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Article

Pattern Recognition and Noncommutativity in Decision Making

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Abstract: Psychological and sociological studies have shown that the order of questions affects the likelihood of obtaining final answers. We studied the influence of image presentation on the efficiency of pattern recognition using the Gollin test. It was found that the correctness/incorrectness of the answer to the first presented image with a larger contour filling affected the subsequent probability of recognizing an image with less contour filling. A qualitative comparison of the obtained results with a quantum-like model and neural network model of pattern recognition in the additional learning mode was also carried out.

Keywords: Gollin test, Recognition efficiency, Learning effect, Question order

1. Introduction

Pattern recognition is one of the key problems for research on visual perception processes. Currently, considerable progress has been made in modeling the features of pattern recognition using artificial neural networks. However, pattern recognition has a connection with another important problem of artificial intelligence (AI), namely the problem of non-commutativity in decision-making under uncertainty, when the sequence of presented questions and their answers affect the result. Reference [1] describes experiments confirming this feature of human behavior and presents a mathematical model to describe them. This model is based on the application of a quantum-like formalism since noncommutativity is one of the main features of quantum mechanics. The experimental evidence for the existence of noncommutativity in decision-making was taken from a Gallup poll [2] in which two questions were asked in a different order: (1) Is Clinton a decent person? and (2) Is Gore a decent man? The results of the survey showed that, in the above order of questions 1 and 2, the "Yes" answers for Clinton and Gore were 50% and 68%, respectively, and for the reverse order of the questions, 57% and 60%. These results cannot be explained based on classical probability theory, but the quantum-like model provides an adequate explanation. Fig. 1 presents a scheme explaining the occurrence of non-commutativity in the survey described above [1]. There are two coordinate systems at an angle to each other: decenter-incommutable (yes-no) for Clinton and Gore. The main peculiarity of the model is that the subject answering the questions is assigned a certain "mental vector" Ψ, the square of the projection of which on the corresponding axes gives the probability of one or another answer. Besides, it is assumed that when answering a question, the mental vector is projected on the corresponding axis and the next answer is given from a new position of vector Ψ. Then, in the case when the first answer refers to Clinton, the direct projection of the state vector on the "yes" axis is smaller than in the case when the first "yes" answer is made for the "more decent Gore", and then the projection on the "yes" axis for the "less decent Clinton" is already made.

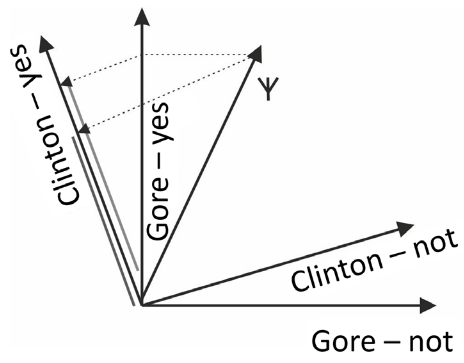

Fig. 1. Schematic of the interpretation of noncommutativity in sociological poll on Clinton and Gore's decency [1].

This model describes noncommutativity in decision-making but raises questions. The main one is that there is no intelligible explanation of a mental vector. On the other hand, the Clinton and Gore decidability problem is similar to the pattern recognition problem for a neural network, where there is the retraining of the network after the first question/answer. With this in mind, we propose a model for visual pattern recognition based on the Clinton/Gore experiment to explain the classical neural network paradigm. To solve the problem, experiments on uncertain image recognition were set using the Gollin test technique [3,4]. The experiment was to demonstrate highly fragmented contours of known objects with varying degrees of fragmentation and varying sequences of presentation. Whereas in the Clinton/Gore experiments subjects were presented with two characters in different but close degrees of decency, two images of the same object with different degrees of fragmentation were presented. We compared the probability of correctly/wrongly identifying the more fragmented image when presented directly and when presented after the subject identified the same image with a lower degree of fragmentation. This was to set up an experiment similar to the Clinton/Gore experiment for visual perception and to interpret the non-commutativity in decision-making within a neural network paradigm.

2. Materials and Methods

A modified technique of the Gollin test was used in the study. To use the test for the problems under study, a forced-choice paradigm was applied to the recognition of fragmented contour images. The research included two series of experiments. The first was to find out the quantitative dependence of the proportion of correct answers on the percentage of image contour filling. The second series of experiments was to quantify the learning effect observed when viewing images with different percentages of contour filling.

The preparation of the stimulus material included the following steps:

(1) 30 images in each category were selected from sets of 100 contour images of living objects and 100 contour images of nonliving objects. The images were selected based on the image recognition thresholds in the computerized version of the Gollin test, obtained earlier in the Laboratory of Visual Physiology of the Pavlov Institute of Psychiatry Knyazeva M.V. The images the recognition threshold of 9−12% of the contour, which corresponded to the central part of the frequency distribution of images with different recognition thresholds.

(2) The obtained 30 images were paired. The pairs were formed from 1 image of a living object and 1 image of a nonliving object, which were the most similar. The similarity of the images was determined by their cross-correlation analysis.

(3) Using the computer program "PictGenerator" developed by Pronin in the Laboratory of Visual Physiology of the Pavlov Philharmonic Institute, 12 variations were synthesized based on each of 30 images, containing from 1 to 12% of the contour length of the original image. The 12% contour limit was set according to the duration of the experiment and the maximum recognition threshold among the selected 30 images. Thus, 360 images were obtained. Each image was captioned with a question about which of the two objects in the pair was depicted. An example stimulus is shown in Fig. 1. The order in which the names of the objects were mentioned in the question was determined randomly with each version of the caption occurring an equal number of times.

(4) An experiment was designed with the computer presentation program "Neurobureau" and consisted of the sequential presentation of 360 stimuli in order of increasing percent contour completion. The order in which image pairs were presented remained unchanged, while images in the pair were presented in order and randomly (Fig. 2). In the first series of experiments, we conducted a psychophysical study of the dependence of the ratio of correct answers and reaction time on the percentage of filling in the outline of images. Four subjects between the ages of 19 and 27 (mean age 19.7 ± 3.2 years old) participated in the experiment. All subjects were male and right-handed. The ratio of correct answers and the average reaction time for each group of 30 stimuli containing images with an equal percentage of contour filling were calculated.

(5) In the second series of experiments, the change in the recognition threshold of images with a lower percentage of contour filling was analyzed as a result of learning when observing images with a higher percentage of contour filling. Seventeen subjects (5 males and 12 females) in age from 20 to 61 years (mean age 41.2 ± 12.5 years) participated in the study. All subjects were right-handed. Each subject underwent a test consisting of 66 stimuli to test three pairs of images. The images were presented with 4% contour filling according to the results of the first series of experiments with the correct answer ratio of 40%), followed by 8% contour filling (a correct answer ratio of 60%), and then again with 4% contour filling. The test stimuli were separated by an equal number of stimuli containing other images with a random percentage of contour filling ranging from 1 to 10% with the same percentage of contour filling presented only once. An S-curve was constructed from these stimuli, which allowed the results of the first and second series of experiments to be compared. The order in which the stimuli were presented in the second series of experiments is schematically shown in Fig. 3. Five tests with different test images were conducted with 30 images.

The ratio of correct answers and the latent response period were analyzed using the t-test to compare samples.

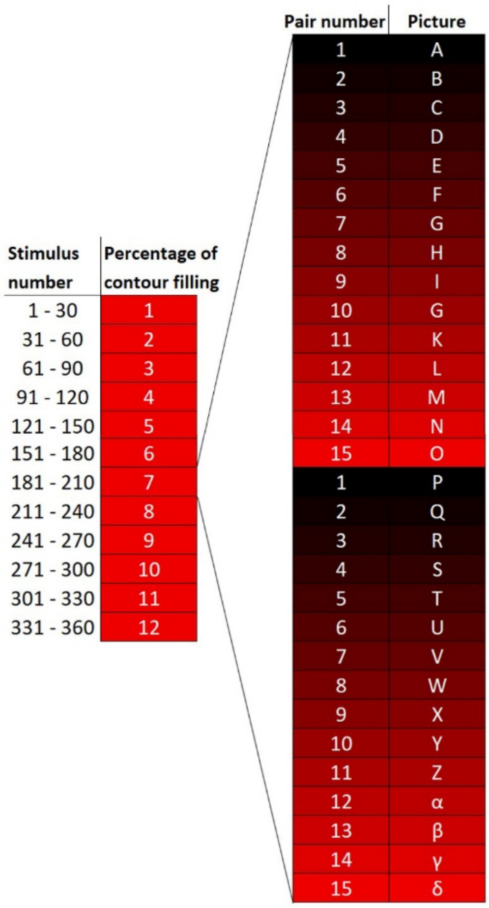

Fig. 2. Stimuli order in the first series of experiments. The images are labeled with different letters in the Latin and Greek alphabets. Stimuli belonging to the same pair are marked with the same tone on the right side of the diagram.

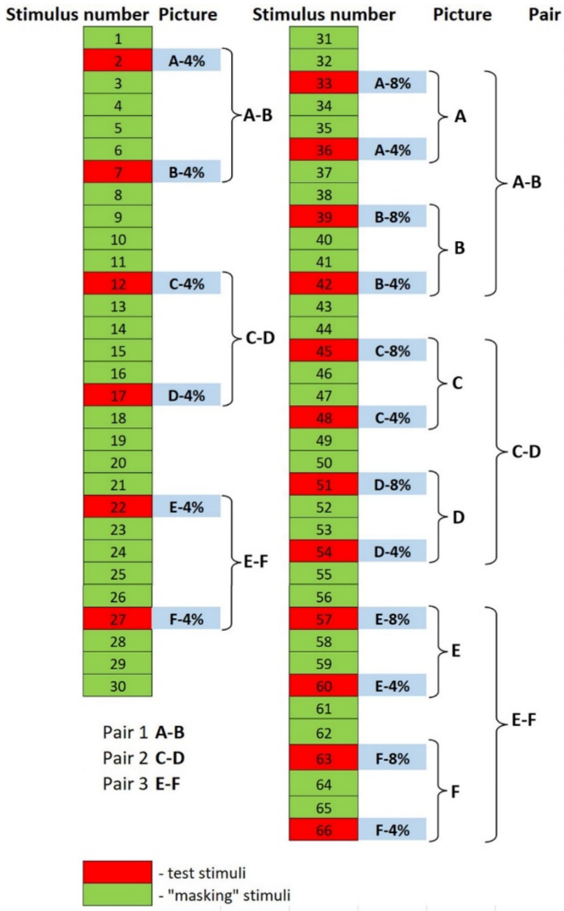

Fig. 3. Stimuli order in the test of the second series of experiments. In this example, the test images are A, B, C, D, E, and F. They are combined into pairs, within which the choice of answer is made: A–B, C–D, E–F.

3. Results

The dependence of the ratio of correct answers on the percentage of contour filling in the first and second series of experiments is presented in Fig. 4. The ratio of correct answers increases smoothly from 50%, which corresponds to random guessing for contour fillings of low percentages, and asymptotically approaches 100% for contour fillings of high percentages. The results of the first and second series of experiments for this parameter showed no significant differences. Figs. 5 and 6 present data on the ratio of correct responses and response latency for the primary image review with 4% contour filling, 8% contour filling, and for the second image presentation with 4% contour filling. In the primary image presentation with 4% contour filling (i.e., before viewing images with 8% contour filling), the correct response ratio is approximately 55%. In the second viewing of 4% contour images (i.e., after viewing 8% contour images), the ratio of correct responses was significantly greater than in the primary viewing ($p < 0.05$) and was nearly 73%. There was no significant difference between the ratio of the correct responses in the second viewing of 4 and in 8% contour images. In the second viewing of the 4% contour-filled images after viewing the 8% contour-filled images, the reaction latent period was significantly less than in the primary viewing ($p < 0.05$). There was no significant difference between the reaction latent periods for the second viewing of 4 and 8 contour images.

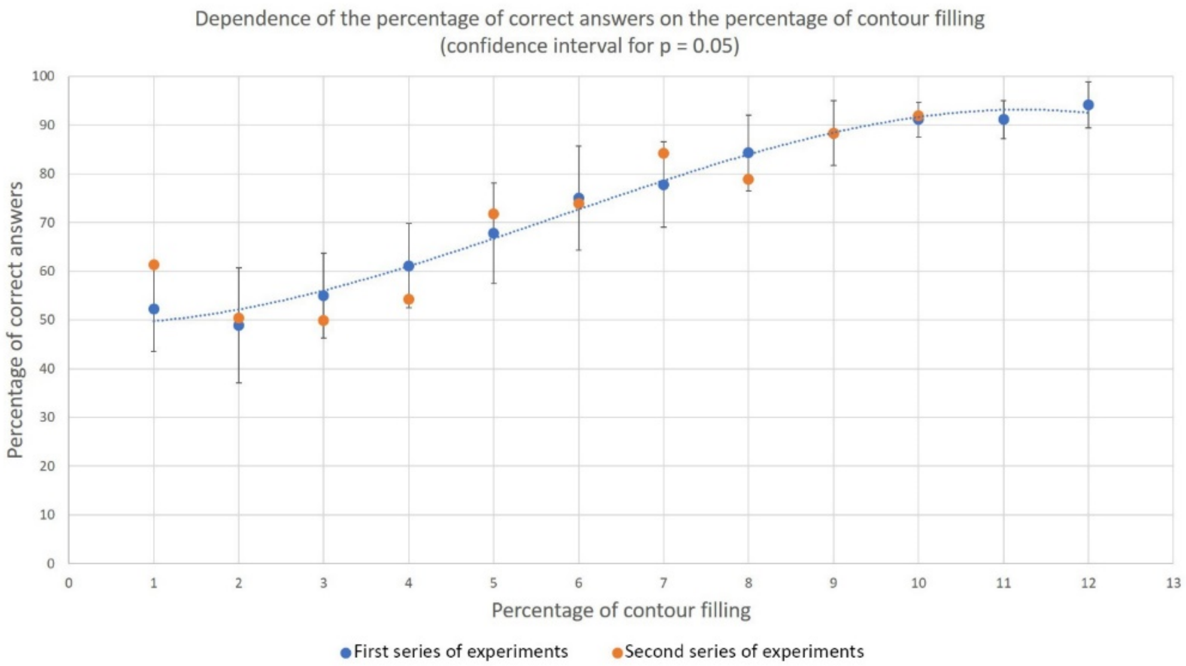

Fig. 4. Dependancy of correct answer ratio on contour filling: blue circles are for the first series of experiments and orange circles are for the second series of experiments.

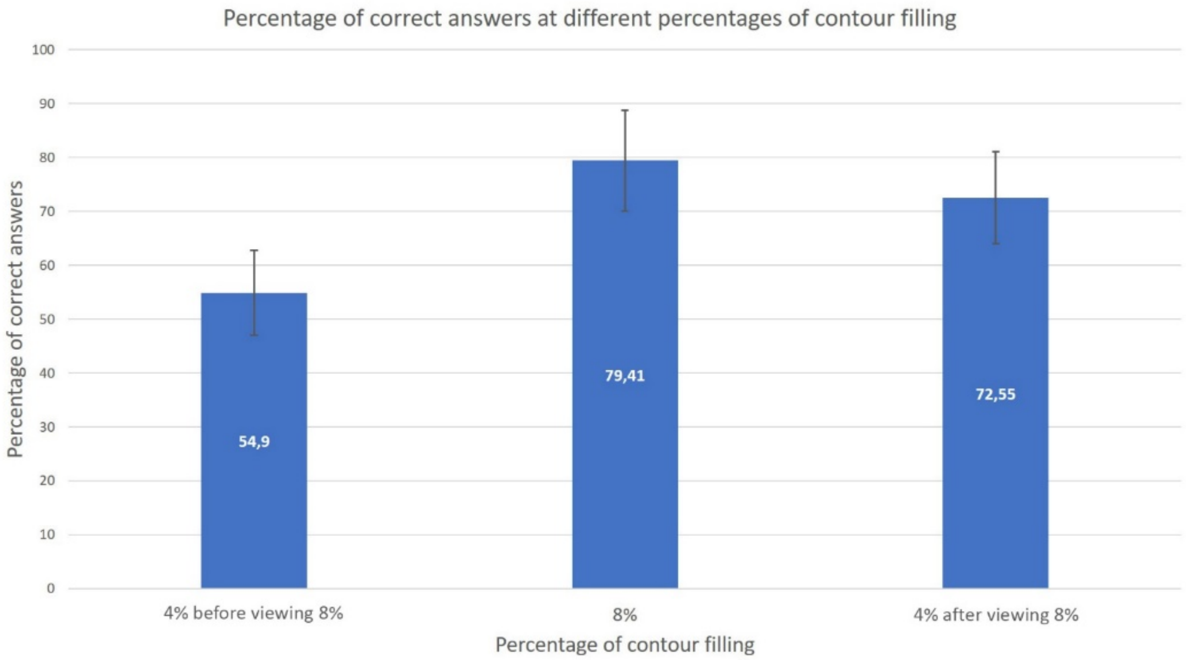

Fig. 5. Comparison of average correct response ratio for 4 and 8% contour filling, and second image viewing with 4% contour filling.

Fig. 5 shows the ratio of correct responses when viewing images with 4% contour filling in two different situations: after correct image recognition at 8% contour filling and after incorrect image recognition at 8% contour filling. For comparison, the result obtained in the second series of experiments is shown. The ratio for 4% contour filling corresponds to the initial viewing of images with 4% contour filling before viewing images with 8% contour filling.

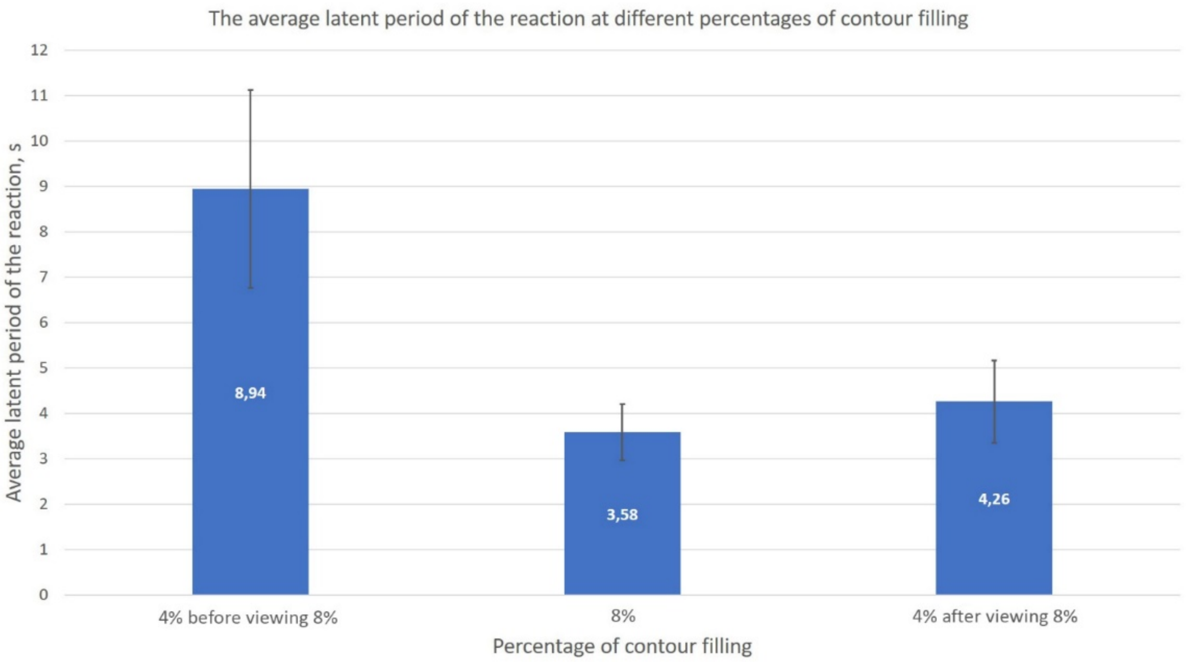

Fig. 6. Comparison of mean latent response time for primary image viewing with 4% contour filling, 8% contour filling, and second image viewing with 4% contour filling.

After correctly recognizing images with 8% contour filling, the ratio of correct responses during the second viewing of images with 4% contour filling increases significantly from 55 to 80%, which is consistent with the data from Ref. [3]. At the same time, after incorrect image recognition with 8% contour filling, the ratio of correct responses at the second viewing of the images with 4% contour filling does not show a significant difference from the primary viewing, although the average value of the proportion of correct responses appears to be lower. The dependence of the reaction latent response time on the percentage of contour filling, obtained in the first and second series of experiments is presented in Fig. 7.

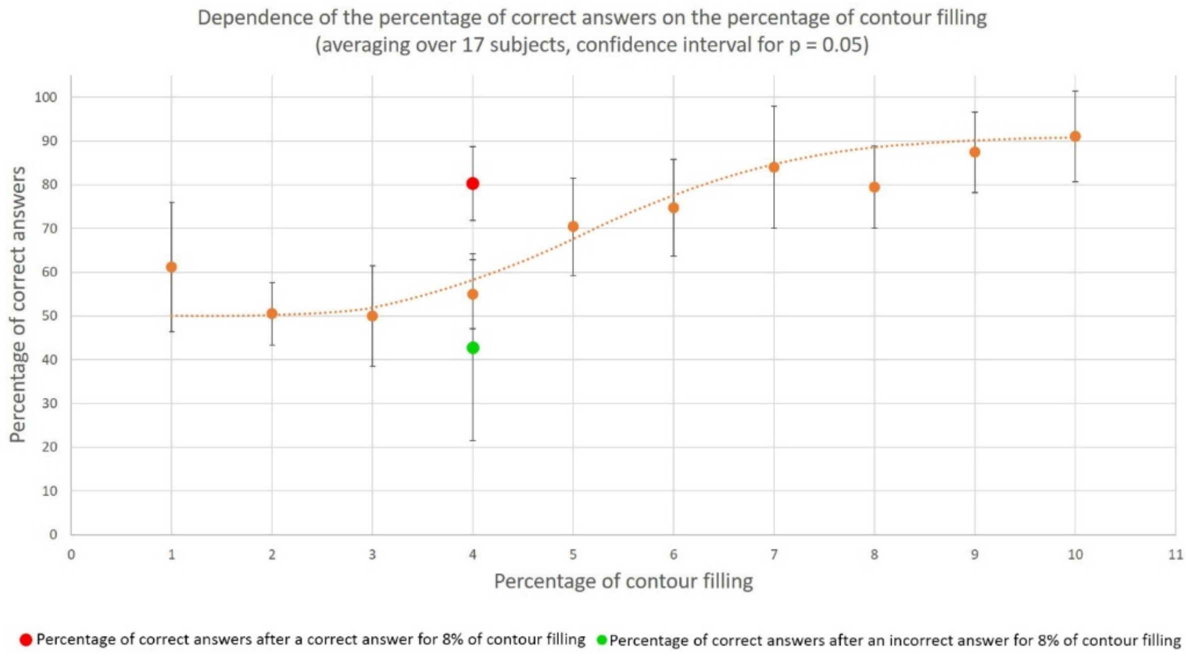

Fig. 7. Change in the ratio of correct/incorrect responses at 4% contour filling after viewing images with 8% contour filling.

The response latent time was significantly shorter in the second viewing of images with 4% contour filling (i.e., after viewing stimuli with 8% contour filling) than in the primary viewing. The mean latent response time in the second series of experiments was greater than in the first series of experiments (Fig. 8).

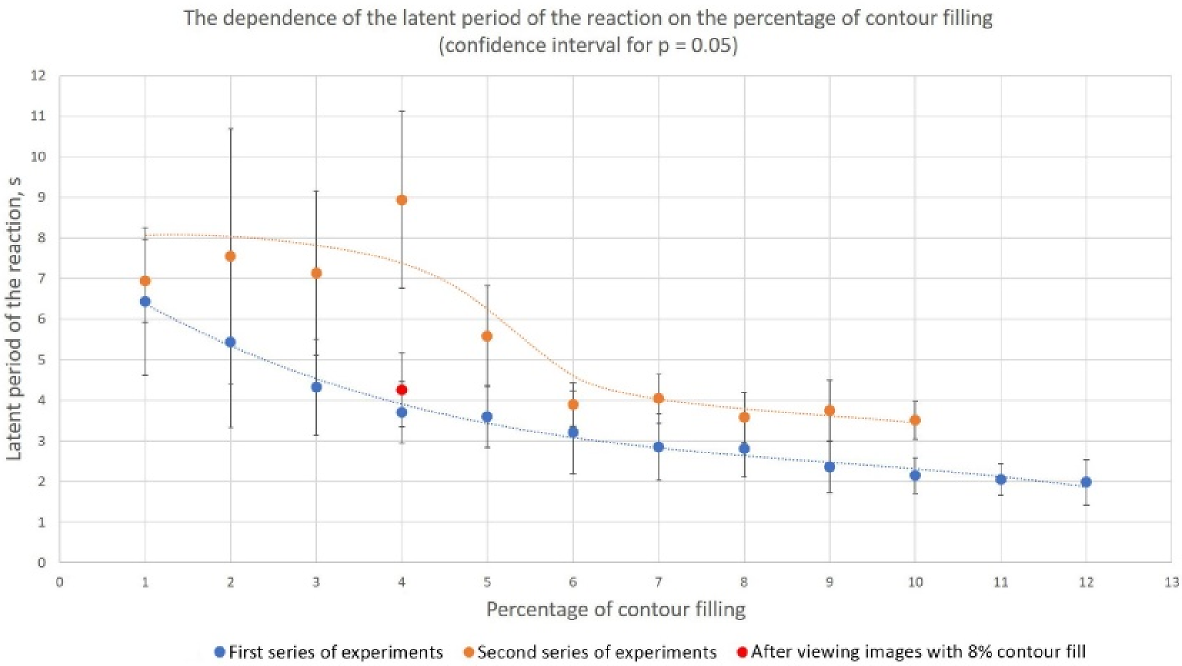

Fig. 8. Dependency of the latent response time on the percentage of contour filling. The data obtained in the first and second series of experiments are presented separately with the latency response time for the second presentation of stimuli with 4% contour filling after viewing images with 8% contour filling.

4. Discussion

Suppose we presented the subject with a fragmented image of an airplane and ask the subject "Is it an airplane or a rabbit?". In the plane/rabbit (C/K) coordinate system, the image vector of an airplane with 4% fill will be located almost at 45º to the plane axis, and the vector with 8% fill will be tilted closer to the A axis (Fig. 9). If the subject identifies the image with 8% contour filling as an airplane, then there will be retraining of the neural network and the A-axis will tilt towards the 8% vector. Such a turn means an increase in the probability of detecting an airplane in the image with 4% contour filling. The value of the projection on the A1 axis at point 2 will be greater than that at point (1). This corresponds to the experimental data presented in Fig. 7. The misidentification of the image with 8% contour filling increases the ratio of incorrect responses for 4% contour filling, that is, the ratio of correct answers decreases, which is also consistent with Fig. 7.

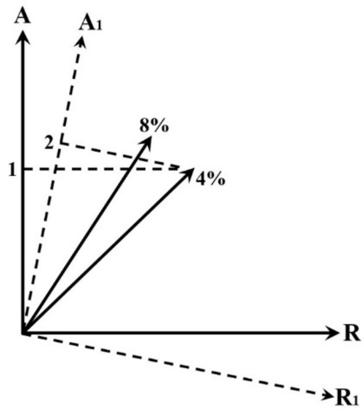

Fig. 9. Change in the ratio of correct answers for images with 4% contour filling after viewing the image with 8% contour filling.

The presented consideration for non-commutativity in responses can be described within the neural network paradigm and with a quantum-like description. This harmonization is more relevant because the neural-network approach cannot describe the increase in response time as the percentage of contour filling decreases. In this sense, the quantum approach is more promising, since it can figure out the connection of time with the energy due to the potential difference in the membrane of the terminal neurons, which affects the processes of spike formation. The form of recognition threshold requires separate consideration and the numerical simulation of information processes using artificial neural networks.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Saint-Petersburg State University (protocol code 02-124, date of approval 21.06.2017).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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