IMPROVEMENT IN AUTOMOBILE INTERIOR COMFORT BY MODIFYING LIGHTING

Hiroshi TAKAHASHI[*a], Hiraku ASAKURA[a] , Hirotomo TERASHIMA[a] , Takashi IRIKURA[a] , Shinichiro II[b] and Daisuke WAKITA[b]

[a] *Shibaura Institute of Technology, Japan*
[b] *Nissan Motor Co., LTD, Japan*

ABSTRACT

This study focuses on automobile interior lighting, and in a first experiment, examines the relationship between the interior illuminance, exterior lighting environment, light source form, and impression evaluations. In a second experiment, the usefulness of electrocardiogram analysis as a biological indicator for evaluating the effects of the interior lighting is examined. The results of experiment 1 indicate that impressions of the interior lighting vary according to the interior illuminance, exterior lighting environment and the light source form. These results also clarify the relationships between each condition and the impression evaluations. In experiment 2, specific tendencies regarding light source forms and electrocardiograms were observed, indicating the possibility of using electrocardiograms as biological indicators for evaluating the effects of the interior lighting.

Keywords: *interior lighting, impression evaluation, physiological response*

1. INTRODUCTION

Recent developments in new types of light sources are bringing about revolutionary changes in lighting environments, even in the automobile industry. Advances in headlamps, as typified by the development of high-efficiency LED lamps, have been particularly remarkable. Various research activities investigating, for example, light distribution and control methods relating to lighting design, form, visibility, glare evaluation, and adaptive front lighting systems are actively being pursued. With regards to interior automobile lighting, however, there are presently no trials underway that seek to change the

[*] **Corresponding author**: 3-7-5, Toyosu, Koutou-ku, Tokyo, 135-8584, Japan

e-mail : htakaha@shibaura-it.ac.jp

conventional form and arrangement of interior automobile lighting, and related research is almost non-existent.

Much research has been conducted into the effect that interior room lighting has on changing a person's impressions. Oshida[1] modeled 36 varieties of interior spaces (assuming a living room reduced in scale by 1/20) in which the ceiling lighting had different forms, arrangement and colors, conducted psychological evaluation experiments, and analyzed the results by factor analysis to clarify the relationship between the extracted image factors and form characteristics. (The following 6 conditions were combined to evaluate a total of 36 conditions (excluding duplicates): (1) size of the ceiling lighting: 3 conditions, (2) changes in the number of lights: 3 conditions, (3) installed location of the lighting: 4 conditions, (4) lighting brightness: 3 conditions, (5) color changes: 13 conditions, and (6) form changes: 15 conditions.)

As a result of factor analyses of impression evaluation experiments with these 36 conditions, three latent image factors and one reference factor were extracted from the evaluation of 30 pairs of adjectives (7-tiered scale) by 38 subjects. The relationship between these four image factors and the ceiling lighting form was obtained by computing a factor score (indicating the influence of a factor) for each form factor. From the above results, the mutual relationship between image factors, obtained from adjective score results, and form characteristics was clarified. Sugimoto et al.[2], [3] conducted indoor experiments involving the effect of illuminance on the human body to investigate the physiological effect of lighting environments. During the experiments, a questionnaire was used to perform psychological evaluations. In terms of the logarithmic value of the illuminance, an illuminance dependency of one-quarter unit illuminance dependency was found for both physiological and psychological aspects. It was also determined that the psychologically desired illuminance level was at a level slightly higher than the illuminance level at which physiological load is a minimum.

However, basic aspects concerning the effects of the automobile interior environment, particularly, constant lighting of the interior automobile while the automobile is being driven, on the physiological response as represented by the visual perception and psychological and physiological responses for both the driver and passengers, have not been clarified. Therefore, using a model that reproduces the interior of an automobile, the present study aims to clarify the way in which impressions of the automobile interior change according to the form, arrangement and illuminance level of lighting in the automobile interior, and to accumulate basic data in order to improve the interior lighting environment of an automobile.

2. EXPERIMENTAL SETUP (MEASUREMENT OF LIGHTING ENVIRONMENT IN AN ACTUAL AUTOMOBILE)

At the beginning of the present study, various luminous and physical quantities were measured in an actual automobile to assess the current lighting environment in automobiles. Measurements were taken under the conditions listed in Table 1, with consideration given to the effects of the headlights and other exterior lights. Measurements were taken for two assumed locations, an urban area and a suburban area. Under conditions (A) and (B) for an assumed urban area, we aimed to measure the values of road surface luminance and automobile interior illuminance due to the exterior lighting environment, with the headlights turned off. Under conditions (C), (D), (E) and (F) for an assumed suburban area, the effect of exterior lighting is thought to be negligible and therefore the road surface luminance and automobile interior illuminance were measured with the headlights turned on. At that time, the automobile interior illuminance was also measured with the interior lighting turned on.

For each condition listed in Table 1, the luminance at representative areas in which driver visibility is thought to be affected (i.e., the instrument panel, car navigation system and meter display) was measured. The automobile interior luminance was measured under all conditions (A) through (F). The results show no change in interior luminance according to the orientation of exterior lights or to the difference in headlight lighting.

As in the measurement of interior luminance, the road surface luminance 10 to 30 m in front of the vehicle was measured along the driver's line of sight for each condition listed in Table 1. According to the results, in the range from 10 to 30 m, the mean luminance in an urban area, with the headlights turned off, was 2.0 cd/m^2 and in a suburban area, regardless of whether the headlights were on or off, was nearly 0.5 cd/m^2. Based on these findings, for the urban area measured here, the road surface luminance (from the viewpoint of the driver) is thought to be in the range of approximately 2.5 to 3.0 cd/m^2 in the case where the headlights are on.

Table 1: Measurement conditions

The place of measurement	**Headlamp condition**	**Interior lighting**	**Exterior lighting**
Urban area (A)	Off	Off	Under of the street lamp
Urban area (B)	Off	Off	Between the street lamps
Suburban area (C)	High beam	Off	None
Suburban area (D)	High beam	On	None
Suburban area (E)	Low beam	Off	None
Suburban area (F)	Low beam	On	None

3. EXPERIMENT 1 (IMPRESSION EVALUATION OF AUTOMOBILE INTERIOR LIGHTING ENVIRONMENT)

3.1. Experimental method

In a space simulating the interior of an actual automobile, impression evaluation experiments were carried out in which the form, arrangement and illuminance of the automobile interior lighting were changed. The subjects immobilized their heads with chin rests installed near the third-row seats so that they were able to observe the interior of the automobile from the same height as when seated in a third-row seat of an actual automobile. For the impression evaluation, a road surface luminance-adjusted image was displayed on a monitor in front of the windshield in the model interior. A photograph of this model interior is shown in Fig. 1. The Semantic Differential (SD) method, using forms with a 7-tiered scale (see Fig. 2), was used for the impression evaluation, and the obtained score data was analyzed and examined. Thirty-two pairs of adjectives commonly used in impression evaluations were selected for use in the present study.

Figure 1: Photograph of model automobile interior

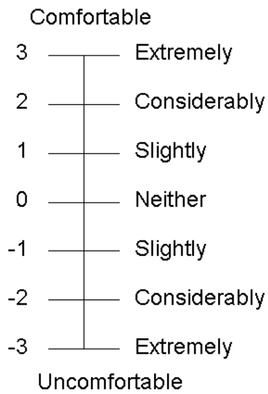

Figure 2: Example of scale used for impression evaluation (comfort)

3.2. Experimental conditions

The automobile interior lighting patterns used in the present experiment are shown in Fig. 3. A total of 9 patterns were used: 5 patterns in which the light source was arranged on the ceiling, 3 patterns in which the light source was arranged on the door area, and the case in which no light source was used. The light source installation on the door area extended as far as the second row. The experimental conditions are listed in Table 2. The experiments were conducted using the model interior in a dark room, and the subjects consisted of 20 to 25-year-old college students (n = 14, 12 males and 2 females).

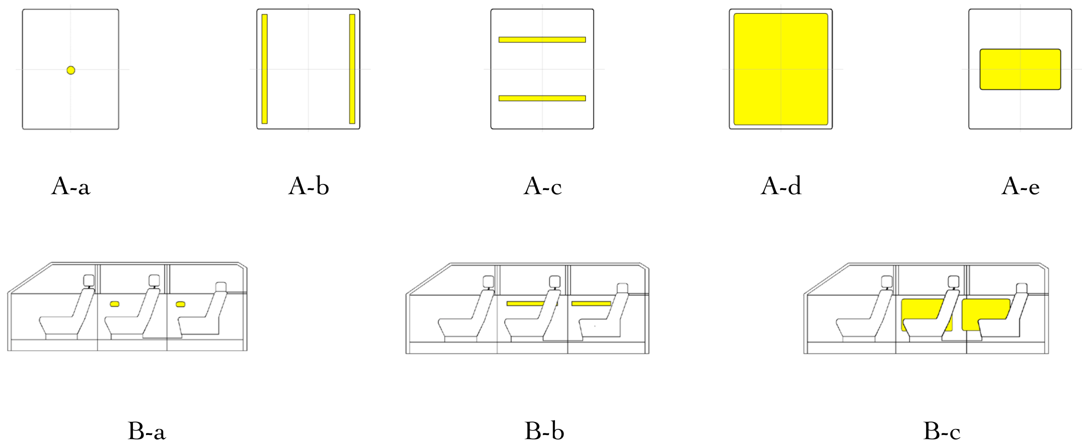

Figure 3: Schematic of automobile interior lighting patterns

Table 2: Measurement conditions

Scale of the model	1/4 of an actual automobile
Beginning adaptation luminance	0.0 [cd/m^2]
Interior illuminance	0.5, 2.0 [lx] (third-row seats)
Color temperature of the light source	3500~4000 [k]
Exterior lighting environment	Urban area (road surface luminance of 2.5[cd/m^2])
	Suburban area (road surface luminance of 0.5[cd/m^2])
Lighting patterns of the ceiling	5 patterns
Lighting patterns of the door	3 patterns
Total	34 patterns

3.3. Experimental procedure

The following procedure was used to conduct the experiment.

1) The subjects adapt to darkness for 10 min in a dark room.

2) The subjects adapt to the lighting environment in the model automobile for 3 min.

3) The subjects evaluate their impressions of the automobile interior lighting and record them on impression evaluation forms. (approximately 10 min including both adaptation and evaluation)

4) The lighting patterns (ceiling and door) and illuminances are changed randomly and steps 1) to 3) are repeated.

During the impression evaluation experiment, subjects were permitted to look anywhere when evaluating their impression of the interior. They were to assume that they were inside a moving vehicle and told to freely look around both inside and out the windows of the vehicle to conduct their evaluation. Subjects were instructed not to simply gaze at the light source area or at scenes out the window of the vehicle, and that their impression of the lighting environment was to be evaluated based on the interior space only. These instructions were provided so as to avoid, to the extent possible, drastic changes to the acclimated state during the evaluation as a result of looking mainly at the light source, which would be much brighter than its surroundings. Moreover, since the objective of this experiment was to evaluate impressions of the interior lighting environment, consideration was given so that the evaluation would not consist of only the exterior environment.

3.4. Experimental results (adjective evaluation scores)

As an example of the results, the mean evaluation scores for comfort when the exterior environment is an urban area (road surface luminance of 2.5 [cd/m^2]) are shown in Fig. 4. Each bar on the graph indicates the illuminance of the automobile interior lighting.

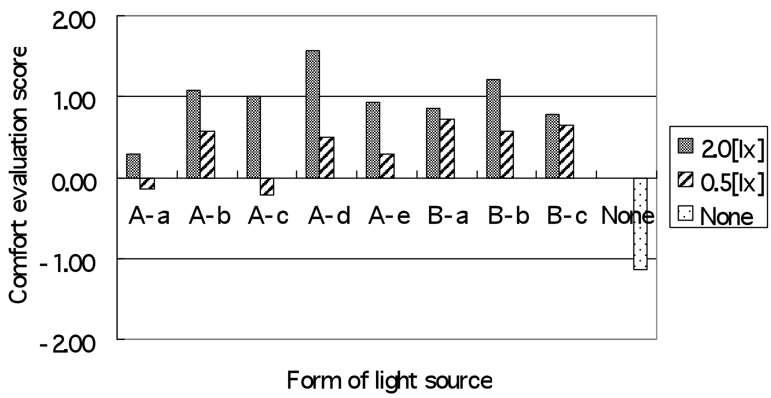

Figure 4: Comfort evaluation scores

As shown by the results presented in Fig. 4, the comfort evaluation scores are higher for all forms of light sources when the interior lighting is 0.5 or 2.0 lx compared to the case in which no interior lighting is used. Moreover, a closer examination of the interior illumination intensity reveals that the evaluation scores are higher when the illuminance is 2.0 lx rather than 0.5 lx, in all conditions. At 2.0 lx, the highest evaluation score was obtained under the A-d form, while at 0.5 lx, high evaluation scores were obtained with the B series (having a light source at the door area), the A-b form.

3.5. Analysis and considerations

Factor analyses (principal factor method, varimax rotation)[4] were performed on the results of the evaluation of the 32 adjective pairs. At that time, adjective pairs (emotional/intellectual and frivolous/profound) having a communality of less than 0.5, and for which no significant difference was observed in variance analyses of all lighting forms, lighting conditions and interactions, were deleted. The factor analysis results are shown in Table 3.

Primary factors, having a factor contribution percentage of 36.57%, are called "light-influencing factors" because of their strong correlation to adjective pairs such as "bright/dark, conspicuous/inconspicuous, showy/plain, open/closed, dynamic/static". Similarly, secondary factors, having a factor contribution percentage of 33.65%, are called "space-evaluating factors" because of their strong correlation to adjective pairs such as "elegant/crude, high-class/cheap, attractive/unattractive and comfortable/uncomfortable," and tertiary factors, having a factor contribution percentage of 10.91%, are called "dramatic factors" because of their strong correlation to adjective pairs such as "fantasy-like/ordinary" and "dramatic/undramatic." The cumulative contribution to the experimental results by these three factors was 81.12%.

Next, in order to ascertain the relationship between the form and lighting conditions and each factor, a factor score was computed. The factor scores for each experimental condition are shown in Figs. 5, 6 and 7.

Table 3: Factor analysis results

	Primary factor	Secondary factor	Tertiary factor	Communality	Uniqueness
Bright–dark	0.87	0.37	0.19	0.93	0.07
Conspicuous–inconspicuous	0.84	0.32	0.30	0.90	0.10
Easy going–ceremonious	0.84	0.27	–0.28	0.86	0.14
Calming–restless	0.82	–0.27	0.23	0.80	0.20
Cheerful–lonely	0.80	0.42	0.36	0.94	0.06
Upbeat–gloomy	0.80	0.45	0.25	0.90	0.10
Open–closed	0.79	0.45	0.12	0.84	0.16
Glaring–not glaring	0.78	–0.01	0.22	0.66	0.34
Dynamic–static	0.78	0.36	0.26	0.80	0.20
Showy–plain	0.78	0.46	0.41	0.98	0.02
Flexible–rigid	0.78	0.48	–0.09	0.84	0.16
Powerful–lacking power	0.76	0.25	0.33	0.75	0.25
Wide–narrow	0.70	0.44	0.24	0.75	0.25
Warm–cold	0.62	0.49	0.04	0.62	0.38
Streamlined–gaudy	–0.02	0.83	0.04	0.69	0.31
Elegant–crude	0.17	0.82	0.34	0.81	0.19
High-class–cheap	0.37	0.80	0.34	0.89	0.11
Harmonized–irregular	0.30	0.78	0.05	0.70	0.30
Peaceful–not peaceful	0.33	0.77	0.13	0.72	0.28
Familiar–unfamiliar	0.35	0.76	–0.08	0.71	0.29
Attractive–unattractive	0.46	0.76	0.33	0.90	0.10
Safe–anxious	0.54	0.75	0.21	0.89	0.11
Refreshing–annoying	0.05	0.74	0.25	0.62	0.38
Clean–dirty	0.41	0.73	0.42	0.87	0.13
Fun–boring	0.52	0.71	0.39	0.93	0.07
Comfortable–uncomfortable	0.64	0.69	0.19	0.93	0.07
New–old-fashioned	0.46	0.69	0.46	0.89	0.11
Fantasy-like–ordinary	0.06	0.48	0.73	0.76	0.24
Artificial–natural	0.41	0.09	0.64	0.58	0.42
Dramatic–undramatic	0.34	0.62	0.62	0.88	0.12
Sum of squares of column	10.97	10.09	3.27		
Contribution ratio (%)	36.57	33.65	10.91		
Cumulative contribution (%)	36.57	70.21	81.12		

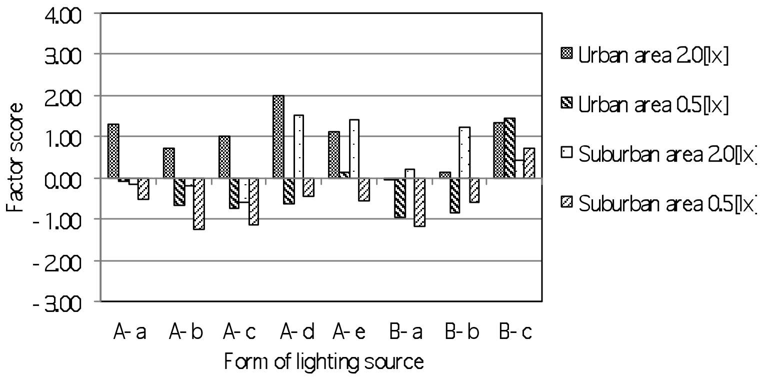

Figure 5: Primary factor score for each condition (light-influencing)

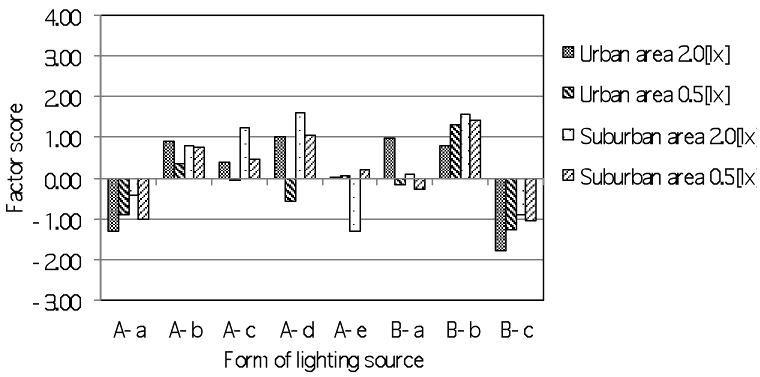

Figure 6: Secondary factor score for each condition (space-evaluating)

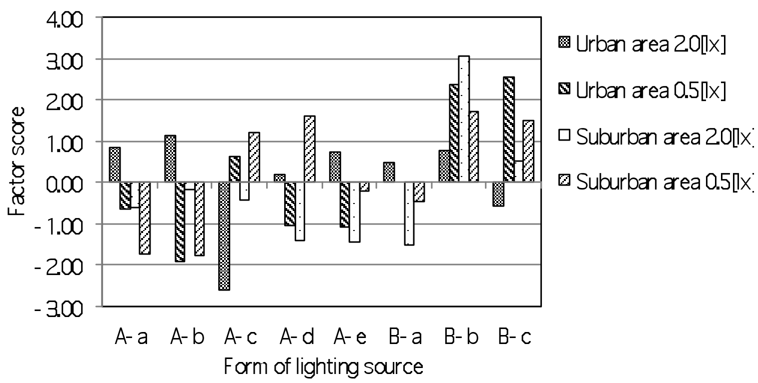

Figure 7: Tertiary factor score for each condition (dramatic)

Primary factors are factors that have been semantically interpreted to be light-influencing. If these factors are highly influential, for the same lighting conditions, the impression evaluations will tend to be higher for adjectives such as “bright, conspicuous, showy, open, dynamic”. Since the factor score for B-c is influenced in the positive direction by the primary factors, regardless of the lighting conditions, this form is thought to impart the impression of being bright, open and dynamic. For other forms, the score differs greatly according to the lighting conditions, and with the exception of B-c, for the same interior lighting illuminance, a higher score was obtained for urban areas than for suburban areas. A-d exhibited the highest score among all lighting forms when the illuminance was 2.0 lx, but the score for A-d became negative when the interior illuminance was 0.5 lx.

Secondary factors are factors that have been semantically interpreted to be space-evaluating. If these factors are highly influential, the impression evaluations will tend to be higher for such adjectives as “elegant, high-class, attractive”. Compared to primary factors, secondary factors exhibit smaller differences among factor scores according to the lighting conditions, with the exception of some lighting forms. In particular, the A-b and B-b lighting forms exhibit high scores regardless of the lighting conditions. Lighting forms A-d and A-c exhibited high scores when the exterior was dark and the interior lighting illuminance was 2.0 lx. On the other hand, lighting forms A-a and B-c exhibited low evaluation scores, and are thought to be forms in which senses of elegance and high-class are impaired.

Tertiary factors are factors that have been semantically interpreted to be dramatic. If these factors are highly influential, the impression evaluations will tend to be higher for such adjectives as “fantasy-like, artificial, dramatic”. Tertiary factor scores vary widely according to the conditions, but lighting forms B-b and B-c exhibit factor scores that are relatively stable. These forms are thought to give the impression of being dramatic and non-ordinary. On the other hand, in cases where the light source is installed on the ceiling, such as A-a, A-b, A-c, A-d and A-e, a tendency for the factor scores to be relatively low is observed.

Next, we examined the relationship between factor scores for two factors under the experimental conditions. As an example, the relationship between primary factor scores and secondary factor scores is shown in Fig. 8. An lighting condition correspondence table is presented in Table 4.

Table 4: Lighting condition correspondence table

Lighting condition	No	Form	Lighting condition	No	Form
Interior illuminance 2.0[lx] urban area	1	A-a	Interior illuminance 2.0[lx] suburban area	18	A-a
	2	A-b		19	A-b
	3	A-c		20	A-c
	4	A-d		21	A-d
	5	A-e		22	A-e
	6	B-a		23	B-a
	7	B-b		24	B-b
	8	B-c		25	B-c
Interior illuminance 0.5[lx] urban area	9	A-a	Interior illuminance 0.5[lx] suburban area	26	A-a
	10	A-b		27	A-b
	11	A-c		28	A-c
	12	A-d		29	A-d
	13	A-e		30	A-e
	14	B-a		31	B-a
	15	B-b		32	B-b
	16	B-c		33	B-c
Urban area	17	None	Suburban area	34	None

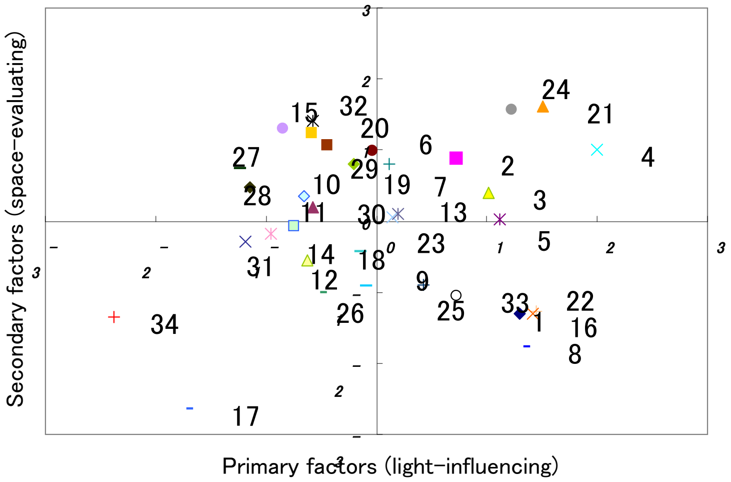

Figure 8: Relationship between factor scores (e.g. relationship between light-influencing factors and space-evaluating factors)

The correlation among factor scores was sought for all combinations of these three factors. Below, each condition is indicated by its classification number (see Table 4).

(1) *Relationship between light-influencing factors and space-evaluating factors*

Both the light-influencing factors and the space-evaluating factors exhibited high factor scores for conditions 24, 21, 4 and 2. The interior illuminance for these conditions was 2.0 lx. The lighting forms were B-b (24), A-d (21, 4) and A-b (2).

(2) *Relationship between light-influencing factors and dramatic factors*

Both the light-influencing factors and the dramatic factors exhibited high factor scores for conditions 16, 33, 2, 1 and 5. The lighting forms were B-c (16, 33), A-b (2), A-a (1) and A-e (5).

(3) *Relationship between space-evaluating factors and dramatic factors*

Both the space-evaluating factors and the dramatic factors exhibited high factor scores for conditions 15, 32, 29 and 2. The lighting forms were B-b (15, 32), A-d (29) and A-b (2).

In all factor score correlations, stable high scores were exhibited by condition 2.

4. EXPERIMENT 2 (PHYSIOLOGICAL RESPONSES TO THE INTERIOR LIGHTING ENVIRONMENT)

4.1. Experimental method

For 30 min, the subjects observed the model automobile interior used in the impression evaluation experiment while electrocardiograms were simultaneously recorded. The subjects consisted of three adult males having no electrocardiogram abnormalities. From the electrocardiogram data, the mean heart rate at 3-min intervals and the LF/HF value, an indicator of sympathetic nervous function, were detected. From previous studies, it is known that HF components (high-frequency components observed in the 0.15- to 0.40-Hz band) are affected by parasympathetic nervous activity caused by respiration, and that LF components (low-frequency components observed in the 0.04- to 0.15-Hz band) are affected by sympathetic and parasympathetic nervous activity. Moreover, the ratio of LF to HF is indicated to increase according to physical and mental loads.

The electrocardiogram data of the present study consists of peak heart rate values measured at a sampling frequency of 2000 Hz. The heart rate R-R interval is measured using BIMUTAS II (Kissei Comtec Co., Ltd., Nagano, Japan) waveform analysis software, and heart rate fluctuation data obtained is sampled at 200 Hz. A Fast Fourier Transform (FFT) is used to perform frequency analyses at 3-min intervals of the 30-min data, and the LF/HF value is computed. From the relationship between the elapsed time and the LF/HF value, we examined whether different mental loads are generated according to the form of automobile interior lighting. A sample electrocardiogram waveform is shown in Fig. 9 and an example of heart rate fluctuation data is shown in Fig. 10. A polygraph system (PEG-1000; Nihon Kohden Corp., Tokyo, Japan) was used for the electrocardiogram measurements. Ag/AgCl electrodes were attached, and the bipolar chest lead method was used.

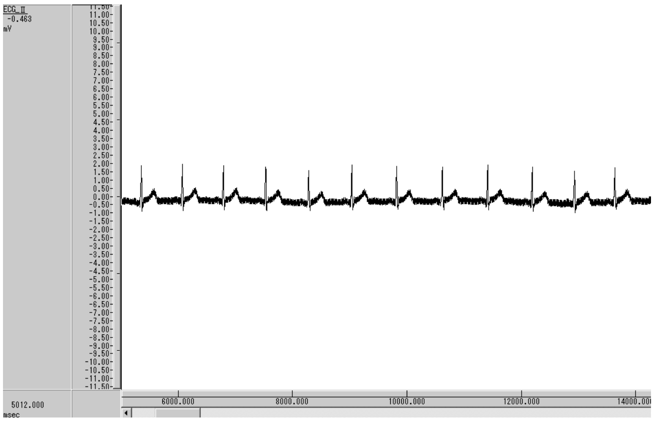

Figure 9: Electrocardiogram waveform example

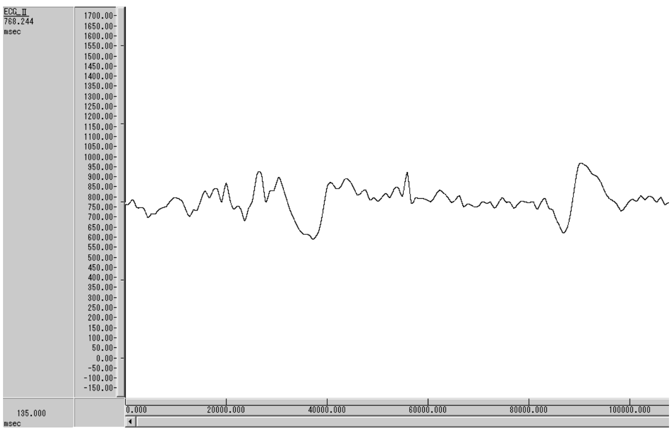

Figure 10: Heart rate fluctuation data example

4.2. Experimental conditions

The light source forms comprised the four conditions of A-b, B-b, A-d and none, for which the evaluation results of experiment 1 were comparatively clear. Moreover, to eliminate influence from the exterior lighting environment as much as possible, suburban areas were used uniformly as the exterior lighting environment condition.

4.3. Experimental results

Experimental results of the mean heart rate and elapsed time are shown in Fig. 11, and the LF/HF values computed from the electrocardiogram data are shown in Fig. 12.

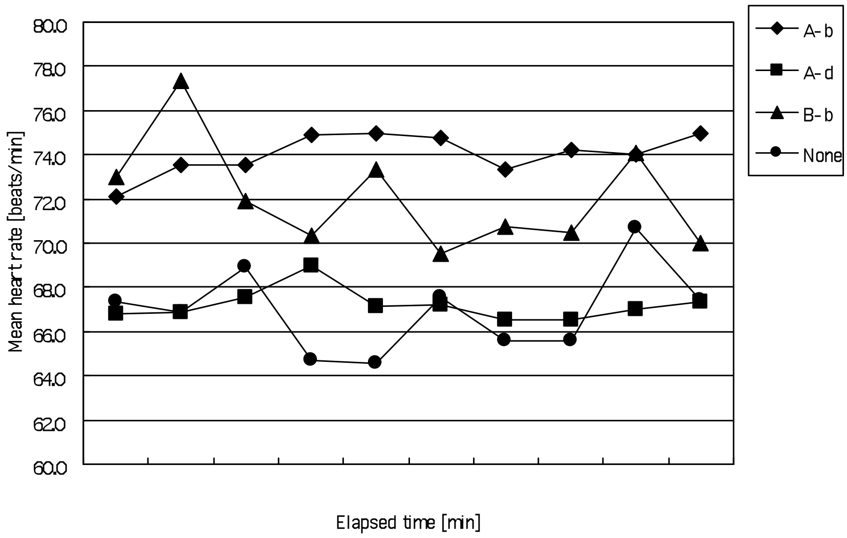

Figure 11: Relationship between automobile interior lighting form and mean heart rate

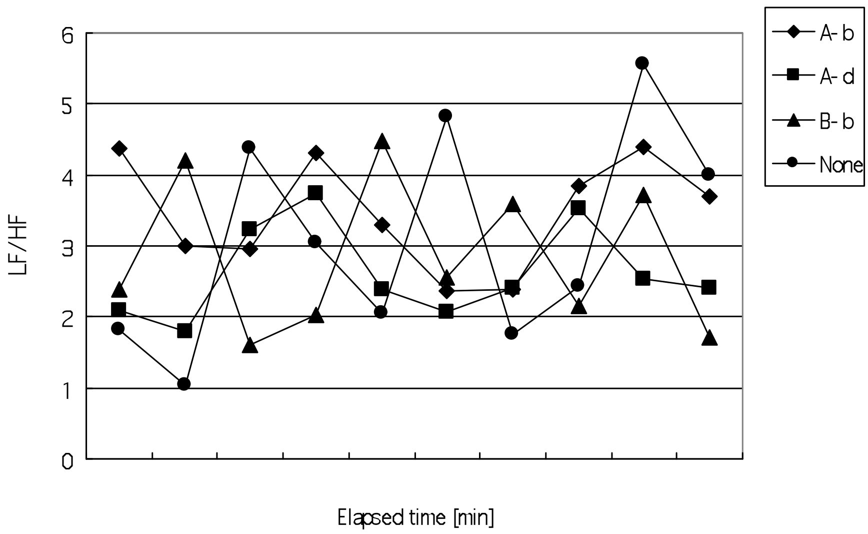

Figure 12: LF/HF value measurement results

In Fig. 11, it can be seen that the mean heart rate is highest for the A-b form, and that the next highest mean heart rate is for the B-b form. The A-d form and the condition of no lighting exhibit similar trends.

As shown in Fig. 12, for each lighting form, the LF/HF value fluctuates significantly according to the elapsed time. We attempted to examine median values extracted from the subject data, but were unable to interpret differences in trends of LF/HF values and elapsed time according to the lighting form.

4.4. Analysis and discussion

To examine the effect of differences in the lighting forms and elapsed time on the mean heart rate, we performed a three-way layout analysis of variance with the following three factors: form (4 levels), elapsed time (10 levels), and subjects (3 levels). The analysis results revealed that the mean heart rate value in a 3-min interval was significantly affected by the subject (factor A) and lighting form (factor C) (factor A: $F(2,54)=193.82$, $p=2.28\text{E-}25<0.01$, factor C: $F(3,54)=54.6$, $p=2.30\text{E-}16<0.01$). Moreover, for factor B (elapsed time) × factor C, the effect of interaction was found to be significant (interaction B×C: $F(6,54)=19.08$, $p=8.83\text{E-}12<0.01$).

Since the interaction effect between B × C was found to be significant, it is not possible to refer to the main effects of factor B and factor C on mean heart rate. However, the mean heart rate was clearly affected by the interaction between the lighting form and the elapsed time. This result seems to suggest that the mean heart rate may be affected by the lighting form. In a comparison of mean values, a tendency for the heart rate to increase was observed in the case of a linear light source arranged in parallel to the forward direction of the automobile. A linear light source has a smaller light source area than other light conditions, and therefore to achieve a uniform illuminance of 2.0 lx at the third row of seats in the interior, the luminance of the light source area is increased. Consequently, the presence of a high intensity area within the field of view is thought to increase the physical stimulation (eyes and/or brain) and potentially elevate the arousal level.

The LF/HF value was analyzed in the same way as the mean heart rate, but no difference in levels was observed according to the form factor. Therefore, the mean LF/HF values were determined for the first 15 min and the second 15 min, and then reexamined. The results are shown in Fig. 13(a) and (b).

In the results for mean LF/HF values and rate of change at 15-min intervals, a tendency for the LF/HF value to increase was observed for the condition of no interior lighting. No significant changes in the 15-min-interval LF/HF values were observed with other lighting conditions. Because the LF/HV value was observed to increase with elapsed time only in the case of no lighting, these results suggest that it may be possible to prevent a rise in the LF/HF value by turning on the lighting.

When the lighting is not turned on, the illuminance of the entire interior of the automobile will be at a low level, and therefore the visual load is thought to be greater in the case where the lighting is turned on. The results, however, show a tendency for the LF/HF value to increase only in the case of no lighting. Consequently, it is thought that mental stress (boredom) might be generated when the quantity of visual information is small.

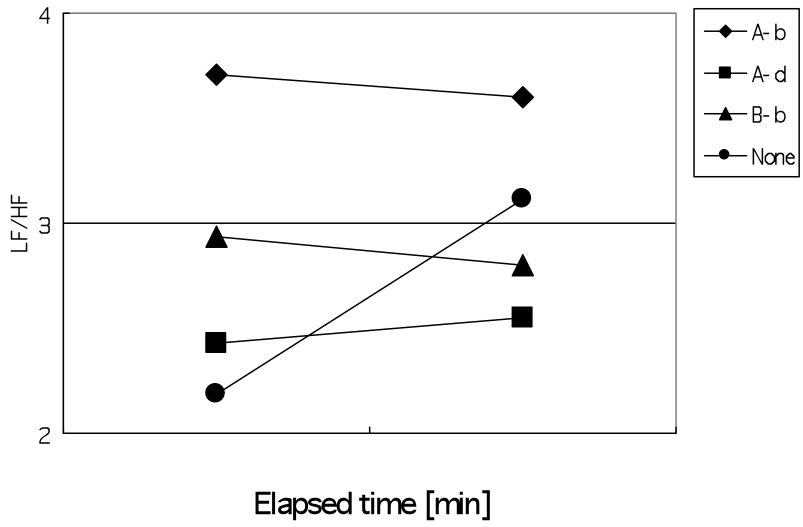

Figure 13(a): Mean LF/HF values for 15-min intervals

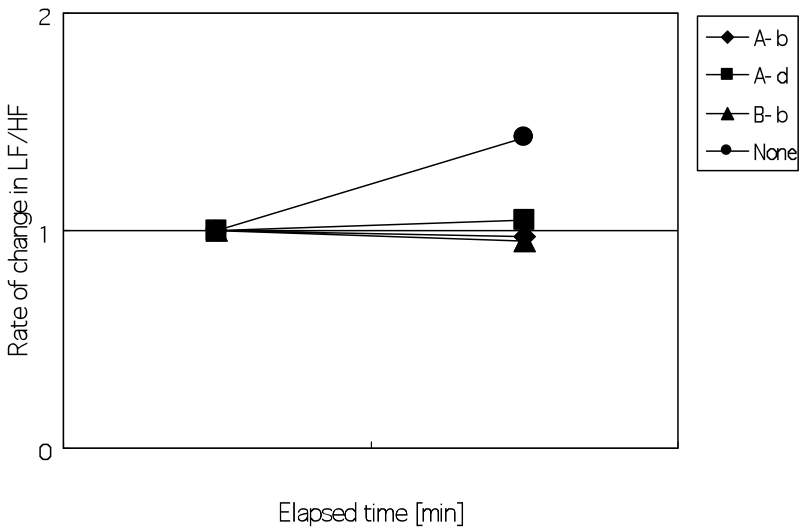

Figure 13(b): Rate of change in mean LF/HF values for 15-min intervals

5. CONCLUSION

5.1. Experiment 1: Impression evaluation experiment for the interior lighting environment

Of the 32 pairs of results in the impression evaluation experiment, factor analysis was performed on the scores for 30 adjective pairs (excluding emotional-intellectual and frivolous-profound), and the structure of the impression evaluation of the automobile interior was clarified. The results of the analysis indicate that three latent factors can be defined to explain 81% of the automobile interior impression evaluations. The findings for each factor are summarized below.

(1) Light-influencing factors

- The “light-influencing” capability is highly correlated with such evaluation results as “bright, conspicuous, showy, open, dynamic”, and is closely linked to the total amount of light in the automobile interior due to interior illuminance and exterior illuminance.

- The lighting form B-c exhibited high factor scores that were stable regardless of the lighting conditions. At a 2.0 lx, the highest factor score was obtained with lighting form A-d.

(2) Space-evaluating characteristics

- “Space-evaluating factors” are factors that are highly correlated with such evaluation results as “elegant, high-class, attractive”.

- The relationship between “space-evaluating factors” and the interior illuminance or the exterior illuminance is weaker than in the case of the “light-influencing factors,” but the “space-evaluating factors” are closely linked to the lighting form.

- The lighting forms A-b and B-b exhibited high factor scores regardless of the lighting conditions, while lighting forms A-c and A-d exhibited high factor scores when the interior illuminance was high.

(3) Dramatic properties

- “Dramatic factors” are factors that are closely correlated to such adjective groups as “fantasy-like, artificial, dramatic”.

- The lighting forms B-b and B-c exhibited factors scores that were stable and high.

- Lighting forms A-a, A-b and A-e tended to exhibit highly negative factor scores.

5.2. Experiment 2: Measurement of physiological responses to the interior lighting environment

- Higher heart rates tend to be exhibited for linear vertical lighting forms (-b group) than in the case of the A-d lighting form (light emitting from the ceiling) or in the case of no lighting.

- Mean LF/HF values measured for 30 min were determined for an initial 15-min interval and a subsequent 15-min interval, and the results indicate an increase in the LF/HF value only in the case of no lighting.

Future studies must include experiments while varying the light source pattern, interior illuminance, light source color temperature and other factors, as well as investigations of the accompanying physiological responses to these variations in greater detail.

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