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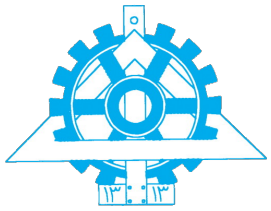

Principles of Cognitive Science

Homework 1

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Abstract

This study investigates the role of spatial frequency information in facial identity recognition using both psychometric function fitting and signal detection theory. Behavioral data were collected under varying spatial frequency conditions and analyzed through two approaches: (1) fitting psychometric curves to estimate sensitivity, and (2) calculating the area under the Receiver Operating Characteristic (ROC) curve to quantify separability. Model comparisons between generalized sigmoid and Gaussian CDF functions revealed no significant performance differences. Hypothesis testing showed that sensitivity was highest for intact spatial frequencies compared to low and high frequencies. No consistent effects were found for gender congruence, hand dominance, or handedness. However, a novel analysis revealed that identity detection performance was significantly better in homogeneous blocks (same spatial frequency) than in mixed-frequency blocks. These results suggest that perceptual consistency enhances face recognition performance, likely by reducing cognitive load or enhancing perceptual tuning.

Psychometric Fitting

To begin, I fitted a sigmoid function to two representative blocks of data to illustrate psychometric trends:

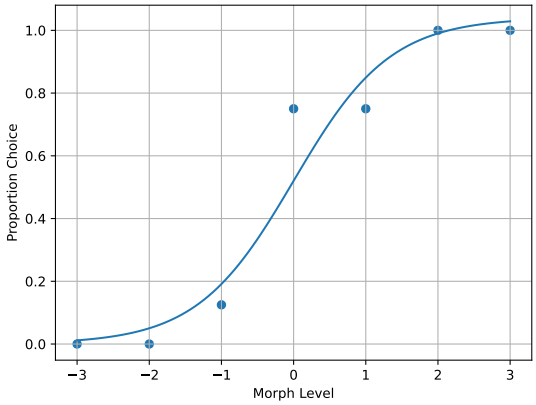

Figure 1: Sigmoid fitted to the data of subject 1 (Trial Key: MahGol), block type: Same, frequency level: Intact

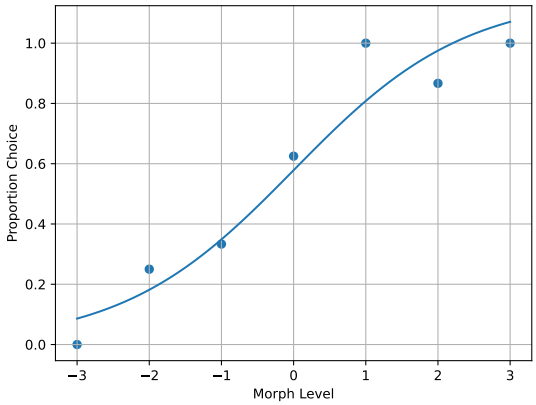

Figure 2: Sigmoid fitted to the data of subject 4 (Trial Key: AbHa), block type: Mix, frequency level: Low

2.1 Model Comparison: Generalized Sigmoid vs. Gaussian CDF

I computed the proportion of correct responses at each morph intensity level and visualized the data using a scatter plot:

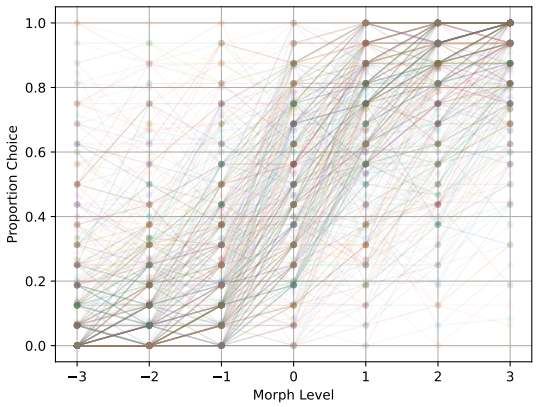

Figure 3: Scatter plot of correct responses by morph intensity for all blocks

Two psychometric models—a generalized Sigmoid function and a Gaussian cumulative distribution function (CDF)—were fitted to the data. Model performance was evaluated using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC).

Table 1: Model comparison based on AIC and BIC

Model	Mean AIC	Mean BIC	Preferred (AIC)	Preferred (BIC)
Gaussian CDF	-38.30	-38.46	275 blocks	274 blocks
Generalized Sigmoid	-37.84	-38.05	181 blocks	182 blocks

Paired t-tests and Wilcoxon signed-rank tests were conducted to determine whether the differences were statistically significant. The tests suggested that although the Gaussian CDF had slightly better AIC and BIC values on average, the differences were not statistically significant:

- **Paired t-tests:** AIC $p = 0.43$, BIC $p = 0.48$
- **Wilcoxon signed-rank tests:** AIC $p = 0.13$, BIC $p = 0.23$

2.2 Hypothesis Testing

To choose between parametric and non-parametric methods, the Shapiro-Wilk test was applied to assess normality. Based on the results, appropriate statistical tests were selected.

2.2.1 Sensitivity Across Spatial Frequency Bands

Given the presence of three dependent conditions, I used the Friedman test (non-parametric) due to non-normality. The test indicated a significant difference across frequency bands:

- AbHa: $\chi^2 = 13.0, p = 0.0015$
- MahGol: $\chi^2 = 45.8, p < 0.0001$

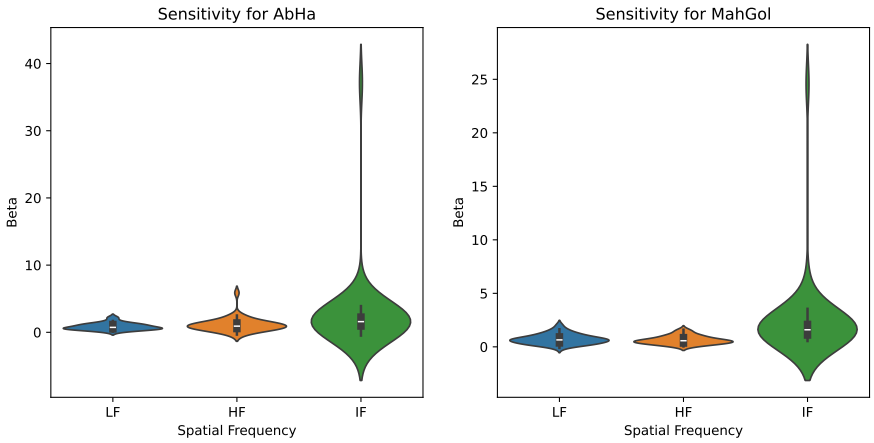

Figure 4: Sensitivity across spatial frequency bands

For pairwise comparisons (intact vs. low, intact vs. high, low vs. high), Wilcoxon signed-rank tests and paired t-tests were used:

- Sensitivity for intact images was significantly different from low and high frequencies.
- No significant difference was found between low and high frequencies.
- **IF vs. LF:** AbHa: $p < 0.0001$; MahGol: $p < 0.0001$
- **IF vs. HF:** AbHa: $p = 0.0148$; MahGol: $p < 0.0001$
- **LF vs. HF:** AbHa: $p = 0.2675$; MahGol: $p = 0.3185$

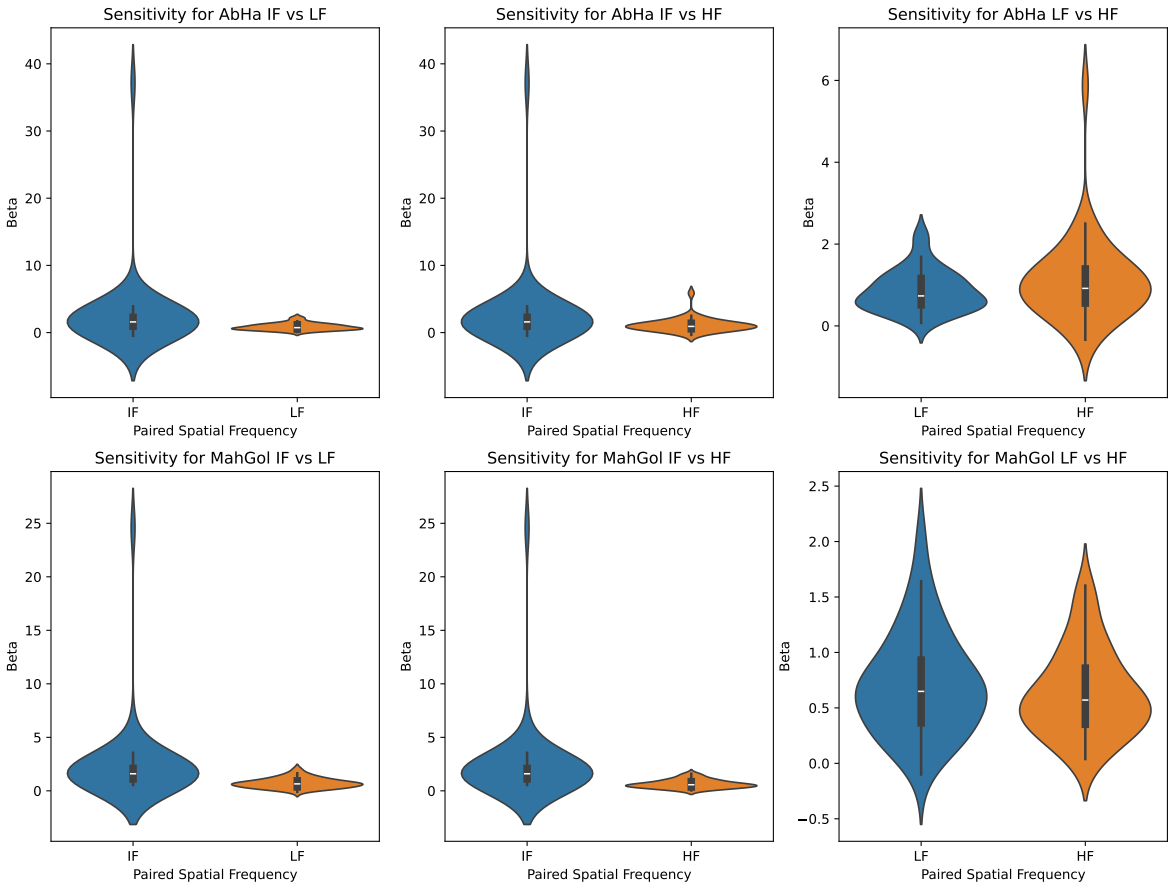

Figure 5: Pairwise comparisons across frequency bands

2.2.2 Identification Based on Gender of the Image (Conspecific vs. Hetero-specific)

As the groups were independent and data were normally distributed, an independent t-test was used. Results showed no significant difference in identification accuracy based on gender congruence:

- AbHa: $t = -1.0, p = 0.31$
- MahGol: $t = 0.5, p = 0.59$

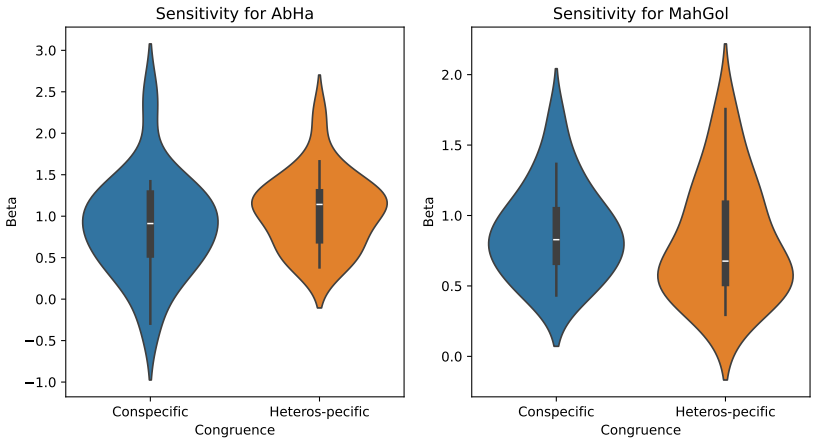

Figure 6: Performance by image gender congruence

2.2.3 Effect of Using the Left Hand

As the same participants used both hands, data were paired; due to non-normality, Wilcoxon signed-rank tests were applied. The tests were one-sided, as the hypothesis was directional (left hand being better). No significant effect was found:

- **IF:** AbHa: $p = 0.1048$; MahGol: $p = 0.3546$
- **LF:** AbHa: $p = 0.4771$; MahGol: $p = 0.5513$
- **HF:** AbHa: $p = 0.2733$; MahGol: $p = 0.9029$

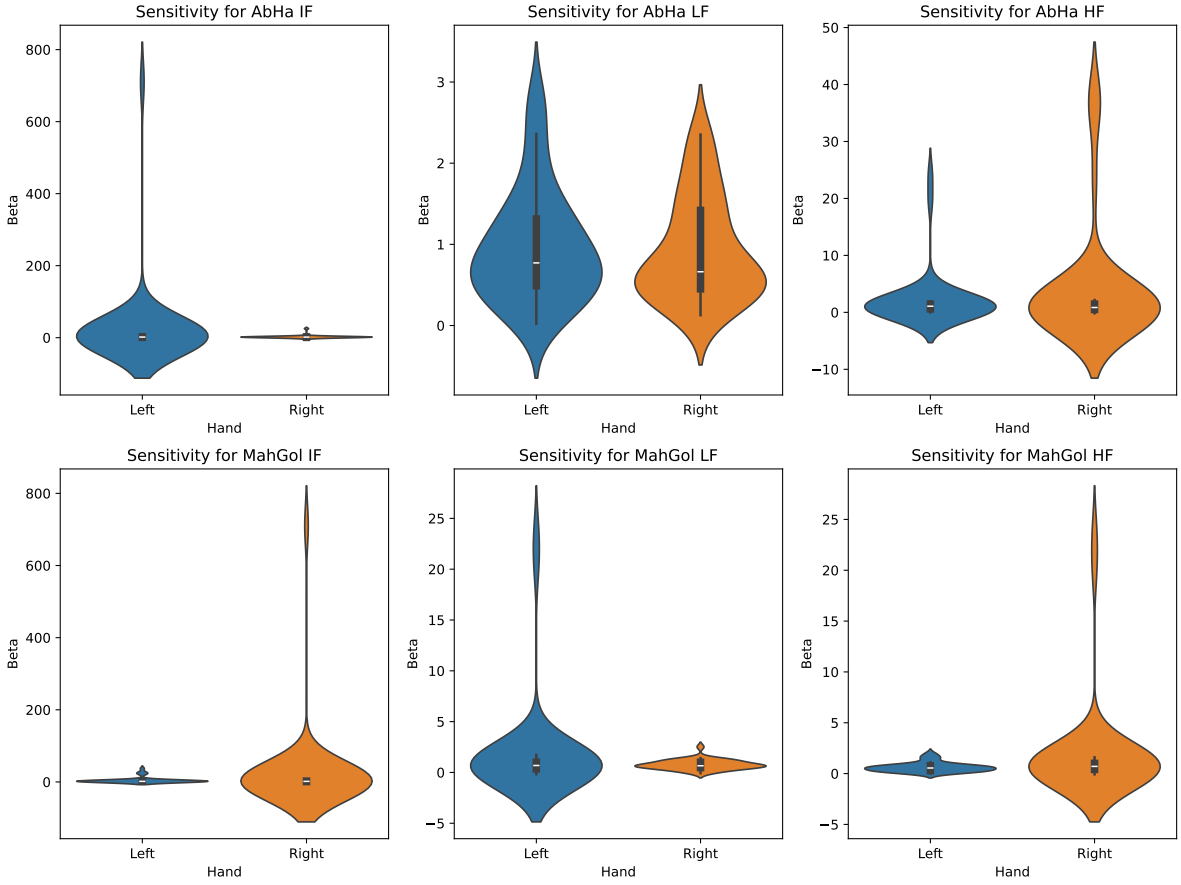

Figure 7: Left hand performance by frequency

2.2.4 Effect of Using Dominant Hand

Data were non-normal, so Wilcoxon signed-rank tests were used (one-sided). No significant difference was found:

- **IF:** AbHa: $p = 0.8175$; MahGol: $p = 0.4487$
- **LF:** AbHa: $p = 0.7219$; MahGol: $p = 0.3817$
- **HF:** AbHa: $p = 0.6128$; MahGol: $p = 0.2105$

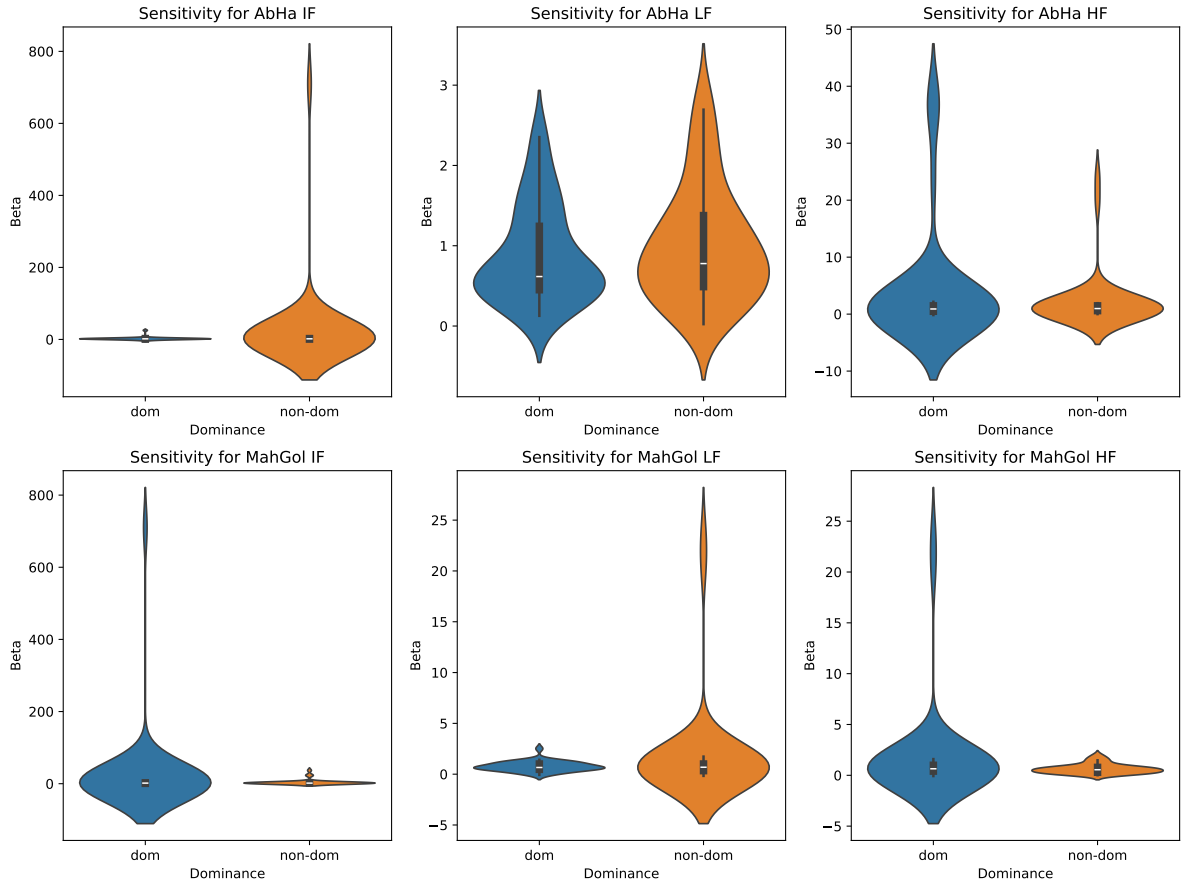

Figure 8: Performance by dominant hand

2.2.5 Gender Differences in Identity Detection Performance

This comparison involved two independent groups (men vs. women), and the data were normally distributed. An independent t-test was used and showed no significant difference:

- AbHa: $t = -0.9, p = 0.18$
- MahGol: $t = -0.9, p = 0.19$

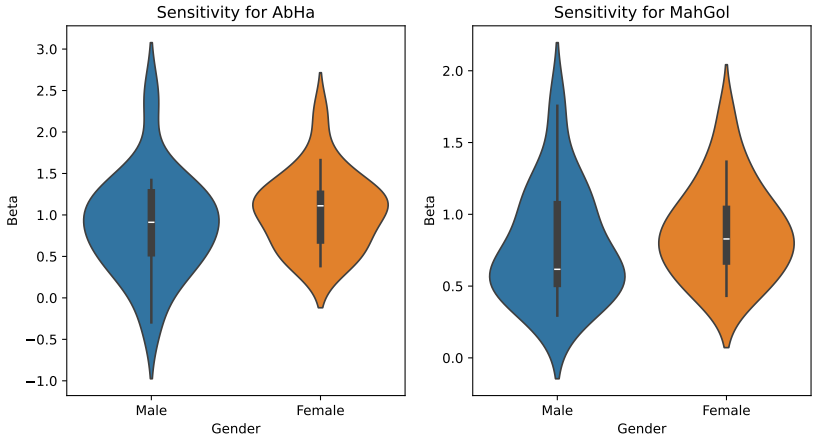

Figure 9: Performance by participant gender

Evaluation of Subject Sensitivity using Receptive Operating Curve (ROC)

To evaluate subject sensitivity from a signal detection perspective, we computed the Area Under the Receiver Operating Characteristic Curve (AuROC). This approach quantifies how well subjects distinguish between signal-present and signal-absent trials. Specifically, we assigned positive labels to trials with positive morph levels (corresponding to ”Hasan” and ”Goli”), and negative labels to those with negative morph levels (”Abbas” and ”Mahnaz”). Trials with zero morph levels were excluded. The AuROC was then calculated using the `roc_auc_score` function from `scikit-learn`, with the subject's binary identity choice serving as the prediction.

3.1 Sensitivity Across Spatial Frequency Bands

To examine whether separability varies across spatial frequency bands (Low, High, Intact), we applied the Friedman test within each pair. Results indicated significant differences in separability:

- **AbHa:** $\chi^2(2) = 14.1, p = 0.0009$
- **MahGol:** $\chi^2(2) = 56.3, p < 0.0001$

Figure 10: Sensitivity across spatial frequency bands

Follow-up pairwise Wilcoxon signed-rank tests revealed that sensitivity for Intact images was significantly greater than for both Low and High frequencies. No significant difference was found between Low and High frequency conditions.

- **AbHa:** IF vs. LF: $p = 0.0017$; IF vs. HF: $p = 0.0512$; LF vs. HF: $p = 0.6462$
- **MahGol:** IF vs. LF: $p < 0.0001$; IF vs. HF: $p < 0.0001$; LF vs. HF: $p = 0.3332$

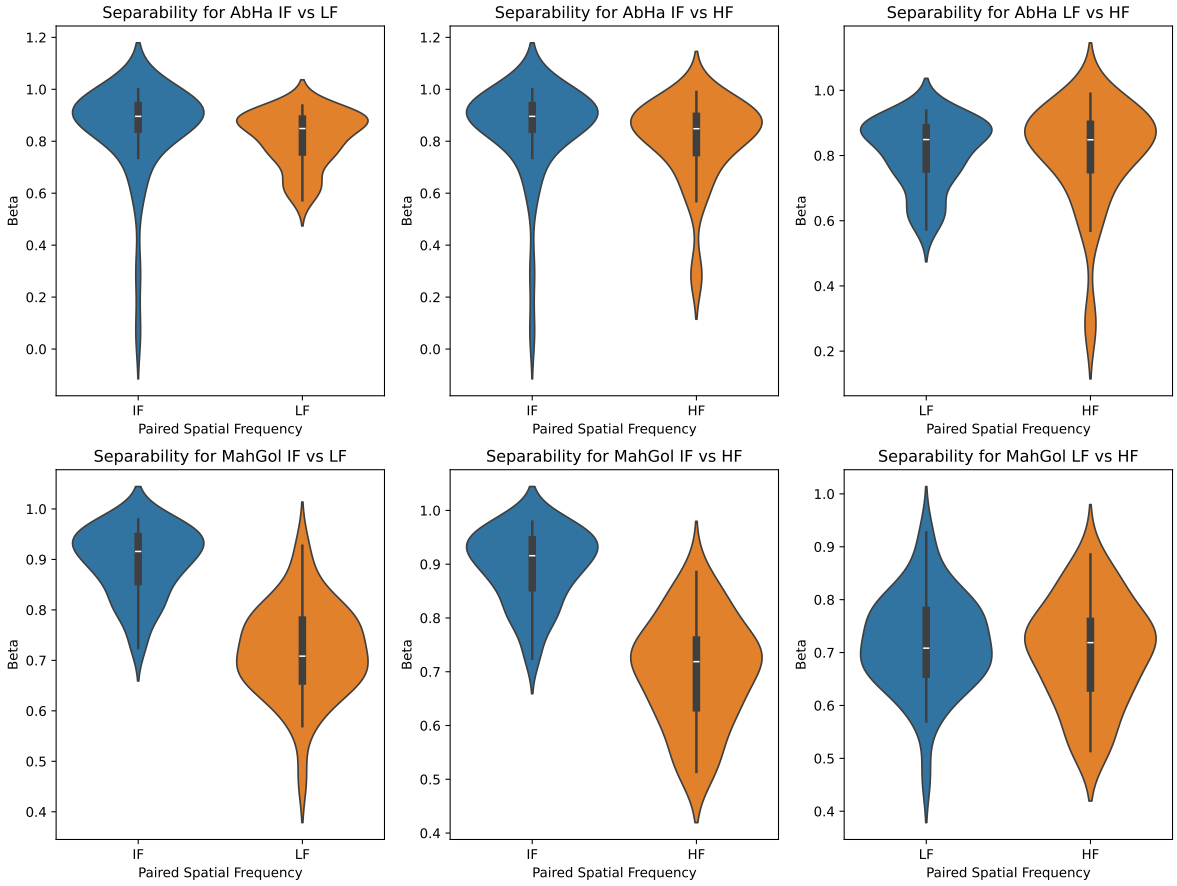

Figure 11: Pairwise comparisons across frequency bands

3.2 Identification Based on Gender of the Image (Conspecific vs. Hetero-specific)

To assess whether subjects were more sensitive to faces of their own gender, we grouped participants into conspecific and hetero-specific categories. No significant differences were found in either group:

- **AbHa:** Mann–Whitney $U = 134.0, p = 0.1964$
- **MahGol:** $t(28) = 1.6, p = 0.1111$

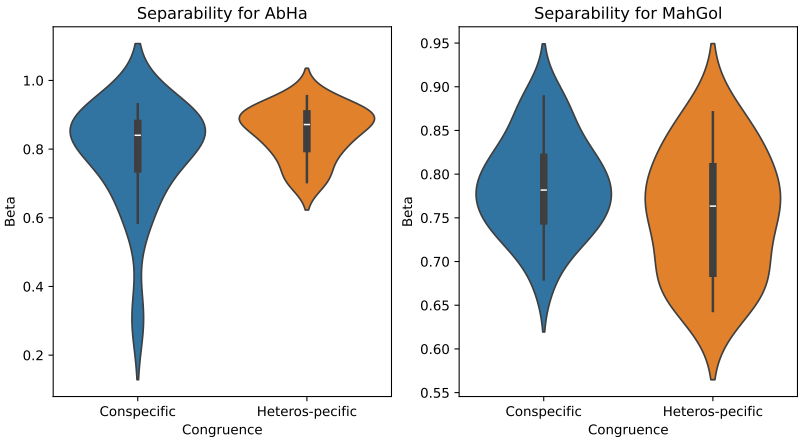

Figure 12: Performance by image gender congruence

3.3 Effect of Using the Left Hand

We tested whether hand usage influenced identity detection. While most comparisons yielded non-significant results, the MahGol group showed a trend toward higher sensitivity when using the left hand for intact images ($p = 0.0921$), though this did not reach conventional significance.

- **IF:** AbHa: $p = 0.3186$; MahGol: $p = 0.0921$
- **LF:** AbHa: $p = 0.8978$; MahGol: $p = 0.6310$
- **HF:** AbHa: $p = 0.2438$; MahGol: $p = 0.6165$

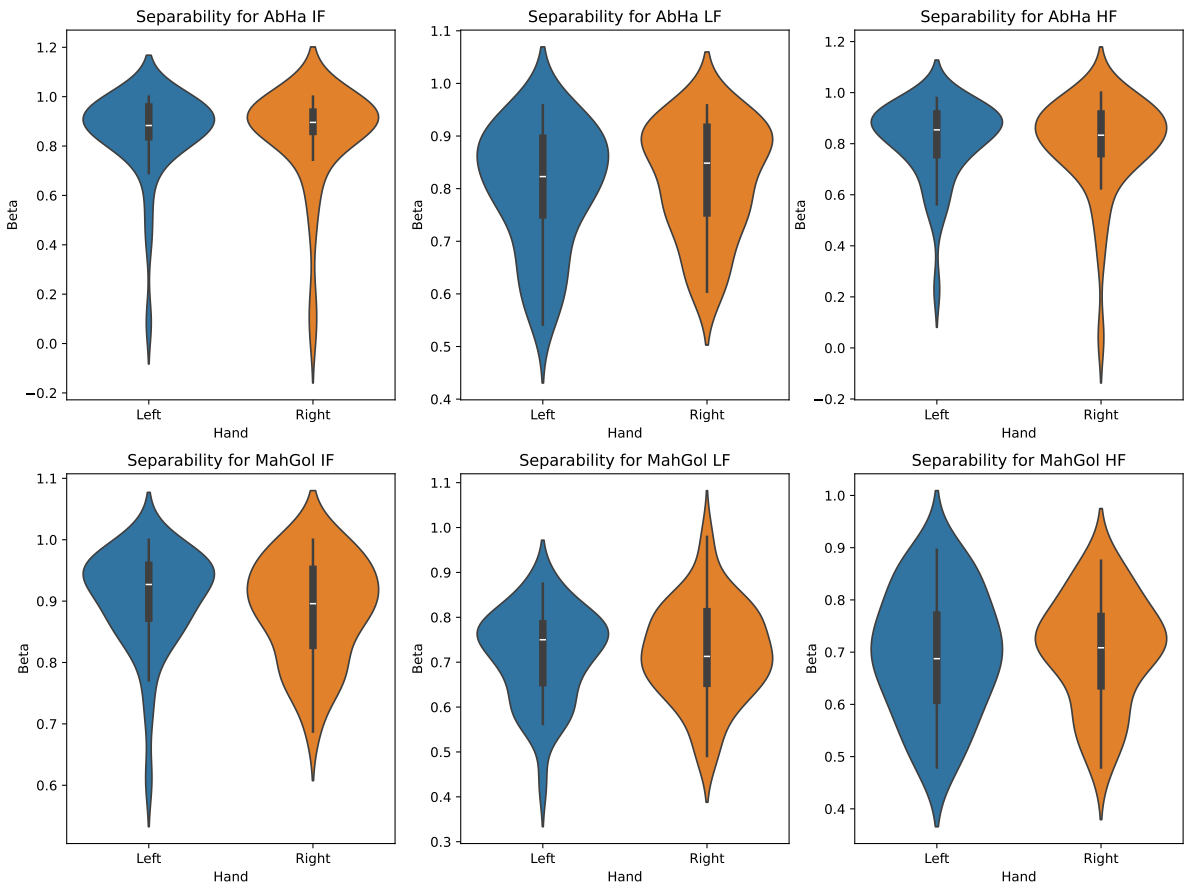

Figure 13: Left hand performance by frequency

3.4 Effect of Using Dominant Hand

We examined whether using the dominant hand improved separability. Across all frequency bands and both identity pairs, no significant differences were observed:

- **IF:** AbHa: $p = 0.6470$; MahGol: $p = 0.8324$
- **LF:** AbHa: $p = 0.2105$; MahGol: $p = 0.4829$
- **HF:** AbHa: $p = 0.6554$; MahGol: $p = 0.5112$

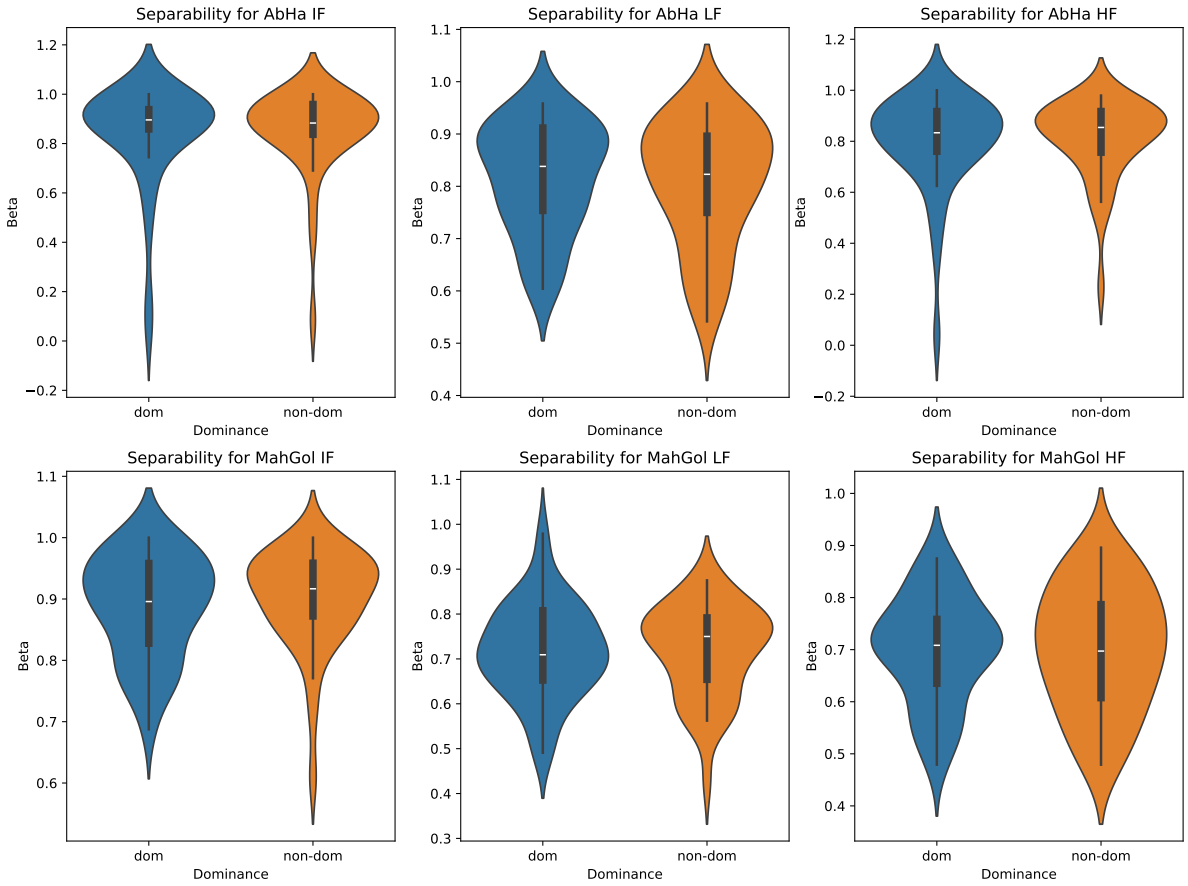

Figure 14: Performance by dominant hand

3.5 Gender Differences in Identity Detection Performance

Lastly, we compared overall performance between male and female participants. No significant gender effect was found in the AbHa pair. However, in the MahGol pair, female participants showed significantly higher separability than males:

- **AbHa:** $U = 133.0, p = 0.1330$
- **MahGol:** $t(28) = -2.0, p = 0.0254$

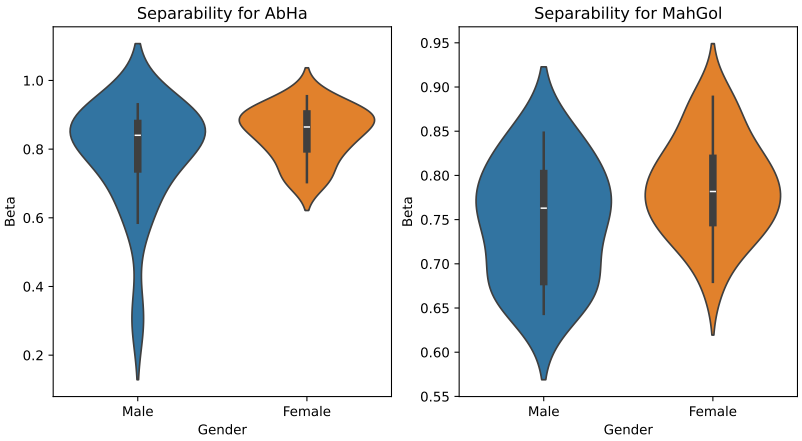

Figure 15: Performance by participant gender

Make a Hypothesis

Hypothesis: The Effect of Block Type on Identity Detection

In this final analysis, I investigated whether the type of block presentation—'same' versus 'mix'—influences identity detection performance. The 'same' blocks allow subjects to potentially adapt or attune to a specific spatial frequency band. In contrast, the 'mix' block requires subjects to constantly adjust their perceptual processing as the spatial frequency changes from trial to trial, potentially incurring a task-switching cost or increased cognitive load, which might impact performance metrics like sensitivity or reaction time

The dependent variables used for comparison were sensitivity estimates derived from psychometric function fitting and ROC analysis. To assess the effect of block type, I conducted both parametric (paired t-tests) and non-parametric (Wilcoxon signed-rank) tests, depending on the normality of the data distribution, which was verified using the Shapiro–Wilk test.

4.1 Psychometric Fitting

First, I computed sensitivity using the slope (β) of the fitted psychometric (sigmoid) function across the 'same and 'mix' block types. Results showed a significant difference in sensitivity, with higher slopes in the 'same' condition, indicating improved discriminability when trials were blocked by identity pair.

- **AbHa:** Wilcoxon signed-rank test: $W = 182.0, p = 0.0054$
- **MahGol:** Wilcoxon signed-rank test: $W = 173.0, p = 0.0035$

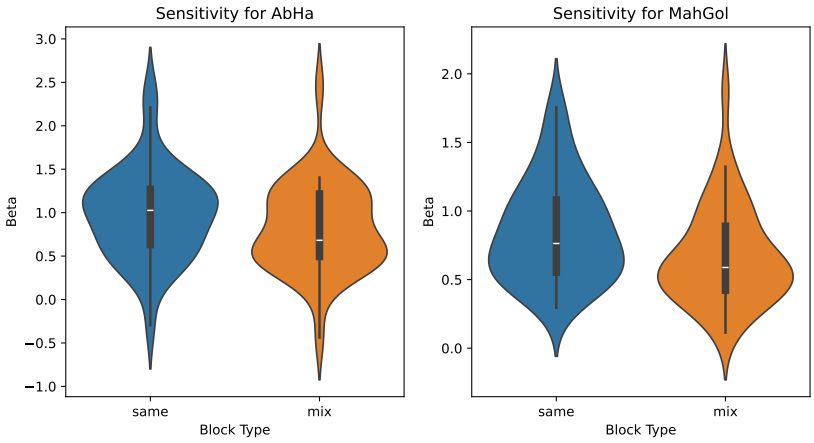

Figure 16: Performance by block type

4.2 ROC AUC Analysis

To complement the psychometric analysis, I computed the Area Under the ROC Curve (AuROC) for each subject in both block types. This measure reflects the model's ability to distinguish between the two identity classes. Consistent with the psychometric results, the 'same' block condition led to significantly higher ROC AUC values for AbHa, while MahGol showed a trend toward significance.

- **AbHa:** Wilcoxon signed-rank test: $W = 160.0, p = 0.0017$
- **MahGol:** Paired t-test: $t(28) = 1.8, p = 0.0785$

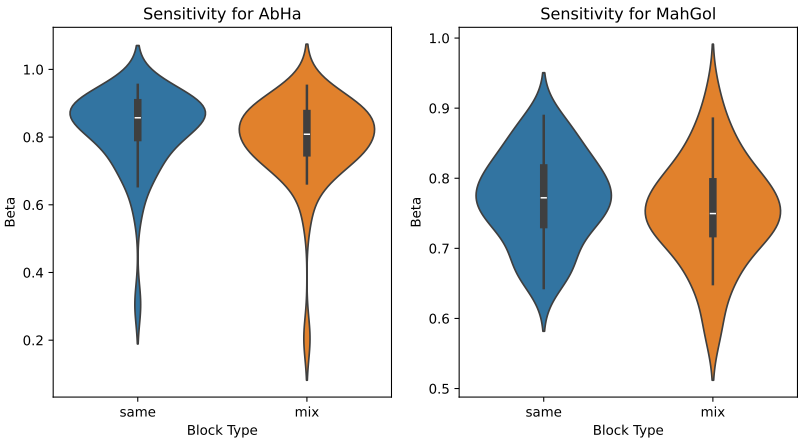

Figure 17: Performance by block type

These findings suggest that the structure of trial presentation affects identity sensitivity, with blocked (homogeneous) trial sequences supporting better discrimination than mixed blocks. This may be due to reduced cognitive load or increased perceptual tuning when subjects are exposed to a consistent identity context.