Simulating success: power analysis with nonlinear models using the *simr* package

Roberta Cessa

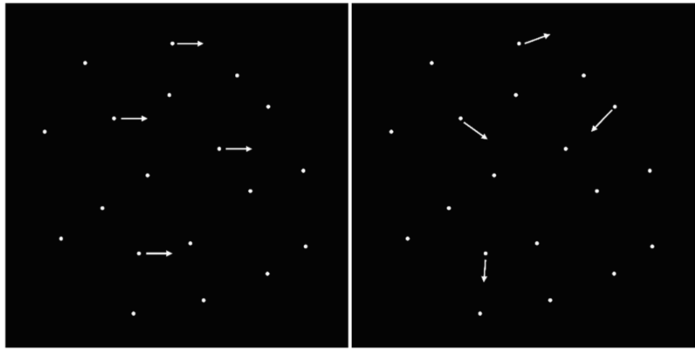
Psicostat meeting – 06/12/2024

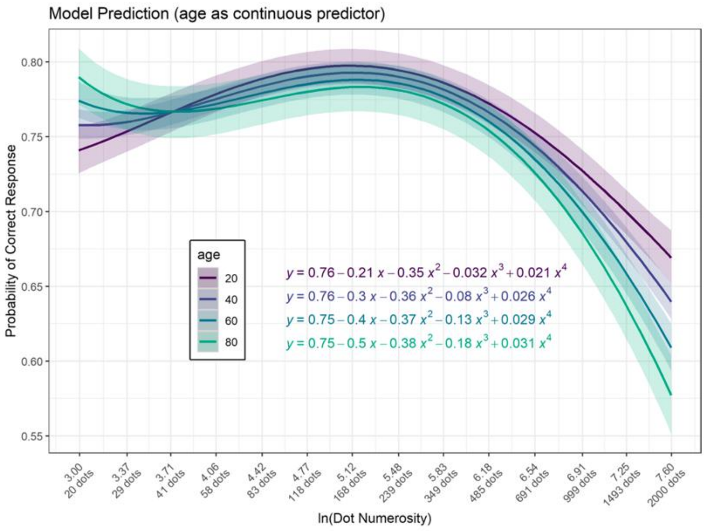
The *simr* package

- The *simr* package in R is a tool for conducting power analysis in the context of generalized linear mixed models (GLMMs).
- *simr* allows for
  - **simulation-based** power calculations, which makes it particularly useful for models involving hierarchical data structures;
  - handling **mixed models** with random intercepts and slopes;
  - applications to **non-normal distributions** (e.g., binomial, Poisson), common in psychophysical experiments;
  - **extension** of existing models to **simulate** larger sample sizes using the *extend()* function
  - **visualizations** of power to assess power across different sample sizes;
  - interactive and flexible **adjustments** of effect sizes, variances, or design parameters to perform sensitivity analyses;
  - evaluation of **specific terms** (e.g., interactions or polynomial effects).

Green and McLeod (2016)

The original study



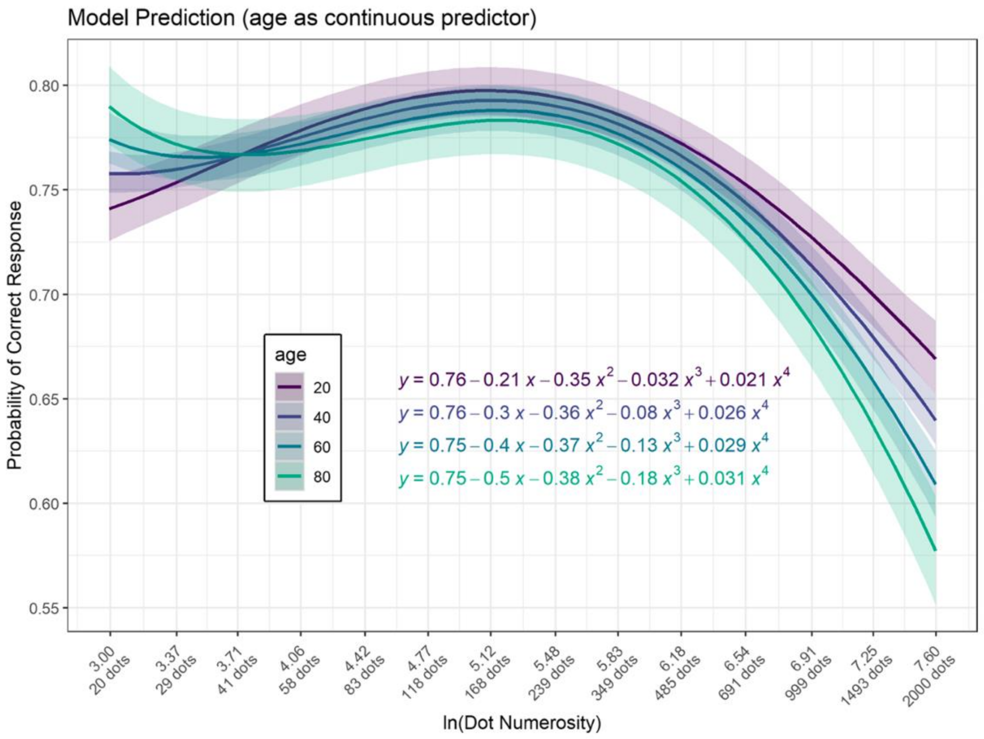


- The study examined **stochastic resonance (SR)** in motion detection across a lifespan, focusing on how dot numerosity influences performance.
- Results confirmed the characteristic **inverted U-shaped curve of SR**, where optimal performance occurs at intermediate noise levels.
- **Key findings:**
  - Younger participants showed enhanced motion detection performance with higher dot numerosity
  - Older participants exhibited a **flattened curve** with peak performance at lower noise levels

Di Ponzio et al. (2024)

The original study

N = 286

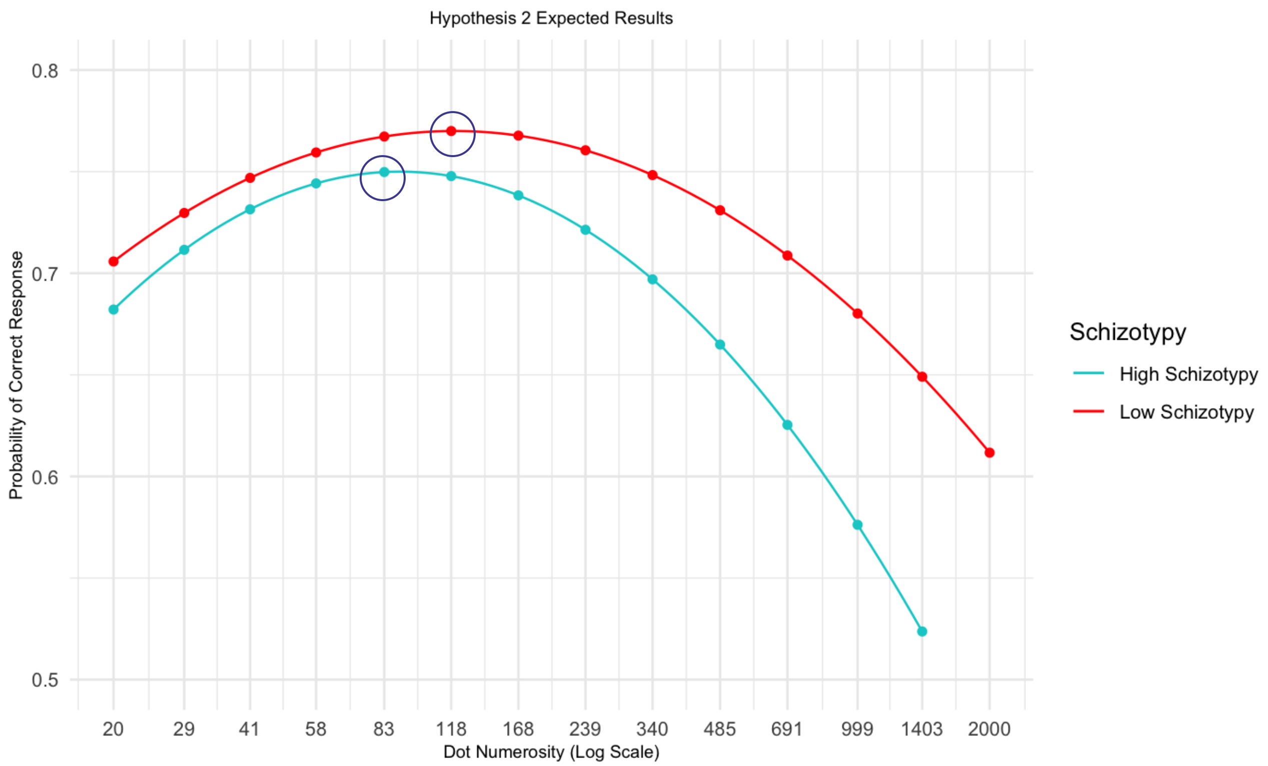


- The study employed a **generalized linear mixed model (GLMM)** with a **binomial family** to analyze motion detection accuracy, accounting for:
  - Fixed effects → external noise (dot numerosity) modeled as a polynomial function (1), age (2), and their interaction (3)
  - Random effects → subject-level variability to capture individual differences.
- This model was chosen to reflect the **non-linear relationships** (e.g., inverted U-shaped curve) between noise levels and detection performance and to address the hierarchical structure of the data (repeated measures per participant).

Di Ponzio et al. (2024)

The new study

- Builds on previous findings of stochastic resonance in visual perception.
- Focuses on **schizotypal traits** and their influence on the interaction between external noise and motion detection accuracy.
- Aims to explore how internal noise impacts perceptual processes and group differences.



Why is *simr* so appropriate for this study?

- **Hierarchical design** → The GLMM accounts for repeated measures within participants
- **Non-linear Interactions** → The package allows simulation of power for detecting the hypothesized non-linear relationship between noise levels and performance
- **Customized effect sizes** → Possibility to adjust effect sizes conservatively to reflect a realistic scenario

Simulating success – model fit

```
best_model <- glmer(cbind(correct, failures) ~ poly(LogDots, 3, raw = FALSE)
                    * age + (1|subj), data = scaled_data,
                    family="binomial", nAGQ = 0)
```

First, we fit a GLMM to the old dataset to have the **baseline model parameters** and interactions (e.g., between age and external noise levels) that would inform our simulation-based power analysis for the new study.

Simulating success - extend() and fixef()

```
extended_model <- extend(best_model, along = "subj", n = 300)  # Adjust 'n' based on your needs
fixef(extended_model)['poly(LogDots, 3, raw = FALSE)1:age'] <- fixef(best_model)['poly(LogDots, 3, raw = FALSE)1:age']*0.5
fixef(extended_model)['poly(LogDots, 3, raw = FALSE)2:age'] <- fixef(best_model)['poly(LogDots, 3, raw = FALSE)2:age']*0.5
fixef(extended_model)['poly(LogDots, 3, raw = FALSE)3:age'] <- fixef(best_model)['poly(LogDots, 3, raw = FALSE)3:age']*0.5
```

Extend model to include the effect of interest

Extends the fitted model (`best_model`) to simulate data for a larger sample size (300 subjects).

- `along = "subj"`: Specifies that the extension is along the subj (subject) random effect.
- `n = 300`: Sets the new sample size to 300 subjects.

Adjust fixed effects for power analysis

Modifies the fixed effects of the extended model to simulate a smaller effect size (50% of the original effect size). This is done to test the model's power to detect smaller effects.

- `fixef`: Accesses the fixed effects of the model.
- `0.5`: Reduces the effect size by half for the interaction terms involving LogDots and age.

Simulating success - `extend()` and `fixef()`

```
fixef(extended_model)['poly(LogDots, 3, raw = FALSE)1:age'] <- fixef(best_model)['poly(LogDots, 3, raw = FALSE)1:age']*0.5
fixef(extended_model)['poly(LogDots, 3, raw = FALSE)2:age'] <- fixef(best_model)['poly(LogDots, 3, raw = FALSE)2:age']*0.5
fixef(extended_model)['poly(LogDots, 3, raw = FALSE)3:age'] <- fixef(best_model)['poly(LogDots, 3, raw = FALSE)3:age']*0.5
```

The three `fixef()` adjustments correspond to the polynomial coefficients (`` `poly(LogDots, 3, raw = FALSE)` ``) that model non-linear interactions between dot numerosity and age.

Why three adjustments?
The polynomial includes:

- Linear term → changes in slope with age.
- Quadratic term → changes in curvature with age.
- Cubic term → captures more complex, S-shaped relationships between the two variables

Purpose of adjustment
The terms are scaled by 50% to simulate smaller effect sizes, creating a conservative scenario for power analysis.

- **Simulating the interaction as a whole?**
- **Using different scaling for each term?**

Simulating success - powerCurve()

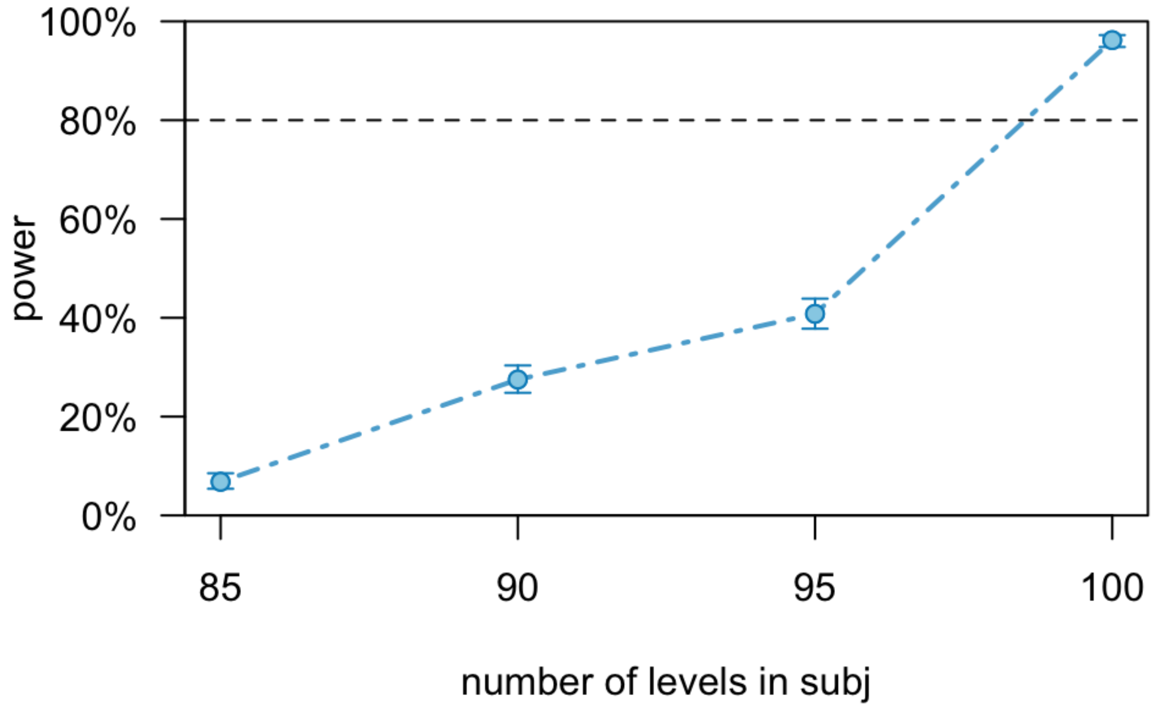
```r
power_simulation1 <- powerCurve(extended_model,
                                fcompare(~ poly(LogDots, 3, raw = FALSE) + age),
                                along = "subj", breaks = c(85, 90, 95, 100),
                                nsim = 1000)
```

Perform power simulation for the interaction term

It calculates power at different sample sizes by running simulations on a statistical model. It tests a specific hypothesis or comparison.

- **`fcompare`**: Specifies the null model for comparison. This tests whether the fixed effects (polynomial terms and age) improve the model fit significantly when compared to a simpler model (without these terms).
- **`along = "subj"`**: Varies the sample size along the subj random effect.
- **`breaks = c(85, 90, 95, 100)`**: Tests power at specific sample sizes
- **`nsim = 1000`**: Runs 1,000 simulations for each sample size.

Simulating success - `plot()` and `summary()`




```
> summary(power_simulation1)
  nrow nlevels successes trials  mean     lower      upper
1 2380      85        68   1000 0.068 0.0531881 0.08541305
2 2520      90       275   1000 0.275 0.2475213 0.30381008
3 2660      95       408   1000 0.408 0.3773486 0.43919468
4 2800     100       962   1000 0.962 0.9482129 0.97297118
```

- Power of 80% is reached with roughly 100 participants
- The curve goes up quite steeply

powerCurve

The *powerCurve* function in the *simr* package estimates statistical power across a range of sample sizes for a specified model. It's a cool tool because it:

- Evaluates power by **simulating data** from a fitted model.
- Allows testing for fixed effects, random effects, or specific terms.
- Provides **flexibility** to define sample size increments (`breaks`) and the number of simulations (`nsim`).
- Outputs power estimates with confidence intervals and visualizations via `plot()`.
- Allows for the implementation of **customized functions** with `test = argument`, instead of the default value

Thank you for your attention!

Any questions, comments or suggestions are very welcome!

Resources

- https://github.com/pitakakariki/simr
- https://www.rdocumentation.org/packages/simr/versions/1.0.7/topics/powerCurve
- https://cran.r-project.org/web/packages/simr/simr.pdf

- Green, P., & MacLeod, C. J. (2016). SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, *7*(4), 493-498.
- Cessa, R., Contemori, G., Battaglini, L., Cenk, E., & Bertamini, M. (2024, December 6). Stochastic resonance and neural noise in schizotypal traits: a random dot kinematograms paradigm. https://doi.org/10.17605/OSF.IO/ZX27C
- Di Ponzio, M., Battaglini, L., Bertamini, M., & Contemori, G. (2024). Behavioural stochastic resonance across the lifespan. *Cognitive, Affective, & Behavioral Neuroscience*, *24*(6), 1048-1064.