Bayesian Cognitive Modeling

Exploring Stimulus-Response Data

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Data provided by Dr. Jiang of the Psychology department at UNR.

Abstract

When presented with two stimuli separated by some small amount of time, our brains have the potential to perceive them as happening at the same time. This perception of temporal order may be modified through a process called an adaptation period, and quantified by the point of subjective simultaneity (PSS), and the just noticeable difference (JND).

On the entire subject group level, an adaptation will shift the average PSS from 23ms to 18ms, and reduce the JND from 93ms to 73ms. The shift in PSS is not significant enough to conclude if an adaptation will modify a subject's perception of temporal order, but the JND does suggest that it will modify a subject's temporal acuity.

Background

The way our brain processes sound is different than the way it processes sight and touch. So even if two events happen at the same time, we may not perceive them as such. When a subject is presented with two stimuli, say an audible beep and a flash of light, contextual and biological factors can modify their temporal perception.

Experimental Design

Two stimuli are presented to a subject: an audial beep, and a flash of light. This is called the audio-visual task (AV). The subject responds as to which stimulus they thought came first (encoded as a 1 if they thought the flash came first and a 0 if they thought the beep came first). The stimuli are presented at fixed time delays in random order (i.e. a time separation between -500ms and 500ms in 50ms steps). After collecting data, the responses are turned into proportional data where the proportion represents the number of visual-first responses. E.g. at an SOA of 100ms, a subject may have 3 visual first responses out of 5 trials at that SOA, so the proportion is calculated as 0.6. If the time separation is large in the positive direction, the proportion will be close to 1, and if it is large in the negative direction, the proportion will be close to 0.

Key Terms

- *Stimulus Onset Asynchrony* (SOA): Time separation between stimuli
- *Point of Subjective Simultaneity* (PSS): The time separation at which a subject perceives two stimulus as happening simultaneously
- *Just Noticeable Difference* (JND): The difference in SOA needed to increase the proportion of responses from 0.5 to 0.84

Data and Design

We are fitting what is called a logistic model

$$\theta = \frac{1}{1+e^{-x}}$$

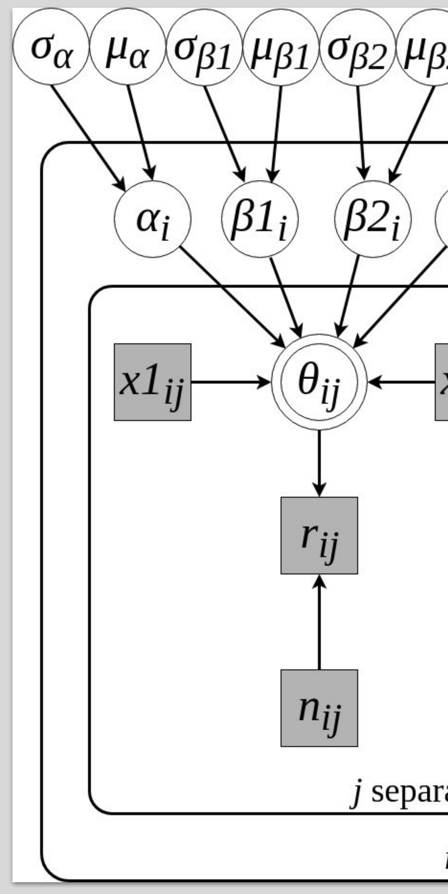
which produces outputs between 0 and 1. The log-odds of this equation simplifies to a linear equation. In this context, the model becomes

$$\operatorname{logit}(\theta) = \alpha + \beta_1 \times \text{soa} + \beta_2 \times \text{trial} + \kappa \times \text{soa} \times \text{trial}$$

where the *trial* is encoded as a 0 (baseline) or 1 (post-adaptation). When we formulate the model in this way, we can interpret the β_2 and κ coefficients as the added effect of undergoing an adaptation period. The baseline and adaptation models are

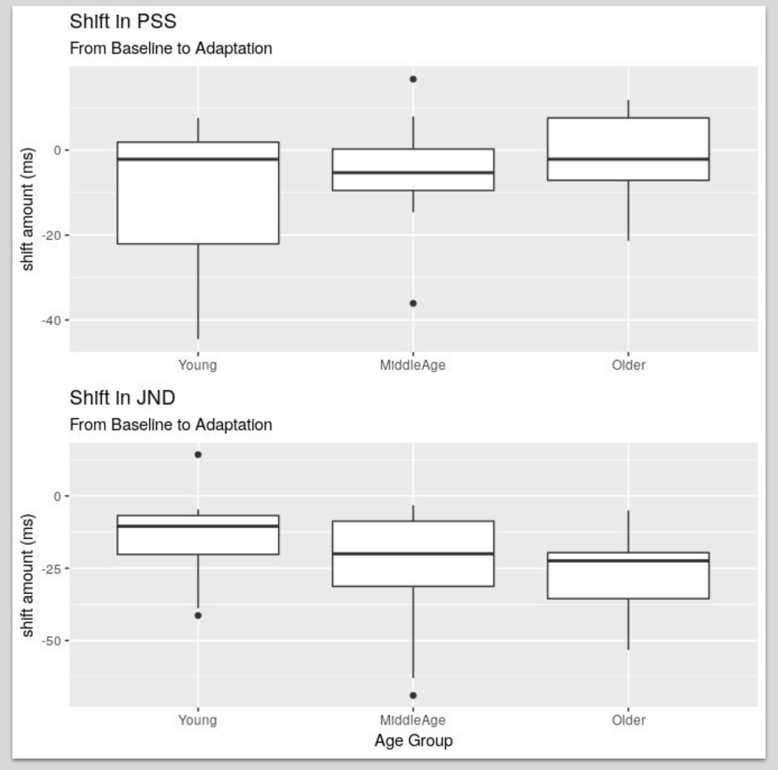
$$\operatorname{logit}(\theta) = \alpha + \beta_1 \times \text{soa}$$

$$\operatorname{logit}(\theta) = (\alpha + \beta_2) + (\beta_1 + \kappa) \times \text{soa}$$



The data was fit for each subject using a program called Stan which implements Hamiltonian Monte Carlo techniques to estimate the posterior distribution of the parameters. The benefit is that the model also produces group-level parameter distributions in tandem with the individual's estimations. The graphical hierarchical model above is a representation of the individual and group level parameters.

Results



PSS

The younger and middle age groups (ages 18-30 and 40-50) experienced the most noticeable shift in PSS. The older age group (ages 65-75) was nearly divided with half of them experiencing a positive shift.

JND

All but one subject had their JND decrease after an adaptation period. The older age groups experienced a larger decrease than the younger group, especially when looking at the median shift.

Coefficient	Mean	Std. Dev.	2.5%	25%	50%	75%	97.5%
μ_α	-0.4013	0.1157	-0.6306	-0.4758	-0.3972	-0.3267	-0.1852
μ_{β_1}	5.4456	0.4188	4.6593	5.1554	5.4346	5.7173	6.3075
μ_{β_2}	-0.0289	0.1084	-0.2393	-0.1014	-0.0308	0.0448	0.1795
μ_κ	1.5194	0.3971	0.8006	1.2472	1.4993	1.7823	2.3275
σ_α	0.6827	0.0977	0.5130	0.6142	0.6733	0.7432	0.8891
σ_{β_1}	1.4567	0.3528	0.8729	1.2066	1.4270	1.6678	2.2463
σ_{β_2}	0.1653	0.0829	0.0365	0.1056	0.1549	0.2126	0.3607
σ_κ	0.5758	0.3050	0.1216	0.3564	0.5278	0.7513	1.2612

Group level Summary

Posterior distribution of the group level coefficients. These represent the distribution from which all subject parameters all drawn.

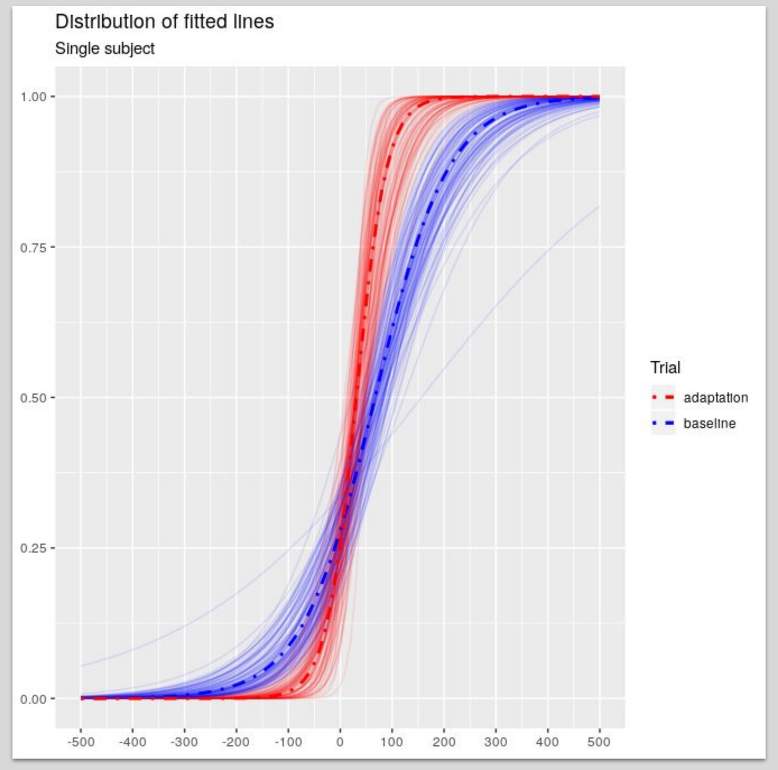
Discussion

Group level Summary

The average β_2 coefficient is statistically 0, which results in a simplified model:

$$\operatorname{logit}(\theta) = \begin{cases} \alpha + \beta_1 \times \text{soa} & \text{if baseline trial} \\ \alpha + (\beta_1 + \kappa) \times \text{soa} & \text{if post adaptation trial} \end{cases}$$

We can infer that a post-adaptation trial will not change the intercept of the model, but the intercept doesn't explain the key elements of a fitted curve, namely the PSS and JND tell us more about a subject's performance. Based on the posterior mean of the coefficients, the baseline PSS and JND are 23ms and 93ms. This means that a SOA of 23ms is roughly when the subjects perceive the stimuli as happening at the same time, but this is already bordering on the threshold of human perception.



Subject level

Even though the group level suggests no significant shift in PSS, the results are different and noticeable at the subject level, especially when we observe plot of the posterior samples. The effect of an adaptation period is clear for this subject on the left. The slope of the curve (a proxy for the JND) after the adaptation is steeper. This decrease in JND (increase in slope) occurs with 97% of the subjects in the study.

Closing Remark

There are other cofactors that are yet to be implemented into this study. The primary interest is seeing if age plays an important role in determining the shift in PSS and JND. For now we can subset the results by age, but we would like to incorporate age as another variable for which we can get a posterior distribution for.

References

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