Asymptotics of Psychometric Function of Gray Color Categorization

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ABSTRACT

The results of conducted experiments on categorical perception of different shades of gray are reported. A special color generator was created for conducting the experiments on categorizing a random sequence of colors into two classes, light-gray and dark-gray. The collected data are analyzed based on constructing (i) the asymptotics of the corresponding psychometric functions and (ii) the mean decision time in categorizing a given shade of gray depending on the shade brightness (shade number). Conclusions about plausible mechanisms governing categorical perception, at least for the analyzed system, are drawn.

Categories and Subject Descriptors

J.4 [**Social and Behavioral Sciences**]: psychology; H.1.2 [**User/Machine Systems**]: human factors

General Terms

Experiment

Keywords

Categorical perception, psychometric function, asymptotics

1. INTRODUCTION

Categorical perception is a general term describing situations when we perceive our world in terms of the categories formed previously during our communication with the social environment. Our perceptions are warped such that differences between objects that belong to different categories are accentuated, and differences between objects that fall into the same category are deemphasized [1]. The reported research concerns categorization of colors. In spite of a vast amount of literature about various aspects of color categorization (see, e.g., [2]) even classification of possible mechanisms governing these processes is not understood well.

In previous pilot experiments on shape recognition near perception threshold [3] we found some arguments for the hypothesis that this process is governed by a certain potential mechanism. The given conclusion is based on the analysis of the *asymptotics* of the psychometric functions; it seems to be a novel way to discriminating directly plausible mechanisms governing human recognition near perception thresholds. The purpose of the reported experiments is to verify this hypothesis for categorical perception being a more complex cognitive process involving mental processes in addition to pure physiological ones. By way of example, categorization of different shades of gray color was selected for investigation.

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2. EXPERIMENTAL SETUP

Colors for categorization were generated as follows. A computer visualizes a window of size of 17×16 cm with a square $\mathbb{S}$ of size of 11×11 cm placed at its center. Color inside this square is changed during experiments; the remaining window part is filled with a neutral gray. Each trial of shade categorization is implemented as follows. A random integer $I \in [0, 255]$ is generated and the area $\mathbb{S}$ is filled with the gray color $G(I) := \mathrm{RGB}(I, I, I)$. Then a subject has to classify the visualized gray color $G(I)$ according to his/her perception into two possible categories, "light gray" (LG) and "dark gray" (DG). A made choice is recorded via pressing one of two joystick buttons. Then a mosaic pattern of various shades of gray is visualized for 500 ms. This mosaic pattern is used to depress a possible interference between color perception in successive trials that can be caused by human iconic memory. After that a new number I is generated and the next trial starts. Four subjects, two female and two male students of age 21–22, were involved in these experiments. The experiments spanned 5 successive days, for each subject the total number of data records was 10 000. One day set comprised four blocks of 15 min experiments separated by 3 min rest.

3. RESULT AND DISCUSSION

The collected data have been used in constructing three functions. The first one is the psychometric function for the light-gray category, i.e., the probability $P_w(I)$ of choosing the light-gray category for the shade of gray, $G(I)$, specified by a given integer I. The second one, $P_b(I)$, is actually the same function for the dark-gray category. The third function, $T(I)$, is the mean duration time of making decision during one trial of categorization for a given shade $G(I)$ of gray. The results are illustrated in Fig. 1 for one of the four subjects.

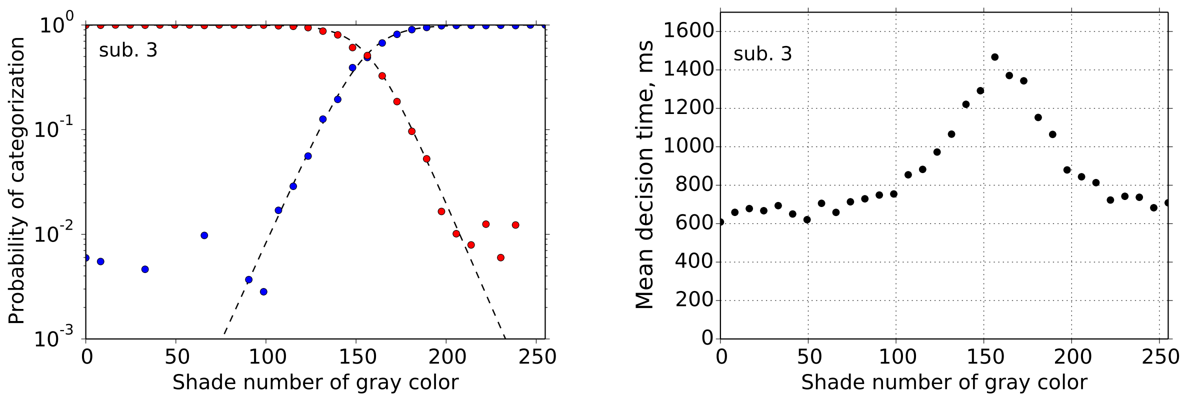

Figure 1: *Left frame:* the psychometric functions of categorization of shades of gray, red and blue points correspond to the light-gray and dark-gray categories, respectively, dashed lines represent fitting function (1). *Right frame:* the mean delay time in decision-making vs. the shade number of gray.

As seen in Fig. 1 (left frame), the asymptotics of the constructed functions $P_{w,g}(I)$ can be approximated by

$$P_{w,b}(I) \approx \frac{1}{2}\left\{1 + \tanh\left[\pm\frac{(I - I_{m:w,b})}{\delta I_{w,b}}\right]\right\}, \qquad (1)$$

where $I_{m:w,b}$ is the center point of the crossover region and the value $\delta I_{w,b}$ characterizes its thickness. As seen in Fig. 1, the asymptotics of both the psychometric functions looks like exponential function of the shade number,

$$P_{w,b} \propto \exp(\pm I/\delta I_{w,p}),$$

what is the typical dependence for the model of random systems residing in a bimodal potential well near the equiprobable distribution. In this case the difference δU in the well minima leads to the asymmetry in the well populations quantified by their ratio proportional to $\tanh(\delta U/T)$ (here T is some constant). The found results can be regarded as some argumentation for the hypothesis that categorical perception, at least, in the analyzed case is described by a certain potential model, where the corresponding decision-making is regarded as some random process η in a potential relief $U(\eta|I)$ with two minima $U_w(I)$ and $U_b(I)$ determined by the shade number I as a control parameter.

The experimental data shown in Fig. 1 (left frame) contain two domains on both the sides of the crossover region that may be classified as domains of scattered data that are caused by some mechanism rather than lack of statistics in the collected data. In order to clarify a plausible mechanism that could be responsible for this anomalous behavior of these heavy tails of the psychometric functions, we analyzed the dependence of the mean time required for subjects to make decision about classifying a current shade of gray depending on the shade number I. The results are exemplified in Fig. 1 (right frame). For all the subjects these distributions exhibit remarkable peak located inside the crossover region. Outside this peak the values of the mean decision time T are located in the interval 500–700 ms, which can be regarded as the upper boundary of the human reaction delay time controlled by physiological processes of recognizing threshold events within their unpredictable appearance. The mean decision time in these peaks is about 1.5 s. To explain these values we pose a hypothesis that mental processes on their own rather than pure physiological mechanisms contribute substantially to the decision making in color categorization under pronounced uncertainty, at least, in the analyzed case. As far as the scattered data domains in Fig. 1 are concerned, we explain their appearance by addressing this phenomenon to a relatively short time of decision when the right choice is rather evident, which can increase the probability of subjects pressing a wrong button accidentally.

4. CONCLUSION

Categorical perception, at least, of shades of gray, is governed by a potential mechanism of decision-making treated as a random process in a potential relief. The previous analysis of shape recognition [3] also reveled the same type asymptotics of psychometric functions. Noting that the cognitional perception and shape recognition should be governed by different mechanisms, the found universality allows us to pose an assumption that human decision-making under uncertainty is implemented via a common emergent mechanism. In this mechanism the uncertainty measure plays the role of a certain parameter aggregating in itself particular physiological details.

The characteristic time scale of decision-making during categorical perception, at least in the analyzed case, depends substantially on the uncertainty in classifying a current event; the higher the uncertainty, the longer the decision time. The obtained data enable use to relate this effect with considerable contribution of mental processes to categorization. In this feature categorization perception differs from recognition process near perception thresholds seemed to be governed by physiological mechanisms only.

5. REFERENCES

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