Behavioral Analysis (Part 2)

Spatial Heterogeneity in the Perception of Face and Form Attributes *

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In the previous assignment, we had worked on a basic task, gathered some data and now we're ready to extract pretty plots from that data!

The basic idea of our reference paper [1] was that perception of facial characteristics differ in different locations of spatial field of view. So it is expected that our analysis in this assignment is highly similar to what has been demonstrated by Afraz et. al.

We can address a new question that has not been addressed in our reference. Are the variations in the Point of Subjective Equality (PSE) solely related to angular position of stimuli location? Does the eccentricity of the stimuli location plays a role in shaping gender perception?

Keywords: point of subjective equality, spatial homogeneity, heterogeneity, behavioral analysis, cognitive science, neuroscience

1. Cleaning the Data

Data set is composed of trials done by different participants. Some participants might not engage to the task with their utmost attention, so its only reasonable to remove outliers before starting the analysis. Find outliers using the inter-quartile range (IQR) of reaction times.[1] Report outliers by their unique numbers, and remove them from data set.

1: Samples that have values larger than 1.5× iqr + Q_3 (third quartile) or less than Q_1 (first quartile) - 1.5 iqr are generally considered to be outliers. For analysis of reaction times, very short reaction times may be considered as outliers too. For example, it is physically impossible to respond in this task at about 100 ms after stimulus onset.

2. Exploring the Data

The purpose of this section is to review the data by visualizing the dependent variables (accuracy and response time) with each of the independent variables. Variable set that is going to be used in this assignment is defined in Table 1. You can ask questions such as whether there is a significant difference between accuracy and reaction time in each of the eight independent variables. For example, is the accuracy different in each of the visual fields?

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For statistical comparison between the five groups of the visual fields, you should use the ANOVA test, and for visualization, you can display the accuracy and response time of these five groups with a bar plate. Or is there a significant difference in accuracy and response time in left-eyed or right-eyed individuals? Note that we have the two dependent variables and the nine independent variables so 14 statistical tests and 14 plots must be done.

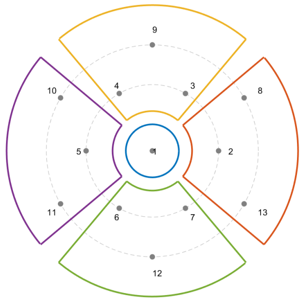


Figure 1: categorization of 13 stimuli location into 5 visual fields

Table 1: Variable Set

Type	Sub-Type	Name	Description
Dependent	-	Reaction Time (rt)	rt column in data set. May be multiplied by 1000 to represent time in units of miliseconds
		Log Reaction Time (lrt)	natural logarithm of reaction time
		Accuracy (acc)	Percentage of correct columns. For stimuli with names 0, 10, 20 and 30, the true label of classification is considered to be male, while for stimuli 50, 60, 70 and 80 it is considered as female. The stimuli with name 40 shall be discarded from this analysis.
Independent	Within Group	Location (loc)	Location of stimuli in spatial field, labelled from 1 to 13.
		Eccentricity (ecc)	Radius of stimulus location, 0 for foveal presentation (over the fixation point), 1 stimuli lying over inner circle and 2 for the outer one. (Figure 2)
		Visual Field (vf)	Generated by separation of location in the following manner: 0 for center visual field (position 1), 1 for right visual field (positions 2, 8 and 13) , 2 for upper visual field (positions 3, 4, 9), 3 for left visual field (positions 5, 10, 11) and 4 for lower visual field (positions 6, 7, 12. Figure 1)
		Used Hand	Column 'uhnd' in data set.
		Used Dominant Hand	1 if the hand used in a trial matches the dominant hand of subject, 0 otherwise.
	Between Group	Gender	
		Handedness	
		Eyedness	

3. Prediction of Behavioral Characteristics

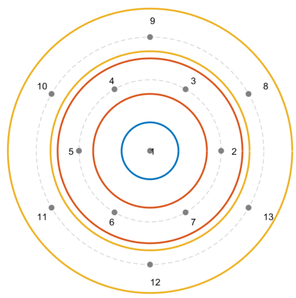


Figure 2: categorization of 13 stimuli location into3 eccentricities

In this section, we use regression models to find a good model for interpreting data. You can first put all the 7 variables that you examined above individually in the multivariable linear regression models for the continuous dependent variables such as reaction time and the logistic regressions for the discrete variables such as accuracy, and delete the non-significant ones from each of the models, finding a sub-optimal model for the data interpretation. For example, the gender variable may not have a significant effect and thus be removed from the model, or third-order interactions may not all have a significant effect, in which case all are removed. Finally, after finding the final model, visualize the results and write a short interpretation for at least 4 plots. Interpreting the R^2 of each of the variables alongside their statistical significance is the main goal of this section.

4. Psychometric Fitting

Using logistic regression, calculate the PSE for each participant. In this part, the dependent variable is placed in such a way that you create a new column with that response and the answer of each image is 1 if the female key is selected and 0 is the case if the male key is selected. Comparison of PSE shall be done for a) different stimuli locations, b) different eccentricities and c) different fields of view.

As any other statistic calculated from random data, PSE is prone to noise. Therefore it is a random variable itself and the mere increase or decrease of its value is not conclusive by itself. To test the statistical significance of results, one should use statistical tests. On such data, we propose two approaches:

- Calculating PSE for each subject, followed by comparison of averages by means of analysis of variance (ANOVA). If the results were significant, the analysis might go further to multiple comparison. (Confidence value shall be modified according to Bonferroni correction.)
- PSE can be calculated for the pooled trials of all subjects and then be tested using a random permutation test. In this test, the order of trial's condition (stimuli's morphing signal or its spatial location) are shuffled multiple times and PSE is calculated over any of these shuffled trials. Multiple permutations end up forming the distribution of null hypothesis (no statistical difference between PSEs of different locations) by which one can estimate the p-value of original psychometric values.

Aside from testing the significancy of results, standard deviation (or even confidence interval) of each of estimated parameters can be calculated using the bootstrap method. In this method, PSE is calculated for each of "boot population"'s data. each member of boot population is a data set with the same length of the original one, which is samples with replacement.

Report the estimated psychometric values, their significance level and their measure of spread in a suitable format. You might get some ideas from the plots of reference paper [1], or visualization libraries' plot galleries.

Compare the results with what had been stated in the reference.

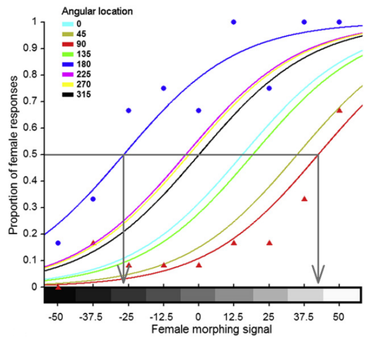


Figure 3: PSE for different angular positions in reference paper

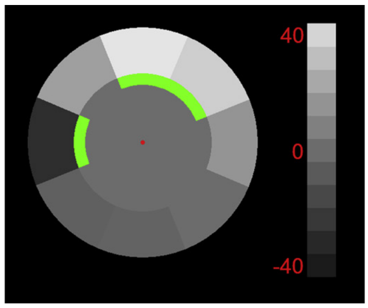


Figure 4: Representing data using a mosaic plot: PSE values are color coded in different locations, green arc shows statistical significance

5. Spread of PSEs

The pattern of PSEs for different locations might vary between different subjects; yet the main idea of the reference article was not the similarity of PSE patterns, but the overall heterogeneity of PSE patterns. To quantify the non-uniformity of PSE spread, Afraz proposed a heterogeneity index, which is simplified here as the standard deviation of PSEs at different locations. Evaluate heterogeneity index in the given data set and test for its statistical significance.

Compare the heterogeneity index for locations in different fields of view and eccentricities by means of statistical methods. Are your results explainable by the neural undersampling and network sparsity hypothesis that was proposed in the Afraz's paper?

6. Reaction Time Correlation to Choice Complexity

Design a method to test the hypothesis that the complex options (stimuli near the PSE) take more time for participants to respond.

7. Representational Similarity Analysis (RSA)

An interesting question that can be addressed is similarity of PSE between subjects. First consider the 13-dimensional space (or less, considering how you divided the spatial field of view) that is generated by PSE values. Each of participants can be represented in this space as single point. To check the distance of these subjects, one can define a metric for distance in this vector space and form a matrix that contains the distance between each pair of participants, a representational dissimilarity matrix (RDM). In this symmetric matrix, cell a_{ij} contains the distance between subject number i and subject j. RDM single-handedly can represent the participants population's distance and their possible similarities. Reorder the rows/columns so that participants form smaller clusters in the RDM, if possible. If any cluster is formed, check if there is an independent variable in the data set that can separate these clusters. (Refer to Figure. 5 for better insight.) There are some available toolboxes to perform RSA for conitive and neural models. Feel free to use any of them.

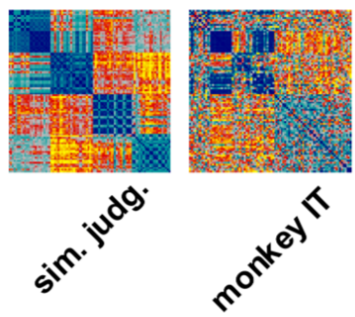


Figure 5: An example of clustering within RDM, taken from [4]

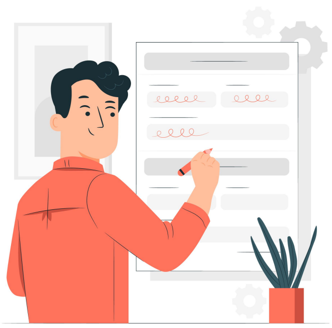
8. Submission

Each of students shall submit a typed `pdf` report by which the gist of their analysis is explained. The figures described in the problem description should be included and discussed within the report. For each of the figures, a separate script should be included, in either MATLAB (`.m`), python3 (`.py`, `.py3`) or R (`.r`). Do <u>not</u> submit your scripts in MATLAB live script, python notebook or r markdown. The submitted codes should run on the grader's system as well. Don't forget to attach all of your functions and non-standard libraries.

The report is considered to be an academic writing, rather than a technical one, so it should not include any codes, neither it should explain the coding logic. It should contain the author's insights about the results and reflect their dominance over the reference article. Academic writings usually are compact and use extremely formal tone.

Each section briefly explains the hypothesis that is going to be tested. The design of test and its implementation is considered as the students duty, as well as the explanations of each of the results. Interpretations shall be comprehensive, while avoiding unnecessary prolixity.

The language in which the report is written in should be either Persian or English, with no preference towards any of them. But if the report is written in Persian, it should use B Nazanin with size 14 as text body font and B Titr 18 for titles. English reports shall use Times New Roman 12 for body and Time New Roman 16 for titles. Sentences should be in passive tense. In persian reports, correct use of zero-width non-joiner is mandatory. In all reports, all equations, figures and tables should be labeled with unique numbers and referenced accordingly. Referencing to a figure with sentences like "the following figure", "the figure above" and etc. is incorrect. All Figures should have descriptive captions below them, while tables have the caption above them. Feel free to use footnotes and citations as needed.



A. Point of Subjective Equality (PSE)

In psychophysics, the point of subject equality (PSE) is any of the points along a stimulus dimension at which a variable stimulus (visual, tactile, auditory, and so on) is judged by an observer to be equal to a standard stimulus. The PSE is the value of a comparison stimulus that, for a particular observer, is equally likely to be judged as higher or lower than that of a standard stimulus. [2].

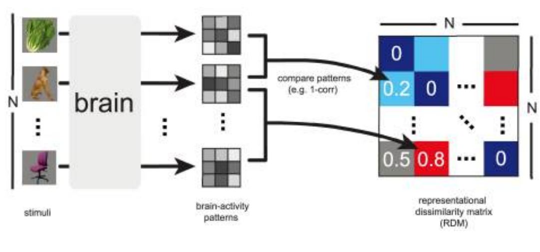
In order to calculate the PSE in their task, with 8 stimulus positions, Afraz et. al [1] describe the following procedure: "Data obtained from the eight tested locations for each subject/task were fit with a logistic function to calculate the PSE for each location.

$$\Pr(x) = \frac{1}{1 + \exp\left(-(\alpha x + \sum_{j=1}^{8} \beta_j I_j)\right)} \tag{1}$$

Where x is the stimulus signal value (e.g. morphing value) and $\Pr(x)$ is the probability of one of the two possible responses (e.g. probability of female response). I is a binary variable, set to either 1 or 0 to indicate the presence or absence of a location condition while j was set from 1 to 8 to indicate all eight tested locations. α and β are free parameters that were fit using the maximum likelihood fitting procedure ([3])."

B. Representation Dissimilarity Matrix (RDM)

One approach to this problem [using measured brain-activity patterns to test computational models] is representational similarity analysis (RSA), which characterizes a representation in a brain or computational model by the distance matrix of the response patterns elicited by a set of stimuli. The representational distance matrix encapsulates what distinctions between stimuli are emphasized and what distinctions are de-emphasized in the representation. A model is tested by comparing the representational distance matrix it predicts to that of a measured brain region. RSA also enables us to compare representations between stages of processing within a given brain or model, between brain and behavioral data, and between individuals and species. [4]



References

[1] Arash Afraz, Maryam Vaziri Pashkam, and Patrick Cavanagh. 'Spatial heterogeneity in the perception of face and form attributes'. In: *Current Biology* 20.23 (2010), pp. 2112–2116 (cited on pages 1, 3, 6).

[2] Giulio Vidotto, Pasquale Anselmi, and Egidio Robusto. 'New Perspectives in Computing the Point of Subjective Equality Using Rasch Models'. In: *Frontiers in Psychology* (2019), p. 2793 (cited on page 6).

[3] William Q Meeker and Luis A Escobar. 'Teaching about approximate confidence regions based on maximum likelihood estimation'. In: *The American Statistician* 49.1 (1995), pp. 48–53 (cited on page 6).

[4] Hamed Nili et al. 'A toolbox for representational similarity analysis'. In: *PLoS computational biology* 10.4 (2014), e1003553 (cited on pages 4, 6).

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