Paper**Study on Establishing an Evaluation Method for Visibility of a Human Face — Visual Factors Used in the Evaluation Method and the Composition of Verbal Expressions Used to Evaluate Visibility —**

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ABSTRACT

Our study sought to establish a universal and comprehensive method for evaluating the visibility of a human face. This paper examines the peculiarity of a human face as a visual object and the prerequisites required for an evaluation method. Two experiments were carried out under various lighting conditions to subjectively evaluate the visibility of a human face seen through a lace curtain. These experiments showed that verbal expressions used to evaluate the whole human face were related to those used to evaluate each part of the face, and that the luminance contrast between the cheek and the eye was a visual factor corresponding to the visibility human face.

KEYWORDS: evaluation method, human face, visibility, visual factor, verbal expression, lace curtain

1. Introduction

The visual task of seeing a human face is one of the tasks done frequently in our daily lives. The process of seeing the face is not simple, since there are a variety of visual tasks where the faces are the visual objects, such as ; an observer seeing his own face reflected in a mirror, seeing the faces of persons in a room through a curtain or seeing the face of an actor on stage. The definition of visibility of a human face in each of these visual tasks is different.

Regarding the knowledge relating to the visibility of human faces, it can be cited that the range in which for example the expressions of an actor on stage, has been reported to be important in designing the auditorium of a theater ¹⁾. Tohyama et al. did an assessment of the farthest distance of the seats based upon the physical quantity (size) of the eye. This, under the assumption that the expression of the eyes constitute the very core of expression ²⁾. Also, in regard to the perception of the modeling of human faces, Cuttle ³⁾ studied the perception and the ratio of an illumination vector to scalar illuminance (vector-scalar ratio), and Tabuchi ⁴⁾ proposed to evaluate the state of the modeling near a window by the ratio of the illuminance of the vertical plane facing the window and the illuminance of the vertical plane facing away from the window.

The studies described handled only one factor of the visibility of the human face, such as the visibility of expression and the perception of modeling, this despite there being many visual tasks involved in the seeing of human faces. There has been no comprehensive study yet, to cover the visibility of human faces that can be applicable in various situations. Also, in the studies, a physical

quantity that defines the visual task, such as illuminance, is used as the physical quantity corresponding to visibility. It is hard to say that the physical quantities of the visual objects (faces) in the visual task field have been clearly defined, and thus, they were made from the view point of practical operations.

Therefore in, aiming at establishing a comprehensive evaluation method that corresponds to the variety of the visibilities of human faces, this study will examine the peculiarity of a human face as a visual object. We will endeavor to establish a universal evaluation method based on the prerequisites for an evaluation method. By the way, although there are many studies regarding face recognition, the recognition of patterns, data processing of the meanings expressed by faces, and so on ⁵⁾⁻⁸⁾, this study does not cover the evaluation of the recognition mechanism in the brain. It examines the evaluation method for the visibility of a human face, assuming that the recognition of a face is achieved when a visual worker is judged it as "visible."

2 Peculiarity of Faces as Visual Objects

It is normal practice to standardize the visual object initially and then predict the evaluation using the standardized visual object, in order to establish an evaluation method for the visibility of objects. However, it is extremely difficult to standardize a human face since there are so many different kinds of human face due to various races and ethnic groups. Even if the standardized face is limited to representing the faces of one specific group, within that group the individual differences are also large.

This seems to be the reason why an evaluation method for the visibility of a human face, as a visual object, has not yet been established, this in spite of the visual task of seeing faces being one of the tasks that is frequently done in our daily lives.

It is noted that a feature of the face as a visual object is that it comprises the face-composing elements; such as the eyes, the nose, the mouth, and so on. This can be said to be the peculiar point of the human face as a visual object and that they generate a luminance distribution as a visual object. There are three visual factors - the background luminance, the luminance contrast, and the size of the visual objects. These are commonly referred to as the physical quantities for predicting visibility, it is difficult to specify the visual factor corresponding to the evaluation, since there are a lot of combinations for visual factor due to the physical quantities of a face in different regions.

Regarding the evaluation of the visibility of a human faces, although there are really various aspects to evaluation, such as the visibility of expression, the perception of modeling, and the identification of acquaintances; it is considered that, in any case, the details such as the states of the eyes, the mouth, the nose, etc., are initially recognized after understanding this data. Thus, it can be said that each evaluation phase is determined by the combination of the discriminations of the regions of the face.

In order to establish an evaluation method for the comprehensive visibility of a human faces, it is necessary to proceed by satisfying the prerequisites for an evaluation method paying attention to the relationship between the evaluation items for the whole face as applied in daily life, and the evaluation items for each face-composing element of a face. The prerequisites for an evaluation method for visibility will be described in the next section.

3 Prerequisites for an Evaluation Method for Visibility

It is necessary to give certain physical stimuli to the subjects so as to have them subjectively judge the feeling or perception of the stimuli, and to measure them in order to establish a measuring method for the visibility under a certain environmental conditions. Regarding the measuring method, there are two kinds of evaluation components; the "feasibility of data acquisition," and the "visibility". This indicates the amount of time and effort required for the acquisition of the data. Therefore, when constructing an evaluation method for visibility, it is necessary to select an appropriate evaluation phase depending on its purpose and to set the verbal expression of an evaluation corresponding to the evaluation phase.

For evaluating the ease of reading printed characters, Sato, et al ¹²⁾ adopted a five-step verbal evaluation scale consisting of evaluation phrases such as "barely readable" and "easily readable" for the documentary visual objects. These evaluation scales correspond to the three visual factors of the size of the characters, the background

luminance, and the luminance contrast, and the usefulness of this evaluation scale, as has been widely recognized. However, the evaluation phrases for documentary visual objects can not be applied as they have been studied since. Unlike the case of the documentary visual objects, the background luminance and luminance contrast are uniform throughout the overall visual object. There is a large variation in luminance for a human face causing differences in regions to be noticed depending on the content of the evaluation phrases as well as the difficulties in specifying certain regions.

In the case of a human face as a visual object, Murakami, et al ¹³⁾, they used a seven-step verbal evaluation scale consisting of evaluation phrases such as "the three-dimensional feeling of the face. It is considerably insufficient" and "the whole image is felt to be somehow excessively bold" for the evaluation of the modeling of a face. However, evaluation phrases for the visibility of the face, as handled in this study with levels of proper discrimination of the detailed data on the face (the eyes, mouth, nose, and so on) were not established in their study. It is necessary to arrange and integrate the content of the data to be adopted for the evaluation scale in order to construct an evaluation method for the comprehensive visibility of a human face.

On the other hand, indices for predicting the evaluation are required in order to make the evaluation for the visibility method universal and versatile, and the indices should be calculated from the physical quantities of the visual objects. However, since there is a luminance distribution in a human face, as described before, it has not yet been clarified in which region of a human face should be observed the luminance level as a physical quantity of the visual object. Also, since the luminance levels of a human face vary with changes in the illumination condition or the presence of window materials such as a roll shade, a curtain, or a shoji ^{14) 15)}, it is necessary to consider these various conditions together.

Furthermore, there should be a consistent correlation formed between the evaluation scale mentioned above and the evaluation prediction indices in a universal evaluation method. In other words, it is necessary that the correlation is formed in which, when the combination of the physical quantities for a certain visual task are given, one evaluation category is determined, and an evaluation method for visibility can not be established unless this prerequisite is satisfied.

Hence, the study aims at clarifying the correlation between the evaluation and the physical quantity, which is the prerequisite for a universal evaluation method for visibility. An evaluating experiment with a photograph of the face of a specific person (Japanese) as a visual object, using various evaluation phrases for the visibility of the face (assuming that there is a one-to-one correlation between the "ease of visibility") that indicates the level of data acquisition pertinent to a face and the three visual factors that are physical quantities of a face. In this

experiment, a lace curtain was used in order to vary the contrast with the background while maintaining the luminance ratio between the face-composing elements such as eyes and nose. It is unrealistic to have the Japanese face as the visual object, varied by each region, and the settings of the size of the visual object, the luminance contrast, and the background luminance were limited to the range that would be considered normal in daily life.

In this paper, the evaluation items were selected under two categories; the visibility of the face-composing elements, (eyes and nose, etc.) and the visibility of the face as a whole. The regions to be noted were examined based upon the ranking and the mutual relations of the evaluation items that are obtained from the results of the "feasibility of data acquisition" on each selected evaluation item. Also, the evaluation items suitable for composing the evaluation scales for "ease of visibility" of the human face were extracted from the evaluation items used, and the corresponding relationship between the physical quantity of each region and the ease of visibility, which were examined.

4 Evaluation and Physical Quantities for Visibility of a Human Face

4.1 Outline of Experiment

The evaluation experiment was implemented with a lace curtain between a subject and the visual object. This was intended to vary the background contrast while maintaining the luminance ratios between each face-composing element. This enabled the changes in luminance and luminance ratio of the visual object in line with the practical situation. An experimental apparatus as shown in Fig. 1 was produced in which the illuminance of the visual target (paper surface) and the illuminance of the lace

Fig. 1 Experimental apparatus.

Table 1. Lighting conditions(at the experiment of evaluation for visibility of human face)

Visual target paper illuminance(lx)	0, 350, 700, 1400, 3500
Curtain surface illuminance(lx)	0, 50, 100, 500, 1000

Fig. 2 Luminance distribution of visual object.

curtain (plain-woven, white, cotton cloth) could be controlled independently. Twenty-five lighting conditions in total were set by varying the illuminance of the visual target (paper surface) and the illuminance of the lace curtain surface, each by five steps, as shown in Table 1. This table shows the former in the range of 0 to 3500 lx, and the latter in the range of 0 to 1000 lx.

For the visual object, a photograph of the face of a male student, as shown, Fig. 2, which was taken; a digital camera was used. The visual target was prepared by printing it monochromatically on high quality paper N9.5 so that the cheek portion was N5.5, was presented in an opening in a black separating wall (350mm × 350mm). The luminance distribution of each region when the luminance of the background mounting surface is 1 is shown in the figure. The size of the face was set at a level in which the face-composing elements could be recognized. The lighting condition was good, and the visual angle was set at 7.15°, assuming a case of seeing a human face from a distance of 2m. Also four kinds of visual targets were prepared: three different expressions and a face with an attachment (glasses) on it.

Table 2 Verbal expression for visibility of a human face.

Evaluation items related to the visibility of the face-composing elements	Length of hair	Shape of hair
	Position of the ears	Position of the nose
	Position of the eyebrows	Shape of the eyebrows
	Position of the mouth	Shape of the mouth
	Open or closed mouth	Open or closed eyes
	Position of the eyes	Shape of the eyes
	Has glasses or not	Has mustache or not
Evaluation items related to the visibility of the whole face	Direction of the eyes(visual line)	
	Discrimination of male and female	
	Discrimination of the individual	
	Discernment of expression	

Table 3 List of subjects.

Subjects	Sex	Age	Visual acuity
K	male	22	1.0
F	male	22	0.7
M	male	24	1.0
N	male	22	1.5
O	male	21	0.7

Regarding the evaluation items for the visibility of the face, 15 items were extracted from the verbal expressions

in daily life. The visibility of the face-composing elements expressed the position, shape, and state of each composing element, and three items of composite verbal expression for the visibility for the whole face. Eighteen items in total, as listed in Table 2, were set.

Under the setting as described above, we had five male students of our university as subjects, shown in Table 3. They were evaluated through the visibility of the visual object and as seen through the lace curtain. During this time, we had them state the possibility of data acquisition for each item, as shown in Table 2, using the evaluation words of "recognized" or "not recognized." By the way, all of the subjects were acquainted with the person who was the visual object.

4.2 Evaluation of the Visibility of Face-Composing Elements

Fig. 3 shows the results for subject K, evaluations related to the mouth as a face-composing element, under lighting conditions that were combinations of the curtain surface illuminance and the visual target paper illuminance. The shaded portions in the figures are the conditional ranges where positive evaluations were obtained in the range of the conditions set in this experiment, and the solid lines in the figures were obtained by tracing the lower limit of the conditional range. Although it is common to all the evaluation items that the positive evaluation is obtained under the condition of a low curtain surface illuminance, coupled with a high visual target paper illuminance. That is, the condition of a high background luminance coupled with a high luminance contrast. It is noted that there are differences in the regions. Since the position of the solid line shows the lower limit of the conditional range in which positive evaluations were obtained indicates the size of the conditional range. The solid line alone, which indicates the lower limit of the conditional range in which, hereinafter will show the positive evaluations were obtained.

Fig. 4 shows the results for subjects K and F. If a smaller conditional range means a higher ranking in the evaluation items, the two evaluation items, "shape of the mouth", "open or closed mouth" can be said to be equivalent. With either subject, the conditional ranges of

Fig. 4 Boudary of verbal expression of evaluation for visibility of the mouth.

Fig. 5 Boudary of verbal expression of evaluation for visibility of the eyes.

these two items where the evaluation "recognized" were obtained were the same. Also, it is known that the "shape of the mouth" is an evaluation item higher in ranking than the "position of the mouth", since the conditional range of the former where the evaluation "recognized" is obtained is smaller compared to the same for the latter.

Regarding the visibility of the eyes as a face-composing element, the results the subjects K and F, whose conditional ranges where positive evaluations, were different; as shown in Fig. 5 by the solid lines alone to show the lower limits. Since the "recognized" conditional ranges were the same for the "shape of the eyes" and the "open or closed eyes", it can be said that these two evaluation items are the same in ranking. Also, since the "recognized" conditional range was the largest for the "position of the eyes" evaluation item among all the evaluation items, the conditional ranges get smaller in the sequence of the "shape of the eyes" and the "direction of the eyes (visual line)". It is known that the "direction of the eyes (visual line)" is the evaluation item in the highest ranking of the evaluation items related to the eyes and that there is a

Fig. 3 Lighting conditions in the case of evaluation for visibility of the mouth.

succeeding rank of the "shape of the eyes" and the "position of the eyes".

From the results above, it is known that the evaluation items related to the visibility of the face-composing elements, that there is a ranking in which the "shape" of each composing element is the evaluation item ranked higher than the "position" of the same.

4.3 Evaluation of the Visibility of the Whole Face

Fig. 6 shows the results of the visibility of the whole face for the subjects K, F, and O. The conditional regions obtained on a positive evaluation are shown in the solid lines, the lower limit alone were different from each other. It is known from these results that the "recognized" conditional range was largest in "discrimination of male and female". Among all evaluation items related to the whole face, the "recognized" conditional ranges for the evaluating item get smaller one in the sequence of the "discrimination of the individual", and the "discernment of expression". In other words, it is known that the "discernment of expression" is the evaluation item in the highest ranking related to the whole face, and that there are succeeding rankings of the "discrimination of the individual" and the "discrimination of male and female".

From the above results, it is known that, although there are personal differences, those in a common ranking in three items related to the whole face and as applied in this experiment. Since it is reasonable to use the "ease of visibility" on a certain selected items on verbal evaluation scale, it is considered to be appropriate for evaluation of the visibility of a human face to extract "discernment of expression". This is the evaluation item in the highest ranking among the evaluation items for the whole face. To set the verbal evaluation scale that expresses the time and work load required reading the expression.

4.4 Physical Quantities Corresponding to the Visibility of the Human Face

Although it was shown that there is a ranking of "discrimination of male and female", "discrimination of the individual" and "discernment of expression". This in the three items of the visibility of the whole face, as shown in Fig. 6. It is noted from the positional relationship of the solid lines, which show the lower limits of the conditional ranges, that the conditional ranges obtained in each

Fig. 7 Boundary of verbal expression of evaluation for visibility of the face composing elements (Subject K).

Table 4 Verbal expression for visibility of a human face and inclination of the lower limit of conditions for the visibility.

Conditional region	Evaluation items related to the visibility of the whole face	Evaluation items related to the visibility of the face composing elements
small ↓ large		Direction of eyes (visual line)
		Shape of the eyebrows
	Discernment of expression	Shape of the eyes Open or closed eyes
		Shape of the mouth Open or closed mouth
	Discrimination of the individual	Position of the eyebrows Position of the eyes
		Position of the mouth Position of the nose
		Position of the ears
	Discrimination of male and female	Shape of hair Length of hair
	Items with large personal difference : Has glasses or not; Has mustache or not	

evaluation get smaller in the sequence. Five items with small conditional ranges were selected on the basis of their size from the fifteen items related to the visibility of each face-composing element, and the results for the subject K are shown in Fig. 7. Based upon this figure, it is considered that the four evaluation items of the "shape of the eyebrows," "shape of the eyes," "shape of the mouth," and "discernment of expression" are the same in ranking and that the "direction of the eyes (visual line)" is the evaluation item with a higher ranking than these four evaluated items.

Similarly, it is considered that each evaluation item can be ranked by the size of the conditional range, and Table 4 shows all eighteen evaluation items ranked and based upon the sizes of the conditional ranges obtained. It is considered that the corresponding relationship between the evaluation items for the visibility of the face-composing element and the evaluation items for the visibility of the whole face can be most likely predicted. Thus, it can be mentioned as an example that the evaluation items such as the "shape of the eyes" and the "shape of the mouth" are predicted to correspond to the evaluation item "discernment of expression".

Fig. 6 Boundary of verbal expression of evaluation for visibility of a whole face.

From the above results, it is considered to be appropriate to note the corresponding physical quantities of the face-composing elements in order to specify the physical quantities corresponding to the visibility of a human face. In other words, it can be predicted that the physical quantities as noted for the size of the region, the luminance level, the luminance contrast, and so on of the noted eyes and a mouth correspond to the evaluation item "discernment of expression".

5 Verbal Evaluation Scale for Visibility

5.1 Outline of Experiment

As already mentioned in Section 2, it is an outstanding feature of a human face as a visual object that it has a luminance distribution owing to the face-composing elements such as the eyes, the nose, the mouth, and so on. Since the luminance level of a face varies by region of the face-composing elements, it is considered that a careful attention should be paid at the time of the calculation of the luminance contrast, which is one of the visual factors.

Luminance contrast is one of the visual factors corresponding to the visibility for a human face. An experiment for evaluating of the visibility was implemented, and with the aim of constructing a verbal evaluation scale that corresponds with the luminance contrast. It was also examined if there is a correspondence between the verbal evaluation scale for the visibility and the luminance level of the specific region being used at the time of calculating the luminance contrast.

The experiment was implemented with a method similar to the method described in Section 3 and using the apparatus shown in Fig. 1, with twelve lighting conditions, as shown in Table 5 were set. The face of a male student, which was photographed by a digital camera and printed monochromatically, was used as the visual target, and it was mounted on thick paper of N9.5, N7.5, and N6.5 to make a visual target, which was shown through an opening (400mm × 400mm) on a separating wall (painted black). The subjects were two persons, K and F of the list of subjects shown in Table 3. Also, the evaluation item of "discernment of expression" that was evaluated as the highest in ranking among the evaluation items was related to the visibility of the whole face, which paid attention to. This, for developing the verbal evaluation scale and for the ease of visibility of the face, as with the five steps of the

Table 5 Lighting conditions(at the experiment of evaluation for the visibility of human face expression)

		Curtain surface illuminance (lx)				
		0	50	100	300	1000
Visual target paper illuminance (lx)	22	○	○	○	○	○
	110	○	△	○	○	○
	550	○	△	△	○	○

5.2 Relationship between the Evaluation of the Ease in Visibility and Physical Quantities

verbal evaluation scale as shown in Fig. 6, were set as phrases to show the degree of effort required to recognize the expressions.

Regarding the calculation of the luminance of a visual object seen through a material with gaps like a lace curtain, a paper¹⁶⁾ reported a method for calculating the luminance of a visual object which is handled as a material that connotes the ratios of the area of the fiber portion of the lace curtain and the visual object seen through its gaps. Hence, the luminance levels of the visual object under each lighting condition shown in Table 5 were calculated using the following equation, which can be introduced from the report¹⁶⁾, and the luminance contrasts were calculated from the luminance levels of each region in the visual object.

$$L_a = L_c \cdot \phi + E_b \cdot \tau + E_c \cdot \rho \quad \dots\dots\dots (1)$$

L_a : Luminance of a visual object seen through a curtain

L_c : Luminance of the visual object

E_b : Luminance of the back of a curtain

E_c : Luminance of the curtain surface

ϕ : Ratio of gaps in appearance

τ : Transmitting property of the curtain

ρ : Reflectance property of the curtain

Fig. 8 Relation between the luminance contrast calculated from background luminance and hair luminance and the visibility

Fig. 9 Relation between the luminance contrast calculated from cheek luminance and eye luminance and the visibility

Shown in Fig. 8 is the relationship between the averages of the luminance contrast and the evaluations of the visibility for the facial expression of the subjects K and F. The difference between the background luminance and the hair luminance, which is the largest difference in luminance in the visual target, divided by the background luminance was used as the level of the luminance contrast. Since a tendency is noted that higher evaluation is obtained in parallel with an increase in the luminance contrast, the verbal evaluation scale as set can be said to be appropriate for the evaluation method for the visibility of a human face. However, it is difficult to say that the use of the luminance contrast of the background luminance versus the hair luminance is appropriate since there is a difference of as much as three steps in the evaluations at the same contrast level.

In view of the fact that the evaluation items of the "discernment of expression" and the "shape of the eyes", here the ranking was the same as in the previous section. The relationships between the averages of the luminance contrasts and the evaluations of the ease of visibility for the face expression by subjects K and F, in a case in which the difference between the cheek luminance and the eye luminance divided by the background luminance was used as the luminance contrast level, as shown in Fig. 9. A tendency that a higher evaluation is obtained in parallel with an increase in the luminance contrast is noted. There is only one step of difference at most in the differences of the evaluations under the same luminance contrast. It is therefore known to be more appropriate to the luminance contrast between the cheek luminance and the eye luminance as an index for predicting the evaluation.

From the above results, the verbal evaluation scale set is useful as the verbal evaluation scale for the visibility for a human face. Also it is reasonable to use the physical quantity related to the eye region for calculating the luminance contrast corresponding to the evaluation.

6 Conclusion

In this paper, evaluation experiments were implemented using evaluation phrases composed of various verbal expressions and a physical quantity was deduced corresponding to the evaluation. This is a prerequisite for an evaluation method for visibility, and with the aim of constructing an evaluation method for the visibility of a human face. In addition, the evaluation items appropriate for the evaluation scale were extracted, based upon the

rankings and differences of the evaluation items. The verbal evaluation scale was set, and the relationship between the ease of visibility and a physical quantity that corresponds with it, was clarified. In future, we plan to implement evaluation experiments on the visibility of the human face using the verbal evaluation scale so that a universal evaluation method for the visibility of the human face is constructed, based upon the correspondences between the three visual factors and visibility.

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Table 6 Verbal expressions for the visibility of a human face expression.

Easy to recognize
Recognized without efforts
Recognized despite slight difficulties
Barely recognized
Not recognized at all

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