

# Eye-Movement-Based Instantaneous Cognition Model for Non-verbal Smooth Closed Figures

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**Abstract.** This study attempts to perform a comprehensive investigation of non-verbal instantaneous cognition of images through the “same-different” judgment paradigm using non-verbal smooth closed figures, which are difficult to memorize verbally, as materials for encoding experiments. The results suggested that the instantaneous cognition of non-verbal smooth closed figures is influenced by the contours’ features (number of convex parts) and inter-stimulus intervals. In addition, the results of percent correct recognitions suggested that the accuracy of the “same-different” judgment may be influenced by the differences between the points being gazed when memorizing and recognizing and factors involved in the visual search process when recognizing. The results may have implications for the interaction design guideline about some instruments for visualizing a system state.

**Keywords:** non-verbal information, cognition model, eye movements, same-different judgment paradigm.

## 1 Introduction

The data and images demonstrating that verbalizing is difficult exist in a factory environment. These images are level meters changing over time combined with several warning lights. It is thought that these signs could not be instantaneously represented by language. Therefore, to achieve instantaneous judgment, several interfaces in factories have to support the intuitive images.

In general, familiar information is easy to memorize verbally, but a new image or an image changing over time is difficult to memorize verbally because of workers’ ability to perceive instantaneously [1]. Human working memory capacity was examined using unstructured information, and the results suggested that the capacity to memorize unstructured information was between 3 to 5 data set sizes [2] [3] [4].

To quickly and accurately recognize different information presented successively, it is necessary to establish an information presentation method that stimulates human reactions without language (verbalized information) intervention.

Some studies on non-verbal smooth closed figures suggested that the enhancing factors for memorizing this type of figures were influenced by (1) distortions of convex parts, (2) psychological similarity [5], (3) physical complexity (ex:  $Perimeter\sqrt{Area}$ ),

(4) the number of convex parts, (5) the length of individual convex parts [6], (6) presentation and retention time [7], (7) the Fourier descriptors [8] [9], (8) spatial frequency characteristics [10], and (9) the number of figures presented simultaneously [11].

As part of a study on Ecological Interface Design in Human-Computer Interaction, the present study attempts to conduct a comprehensive research on the non-verbal instantaneous cognition of smooth closed figures through the “same-different” judgment paradigm using non-verbal smooth closed figures, which are difficult to memorize verbally, as materials for encoding experiments.

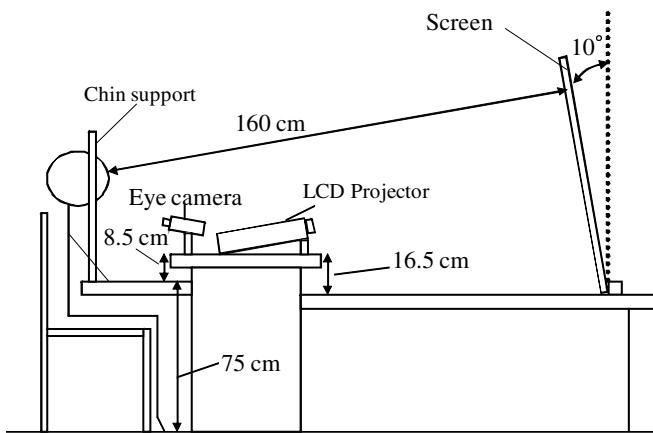
## 2 Method

### 2.1 Subjects

Ten subjects (20–22 years;  $21.6 \pm 0.7$  years) were selected among male university students with no significant eyesight problems. Six had their vision corrected, three by wearing glasses and three by wearing contact lenses.

### 2.2 Apparatus

Smooth closed figures were presented on a screen using an LCD projector. The subjects' eye movements were determined by measuring the sightline of the dominant eye using EMR-NL8 (nac Image Technology) at 60 Hz. The heights of the work table, seat, and chin support were adjusted arbitrarily for each subject. The luminous intensity of the screen background was set as  $230.0\text{ cd/m}^2$  and the luminous intensity of contour line was set as  $80.0\text{ cd/m}^2$ . Our experimental setting is shown in Fig. 1.



**Fig. 1.** Experimental setting for measuring subjects' eye movement

### 2.3 Procedure

After the subject observed the gazing point continuously for 2000 ms, a non-verbal smooth closed figure to be memorized was presented for 250 ms, followed by a

masking pattern, which was also presented for 250 ms. The inter-stimulus intervals (ISI) of 500, 1000, and 4000 ms were used. A recognition figure was presented after the preset ISI, and the subject was asked to discriminate the recognition figure from the memorized figure (“same-different” judgment paradigm [5] [6] [7]). A time limit of 5000 ms was enforced.

## 2.4 Encoding Stimuli

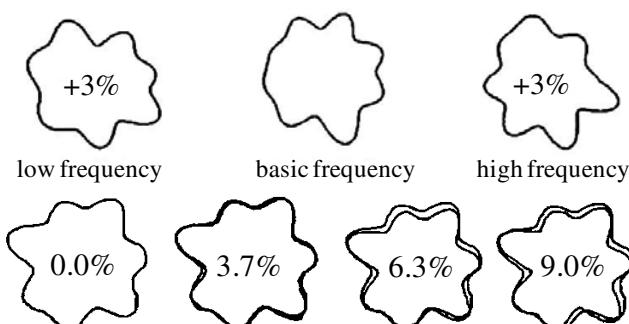
Based on the results of past studies [5] [6] [7] demonstrating that the performance of complex free-form figure recognition diminishes as the number of convex parts of the memorized figure increases, the number of convex parts of memorized figures was set as 5, 7, and 9 [10]. Figures as encoding stimulus were generated by the formula (1) [5] [10] and the formula (2) [5].

$$r(\theta) = A_0 + \frac{1}{3} \sum_{i=1}^5 A_i \cos(f_i \theta - \alpha_i) \quad (0 \leq \theta \leq 2\pi) \quad (1)$$

$A$ : Amplitude,  $f$ : frequency,  $\alpha$ : phase

$$(x(\theta), y(\theta)) = r(\theta)(\cos(\theta), \sin(\theta)) \quad (0 \leq \theta \leq 2\pi) \quad (2)$$

Influences of both local features and general features have been suggested as memory characteristics of non-verbal smooth closed figure’s contour shapes. Therefore, the present study uses both types of contour shapes, those for which the influence of general features has been suggested and those for which the influence of local features has been suggested. In addition, the relationships between the memorized figure and recognition figure were defined as follows: 1) the recognition figure being the same as the memorized figure; 2) the recognition contour intensifying the low or high frequency component of the presented figure by 3.0 or 6.0% [10]; and 3) the differences between the areas of projections and/or indentations are 3.7, 6.3, and 9.0% [11]. Figure 2 shows examples of non-verbal smooth closed figures.



**Fig. 2.** Examples of non-verbal smooth closed figures

## 2.5 Evaluation Indexes

For recognition performance, the ratio of correct answers (percent correct recognitions) and reaction time were determined. In addition, the total length of path in the sightline (the eye movements) when memorizing and recognizing contour shapes, the area being gazed, the number of features in the perimeter of the area being gazed when memorizing (see Fig. 3.), and the number of eye fixation points and fixation time during recognition were determined from the sightline data.

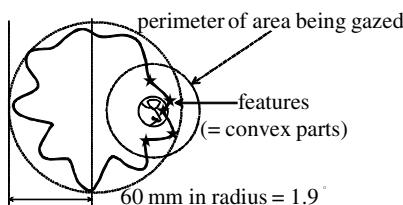
# 3 Results

## 3.1 Recognition Performance

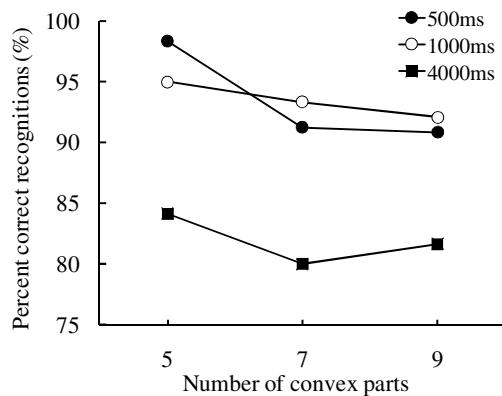
A two-factor analysis of variance was performed for percent correct recognitions (Fig. 4.) and reaction time (Fig. 5.) using the number of convex parts and ISI as factors. Significant main effects were observed for both factors in percent correct recognitions (number of convex parts:  $F(2,18)=6.12, p < 0.05$ ; ISI:  $F(2,18)=10.38, p < 0.001$ ). For reaction time, a significant main effect was observed only for ISI ( $F(2,18)=14.59, p < 0.001$ ).

## 3.2 Eye Movements Performance

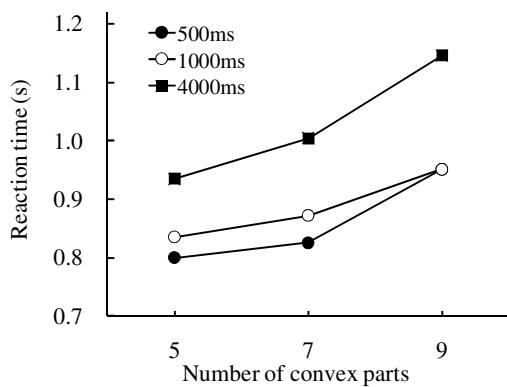
A two-factor analysis of variance was performed for the number of fixation points (Fig. 6.) and the fixation time (Fig. 7.) in the recognition phase using the number of convex parts and ISI as factors. Significant main effects were observed for the number of fixation points (number of convex parts:  $F(2,18)=3.82, p < 0.05$ ; ISI:  $F(2,18)=11.73, p < 0.001$ ). And a significant main effect was observed for the fixation time (ISI:  $F(2,18)=5.69, p < 0.05$ ). To evaluate the effects of area being gazed when memorizing, a single-factor analysis of variance was performed for the area being gazed using the number of convex parts (Fig. 8.). As a result, a significant effect was observed for the area being gazed ( $F(2,18)=6.42, p < 0.01$ ). Subsequently, to evaluate the effects on recognition performance due to the number of features of memorized figures, a single-factor analysis of variance was performed for the number of features on the smooth closed figure using the number of convex parts (Fig. 9.). A significant effect was observed for the number of features ( $F(2,18)=58.62, p < 0.001$ ).



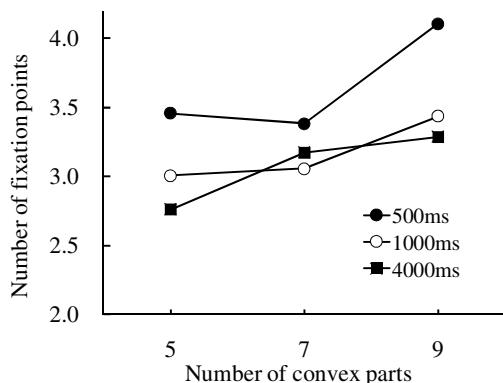
**Fig. 3.** Schema of features in the perimeter of the area being gazed



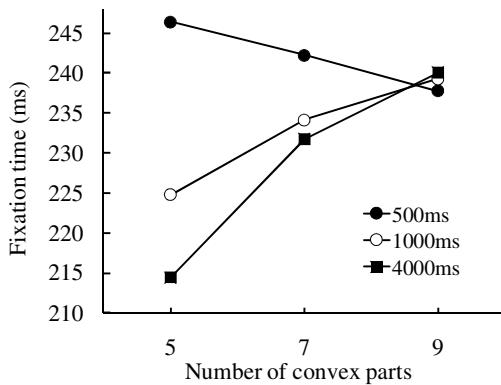
**Fig. 4.** Percent correct recognitions as a function of the number of convex parts with ISI



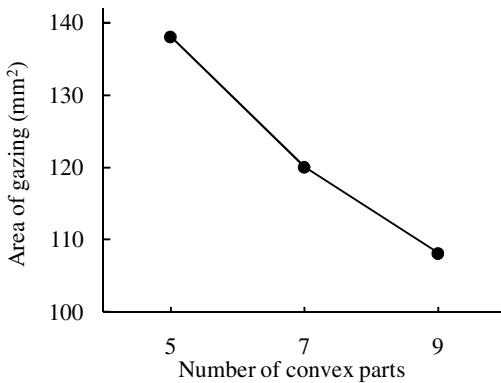
**Fig. 5.** Reaction times as a function of the number of convex parts with ISI



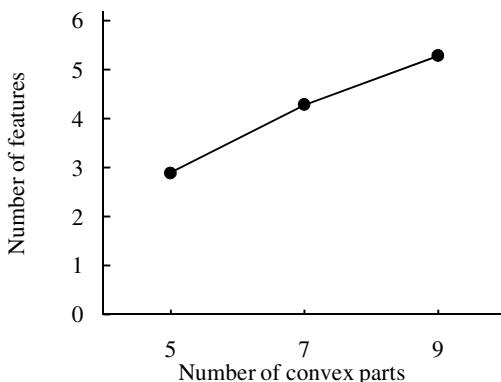
**Fig. 6.** Number of fixation points as a function of the number of convex parts with ISI



**Fig. 7.** Fixation time as a function of the number of convex parts with ISI



**Fig. 8.** Area being gazed around the contour as a function of the number of convex parts

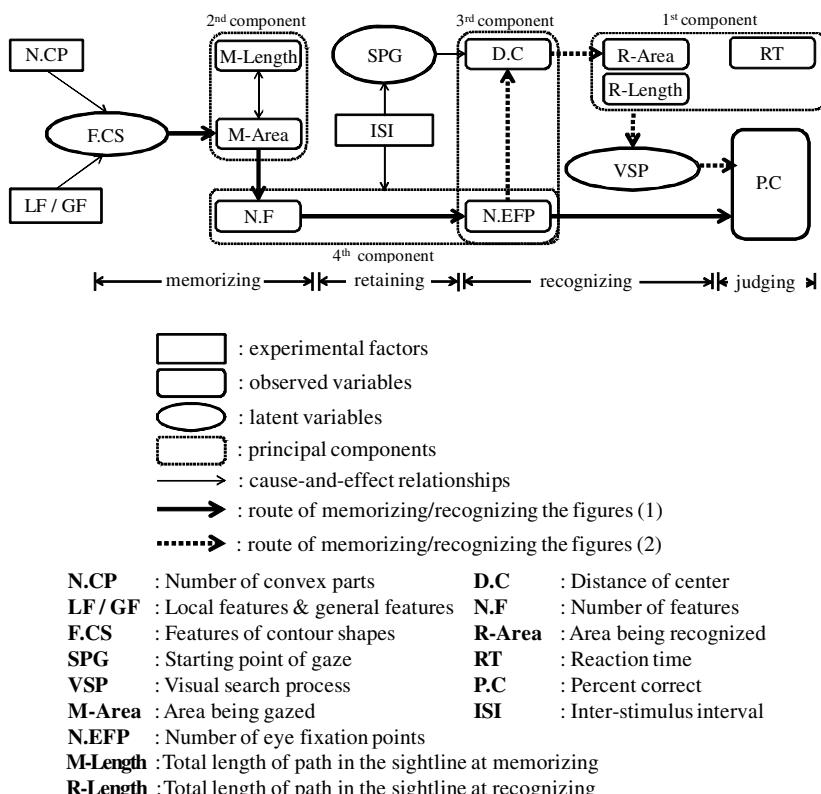


**Fig. 9.** Number of features around the contour as a function of the number of convex parts

### 3.3 Development of Instantaneous Cognition Model

To evaluate the process of instantaneous cognition and recognition for non-verbal smooth closed figures, correlations between various indices used in the experiment were calculated. After eliminating significant partial correlations, a correlation diagram was produced. To generalize the relationships between evaluation indices, a principal component analysis was performed using the indices used to produce the correlation diagram and four major components (focus of attention, fixation points, points from which subjects' began searching, and memorized features) were extracted.

Because the cognitive process of non-verbal smooth closed figures includes a cognitive function that cannot be measured objectively, a maximum-likelihood method was used for a factor analysis and the three latent variables were extracted (Features of contour shapes; F.CS, Starting point of gaze; SPG, and Visual search process; VSP), each of which has a causal relationship with a different indicator. Figure 10 shows an instantaneous cognition model in which the sequential order of cognition-recognition processes, indices, principal components, and cause-and-effect relationships between factors are considered after inserting the extracted factors.



**Fig. 10.** Instantaneous Cognition Model

## 4 Conclusions

The present study evaluated the characteristics of instantaneous cognition of non-verbal smooth closed figures from the perspectives of eye movement when memorizing/recognizing the figures and recognition performance through the “same-different” judgment paradigm using non-verbal smooth closed figures. The results suggested that the instantaneous cognition of non-verbal smooth closed figures is influenced by the contours’ features (number of convex parts) and ISI. In addition, the percent correct recognitions results suggested that the accuracy of “same-different” judgment may be influenced by differences between the points being gazed when memorizing and recognizing and the factors affecting the visual search process when recognizing. Another factor suggested as having a significant effect on “same-different” judgment accuracy is the number of features projected on the retina when memorizing contour shapes. In conclusion, the results of this study may have implications for interaction design guidelines about some instruments for visualizing a system state, particularly developing the supporting devices in work requiring precise detailed observation (factories and other environments requiring quality assurance, such as multi-attribute operations). However, cognition differences may exist at different ages because of depression of visual acuity. In further study, such comparisons across several ages are needs to design the visual instruments requiring the instantaneous cognition.

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