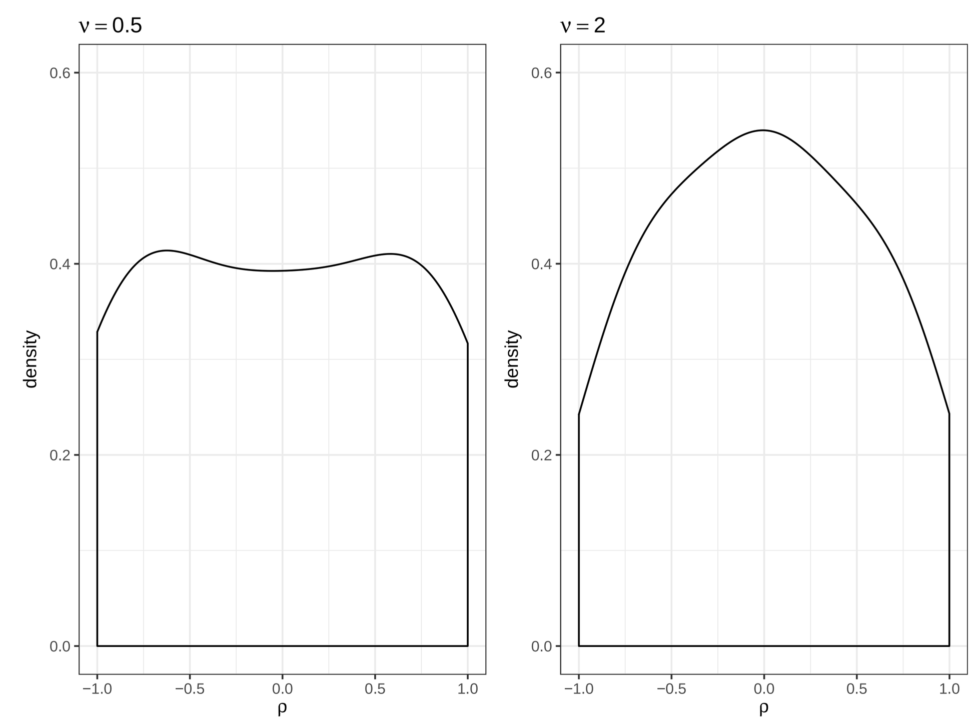
Priors

$$\beta_0 \sim Normal(0, 10)$$
$$\beta_{1,2,3} \sim Normal(0, 1)$$
$$\sigma \sim Normal_+(0, 1)$$
$$\rho \sim LKJ(\nu = 2)$$

$$b_u = MVN_4(0, \Sigma_u)$$
$$b_w = MVN_4(0, \Sigma_w)$$
$$\epsilon = Normal(0, \sigma)$$

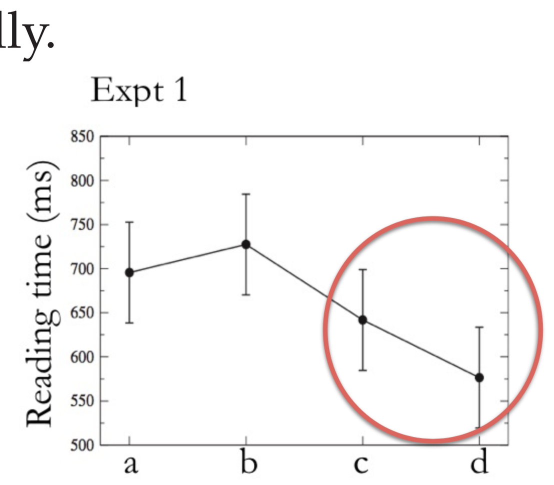
6. LKJ Prior

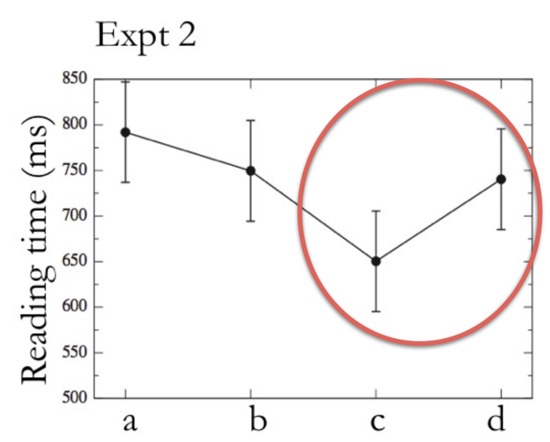
$$\rho \sim LKJ(\nu = 2)$$



7. Why run Expts 5–7?

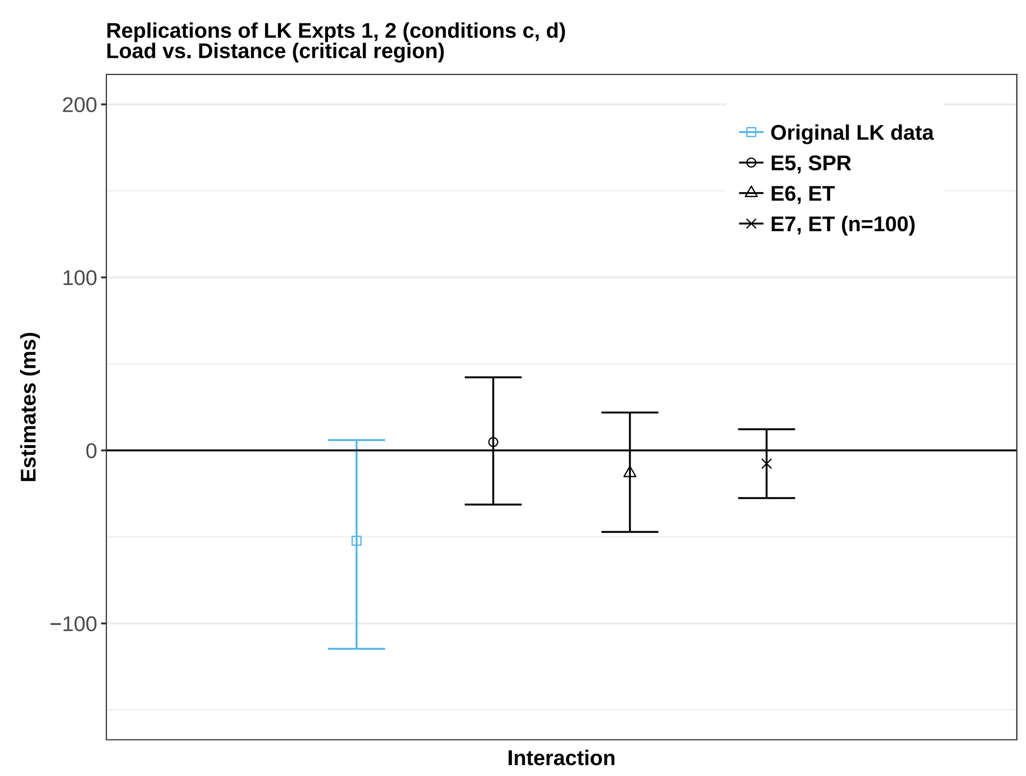
Levy & Keller (2013) claimed an interaction across their two experiments but never checked it statistically.





We tested this formally (see our Expts 5–7).

8. Results of our Expts 5–7



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9. Conclusion

Seven replication attempts found no evidence of the effects found in the original study.

Low statistical power + noisy estimates + flexible multiple comparisons $\Longrightarrow$ many published, 'significant' findings are the result of an overestimation (**Type M error**).

10. Improving current practices

OUR PROPOSAL:

- Move focus away from statistical significance
- Focus on estimation: run high-precision experiments
- Conduct direct replications to establish robustness of effect
- Pre-register hypotheses, design and analyses plan of study