Visibility Study on Design Pattern of Car Tail Lamp Using Perceptual Sensitivity on Face Recognition Abilities

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Abstract—**In recent years, there has been concern about collision accidents involving vehicles driving at nighttime. In order to prevent such accidents from occurring, it is necessary to develop tail lamps with high visibility. In our study, we examined how differences in tail lamp design affect visibility with a view to developing a tail lamp design that offers better visibility, thereby enhancing safety. Focusing on visibility in human face recognition, we conducted an impression-rating test and visual search task using rear shots of vehicles. The results revealed that a human's impression of a rear shot of a vehicle is structurally similar to their impression of a face, and that the tail lamp design affects search time.**

I. Introduction

There has been a growing demand in recent years for preventive safety technology designed to prevent or mitigate accidental damage; for example, automatic emergency braking (AEB) systems. In the EU, AEB became mandatory for all newly launched commercial vehicles in 2013[1]. It is expected that not only AEB mitigating accidental damage but various other preventive safety technology, such as airbags, will become a mandatory international standard.

Against this backdrop, we aimed to propose a rear design for vehicles that offers high visibility with a view to preventing or mitigating rear-end collisions. To this end, we focused on how humans react specifically to the face of another human. Research has shown that an angry expression is detected quicker than a happy expression. It would therefore be possible to create a high visibility rear design by incorporating the perceptual superiority of a human's angry expression into the design - particularly that of the tail lamps where increasing use of LED's is creating greater design freedom - and thus enable the prevention of rear-end collisions.

II. Preceding Research

Regarding the research on visibility, there have been many studies on visual displays such as revealed characters and markers /signs. Visibility of the character displays has been assessed primarily in terms of readability, and discussions have focused on the influence of character size, luminance, and color, and their relationship with the reader's age or recognition characteristics. For example, using a mock driving scenario in which LED signs of varying colors were shown to participants, Yamamoto et al. investigated how reaction times and the way in which colors are seen varied between the different colors[2]; and Oda et al. investigated the various luminous intensities and installation positions of attention-arousing visual guide lights[3]. Both studies were conducted more from a practical perspective than an academic perspective. There have been a number of studies on the influence of environment and the influence of color; such studies have approached the intrinsic "visibility" of visual signs primarily from a visibility perspective. For example, Iizuka et al. examined color perception in heavy fog[4]. Tests were conducted using a fog generator, and the results demonstrated that the luminosity and color intensity of the apparent color declined in tandem with increasing fog concentrations. Visual displays have been used to examine the visual conspicuity of LED lights. Such research has demonstrated that the influence of color is greater at night compared to day. Research has also shown that in their peripheral vision, humans are good at recognizing the presence of blue lights and the shape of red lights. There has been a plethora of research on the conspicuity of different colors or combinations of colors[5][6], but none of these conspicuity studies focused on LED placement patterns or design.

On the other hand, with regard to research on human face recognition, a study examined the recognition characteristics humans exhibit when looking at a face and those when looking at another object, and it was reported that the cerebral activity is different in each case[7]. In fact, one study which used Event-Related Potentials (ERP) to compare the cerebral activity during face recognition and object recognition reported that N170, an ERP component that responds over occipito-temporal electrode sites around 170 ms after stimulus presentation, responded significantly. The study also reported an inversion effect only in response to a face stimulus[8]. Morton and Johnson proposed two cognitive models, CONSPEC and CONLERN, which explain the human face-specific response from a developmental psychology perspective[9]. CONSPEC is an instinctual cognitive system that guides the recognition of the basic human face structure found in newborn infants. The above findings suggest the possibility that when viewing a vehicle rear design that elicits the instinctual face recognition, the recognition characteristics would tend to be similar to that when viewing a face. Furthermore, Ohman et al. conducted tests where participants were asked to rate their impression of visual stimuli consisting of simple schematic faces with modifications to individual features (shape of eyebrows, eyes and mouth, direction of gaze, etc.) Based on the results, Ohman et al. drew up a schematic face recognition model[10]. In this model, they categorized faces with negative features as “threatening,” and faces with more symmetrical features as “friendly faces.” They then set participants a visual search task using the facial schematic stimuli. The results indicated that search times were shorter when viewing threatening facial stimuli which convey feelings of anger, compared to friendly face stimuli. This finding demonstrated the perceptual superiority of angry expressions[11]. In view of the above findings, we posited the hypothesis that an anger-evoking vehicle rear design, particularly with respect to the positioning of tail lamp LED’s, will have high visibility. To validate this hypothesis, we set an subjective evaluation experiment and visual search task using vehicle rear designs as stimulus material.

III. Subjective Evaluation Experiment of Rear Design

The purpose of this study was to experimentally examine and then propose a highly visible vehicle rear design. To this end, it was necessary to investigate people’s impression structure with respect to vehicle rear designs. We therefore conducted tests focusing on the emotions associated with various vehicle rear designs. In this chapter, we describe four tests that we conducted to build the impression structure.

A. Test 1: Impression Word Extraction Test

1) Purpose: To build an impression structure, it is necessary to use a range of impression words (adjectives) for rating/describing vehicle rear designs. Therefore, by means of a free descriptive answer-based questionnaire, we collected a variety of impression words rating vehicle rear designs, particularly tail lamp designs.

2) Method: The test was conducted on five university students in their 20’s (mean age: 23.0; age range: 22-24). For the stimulus material, we prepared 3DCG images based on vehicle rear design images. If we had used photographed images, the participants may have formed a judgment based not only on the tail lamp but on the entirety of the vehicles morphological elements. Therefore, in order to simulate a nighttime driving scenario, we dimmed the luminosity of morphological elements outside the tail lamps so that participants would focus on the tail lamps while maintaining recognition of the overall rear design. Regarding the procedure for preparing the stimulus material, in order to obtain contemporary impression words, we gathered 70 photographed images of newly launched vehicles, selected from this pool 10 apparently typical tail lamp designs, and then prepared 10 3DCG images based on these photographs. The ten 3DCG images we prepared are shown in Figure III-D1.

The participants were asked to write down their impression of this stimuli in a free descriptive format.

3) Results: We extracted 235 impressions words. We then eliminated words with overlapping meaning, which left 125 words. We then divided these 125 words into two categories:

(a) Sample A (b) Sample B (c) Sample C (d) Sample D (e) Sample E

(f) Sample F (g) Sample G (h) Sample H (i) Sample I (j) Sample J

Fig. 1. 3DCG Images of Rear Designs

words describing the participants’impressions of the design of the tail lamp or vehicle, and words describing the emotion conveyed by the tail lamp design. As the focus of the study was on the emotions conveyed by tail lamp design, we eliminated the words in the former category.

4) Discussion: The test results demonstrated that when giving their ratings, the participants were comprehensively assessing a variety of information, including the shape of the tail lamps, their position, and the distance between the left and right tail lamp. The results also yielded a plethora of impression words, ranging from words describing the shape of tail lamps such as “big,” “round,” “spaced far apart,” to words describing the emotion associated with the shape such as “smiling,” “in a good mood,” and “sad-looking.”

B. Test 2: Impression Word Appropriateness Test

1) Purpose: Using the impression words obtained from the previous test, we conducted a test to obtain words that would be appropriate to use for rating tail lamps.

2) Method: The test was conducted on ten university students in their 20’s (mean age: 22.8; age range: 22-24). We used a total of 106 words for this test, including the words yielded from the impression word extraction test as mentioned previously, and also words taken from preceding research on people’s impression of schematic faces and vehicles.

The participants were shown the words in a random order and they were asked to rate each word in terms of whether or not it fits their impression of tail lamps. The participants rated each word on a seven point scale (1: Very inappropriate; 2: Inappropriate; 3: Rather inappropriate; 4: Not sure either way; 5: Rather appropriate; 6: Appropriate; 7: Very appropriate). When briefing the participants about the content of the test, we presented them with the ten 3DCG images in Figure III-D1 as specific examples of vehicle design.

3) Results: The ratings were scored as follows: “1: Very inappropriate” = -3 points; “2: Inappropriate” = -2 points; “3: Rather inappropriate” = -1 point; “4: Not sure either way” = 0 points; “5: Rather appropriate” = 1 point; “6: Appropriate” = 2 points; “7: Very appropriate” = 3 points. As for the criteria we used to qualify rating words, we decided that we would adopt words with mean score of 1.0 or higher and a standard deviation of less than 1.5. Based on these criteria, we ultimately adopted 49 words as “rating words.” Table 1 lists the rating words.

4) Discussion: By conducting an impression word extraction test and then an impression word appropriateness

TABLE I
ADOPTED IMPRESSION WORDS

Impression Word	Average	SD	Impression Word	Average	SD
arrogant	2.8	0.42	gloomy	1.5	1.18
dubious	2.3	0.48	friendly-looking	1.9	1.20
majestic	2.4	0.52	offensive	2.2	1.23
bad-tempered	2.5	0.53	smiling	2.2	1.23
frowning	2.5	0.53	odd	2	1.25
weird	2.5	0.53	surprised	1.6	1.26
smirking	2.2	0.63	relaxed	1.6	1.26
pudgy	1.7	0.67	expressionless	1.6	1.26
uneasy	2.4	0.70	warm	1.2	1.32
slight smile	2.4	0.70	calm	1.8	1.32
craggy	2.9	0.74	oppressive	2.2	1.32
angry	2.9	0.74	amiable	2	1.33
severe	2.9	0.74	lonely	1.3	1.34
unnatural	1.9	0.74	impressive	2.3	1.34
sullen	2.6	0.84	joyful	1.6	1.35
acrimonious	1.4	0.84	confident	1.1	1.37
strange	2.1	0.88	sad-looking	2	1.41
glaring	1.9	0.88	sleepy	1.6	1.43
stupid	2.2	0.92	strict	1.5	1.43
easeful	1	0.94	in a good mood	1.1	1.45
unconfident	1.7	0.95	pleasant	1.9	1.45
scary	2.6	0.97	beaming	2	1.49
clumsy	2.1	0.99	stiff	1.3	1.49
grinning	2.2	1.03	slender	1.7	1.49
cold	1.7	1.06			

test, we extracted from a diverse pool of impression words diverse and valid rating words that would be appropriate for rating/describing tail lamps.

C. Test 3: Rating Word Distance Measurement Test

1) Purpose: In order to systematically ascertain the various psychological states involved in impressions of tail lamps, we estimated the impression structure of tail lamps by focusing on the distances between these rating words extracted from the previous two tests. We used degree of similarity to calculate the distances between the rating words, and we used a cluster analysis on groups of analogous rating words. In this way, we determined "key words" to use in the subjective evaluation experiment.

2) Method: The test was conducted on ten university students in their 20's (mean age: 23.0; age range: 22-24).

We presented the participants with pairs of rating words and asked them to rate, using a two-point scale, whether the words accurately represented their impression of tail lamps. We presented the participants with the ten 3DCG images in Figure 3 as specific examples of tail lamps. Each of the 49 image rating words extracted from the impression word extraction test and impression word appropriateness test were paired with all the other words in a round-robin fashion, making a total of 1,176 rounds.

3) Analysis: If the rate at which a given word *i* is judged to convey an analogous impression is deemed the concordance rate R_i, this concordance rate may be used to express the degree of similarity X_i of given word *i* with other words in 49 vectors as shown in Formula (1) below.

$$X_i = (R_{i1}, R_{i2}, \cdots, R_{i49}) \tag{1}$$

Furthermore, psychological distance D_{ij} from rating word j can be defined according to the formula below.

$$D_{ij} = \sqrt{\frac{1}{49}\sum_{k=1}^{49}(R_{ik} - R_{jk})^2} \tag{2}$$

We performed multi-dimensional scaling (MDS) using the two variables defined above, interpreted the impression structure of tail lamp visually, and also performed a Ward's method-based hierarchical cluster analysis on the rating word group used in the study. In this way, we determined the key words.

4) Results: Using MDS with *D* (psychological distance) as the variable, we mapped the rating words on a two-dimensional plane. The results of this mapping are shown in Figure 2.

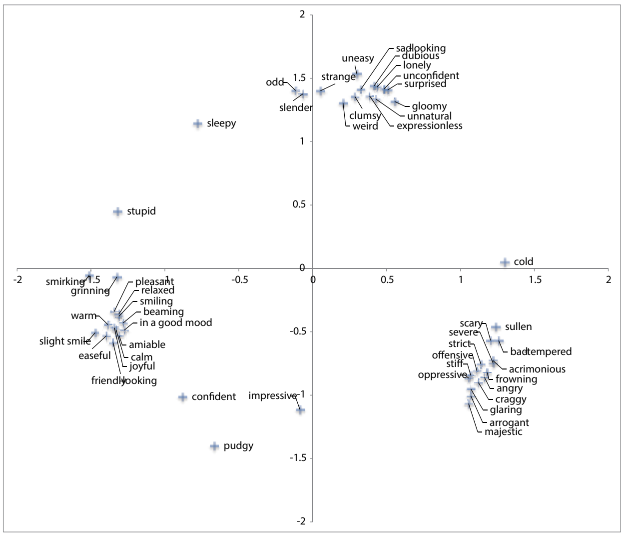
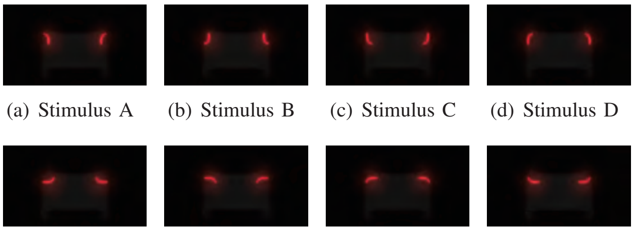


Fig. 2. Mapping of Rating Words

5) Discussion: Looking at the horizontal axis, "angry," "sullen," and "bad-tempered" have high values, whereas "smiling," "slight smile," and "friendly-looking" have low values. Based on this finding, we surmised that the horizontal axis is a scale of comfort (comfortable - uncomfortable). Furthermore, given that when at the same time looking at the vertical axis, "sad-looking," "surprised," and "weird" have high scores, we surmised that the vertical axis is a scale of activity (high - low). These axes are typically seen in the results of general research about human emotion, which implies that our test results have validity.

Next, in order to determine the key words, we performed a hierarchical cluster analysis (Ward's method) and hierarchically categorized the 49 rating words. Using the resulting hierarchical structure, we determined the number of clusters. The criteria for determining the appropriate number of clusters was that the analogous rating words in each cluster should have no semantic incongruity and that they should be as consistent as possible. Following this procedure, we categorized the 49 words into three clusters. We named the cluster containing words such as "smiling," "relaxed," and "pleasant" the "happy cluster." We named the cluster containing words such as "arrogant," "glaring," and "majestic" the "angry cluster." Finally, we named the cluster containing words such as "odd," "slender," and "sad-looking" the "sad cluster."



(a) Stimulus A (b) Stimulus B (c) Stimulus C (d) Stimulus D

(e) Stimulus E (f) Stimulus F (g) Stimulus G (h) Stimulus H

Fig. 3. Recreated Stimulus Material

We then selected 15 words from among these three clusters to use as key words. We defined "key word" as a rating word that can encapsulate/cover the semantic space of its cluster. Accordingly, we calculated the distance of each rating word from the center of its cluster, sorted the words in order of closeness to center, and adopted the words that were in the top three rankings in their each cluster. In addition, we performed a principal component analysis (PCA) on the rating words within each cluster, and adopted (in addition to top 3 words) the highest and lowest values in the first principal component axis (PC1). When doing so, we performed an outlier detection test based on Mahalanobis distance, and removed from the pool of candidate key words rating words judged to be outliers. Table 2 shows the adopted key words in each cluster.

TABLE II
THE SELECTED KEY WORDS

	Happy cluster	Angry cluster	Sad cluster
Close to centroids	pleasant	strict	expressionless
	smiling	severe	dubious
	joyful	acrimonious	sad-looking
Max PC1 score	friendly-looking	majestic	gloomy
Min PC1 score	smirking	bad-tempered	weird

D. Test 4: Subjective Evaluation Experiment

1) Purpose: Test 4 was designed to clarify the tail lamp impression structure derived from a specific constituent element of a vehicle rear design, namely, tail lamp shape using the key words determined in Tests 1, 2 and 3. Therefore, we conducted subjective evaluation experiment based on the 3DCG images as shown in Figure , but controlling for the morphological elements outside the tail lamp. The aim in doing so was to determine the stimulus material to use in the visual search task described in the next chapter.

2) Method: The test was conducted on 20 university students in their 20's (mean age: 22.2; age range: 20-24).

We recreated stimulus material, focusing on the curvature of the tail lamps. Specifically, we made a total of eight rear designs. We based these designs on tail lamp shapes, and we only modified them by changing the direction of the convex side. In addition, in order to increase the focus on tail lamp shape, we eliminated curvature in parts outside the tail lamps and darkened the areas outside the tail lamps. The eight designs we used for the stimulus material are shown in Figure 3. These stimuli were presented in an LCD monitor 1.6 meters away from the participants. We set the size of the presented images such that the participants would view the vehicle as if it was 30 meters away from them. This is the stopping distance of a vehicle travelling at 60km/hour on a dry asphalt road.

The test was conducted in a darkened room, and the stimulus material was presented on an LCD monitor (EIZO ColorEdgeCG210). The LCD monitor was recalibrated for each test.

The participants were shown the images in a random order, and they were asked to rate how accurately each of the 15 key words describe the image shown. The participants rated each word on a seven point scale (1: Very accurate; 2: Accurate; 3: Rather accurate; 4: Not sure either way; 5: Rather inaccurate; 6: Inaccurate; 7: Very inaccurate).

3) Results: We took the mean scores for the 15 persons and performed factor analysis based on the principal factor method and varimax rotation. The criteria for deciding the number of factors was set at 1 or over of eigenvalue. Table 3 shows the factor loadings for each adjective as per the factor analysis. According to the factor analysis, the cumulative contribution ratio is 81.070%, and the eigenvalue is 1.045 for the total factors/variables up to Factor 3.

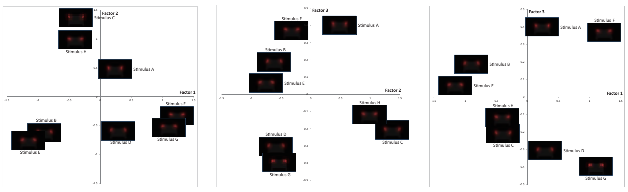
TABLE III
FACTOR ANALYSIS RESULTS

Key words	Factor 1	Factor 2	Factor 3	Factor 4
smiling	**.896**	-.295	.016	.012
pleasant	**.866**	-.246	-.105	-.169
smirking	**.861**	-.291	.117	.026
joyful	**.833**	-.320	-.093	-.047
sad-looking	**-.720**	-.221	.150	.235
friendly-looking	**.624**	-.317	-.481	.221
majestic	-.133	**.921**	.017	.040
strict	-.199	**.897**	.040	.029
acrimonious	-.099	**.798**	.085	-.053
severe	-.343	**.754**	.225	.057
bad-tempered	-.579	**.601**	.224	-.108
weird	.030	.042	**.791**	.011
dubious	.029	.256	**.708**	.027
gloomy	-.396	-.085	**.616**	.134
expressionless	-.070	.021	.044	**.534**

4) Discussion: We interpreted the factors as follows. We determined that Factor 1 is "happy," given that the factor loadings for "smiling, "smirking," "pleasant," and "joyful" were high, at .600 and over. We determined that Factor 2 is "angry," given that the factor loadings for "strict," "acrimonious," "severe," "majestic," and "bad-tempered" were high. We determined that Factor 3 is "scary," given that "suspicious," "weird," and "gloomy" were high. As for Factor 4, it only consisted of "expressionless," and so we deemed it an independent variable.

Next, we plotted the three factors as two-dimensional graphs and then mapped the stimulus material on these graphs in order to determine the impression structure of vehicle tail lamps (see Figure 4).

According to the scatter plot with Factor 1 as the x-axis and Factor 2 as the y-axis, the rear designs that have high Factor 2 scores, specifically, "strict," "acrimonious," and "severe," are the designs shown in Stimulus C and Stimulus G. This finding



(a) Factor 1 by Factor 2 (b) Factor 2 by Factor 3 (c) Factor 1 by Factor 3

Fig. 4. Factor Scores for the Stimuli

reveals that tail lamp designs in which the convex side faces outward or downward create an impression of anger.

Next, according to the scatter plot with Factor 1 as the x-axis and Factor 3 as the y-axis, the rear designs that have high Factor 1 scores, specifically, "smiling," "pleasant," and "joyful," are the designs shown in Stimulus F and Stimulus G. Stimuli F and G both have high Factor 1 scores, but the Factor 3 scores are either positive or negative depending on whether the convex side is facing inward or outward. Figure 5 presents a summary of how factor scores depend on direction of convex side.

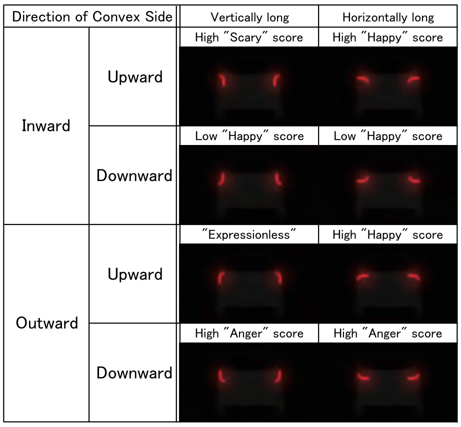


Fig. 5. Differences in Impression depending on Direction of Convex Side

Based on these results, we determined the rear design images (key images) to use in the visual search task discussed in the next subchapter (see Figure 6).

(a) Happy (friendly) face (b) Angry (threatening) face (c) Expressionless face

Fig. 6. Key Images

In our selection of the key images, we selected Stimulus G as a "happy (friendly) face," Stimulus H as an "angry (threatening) face," and Stimulus D as an "expressionless face."

IV. Visual Search Task

A. Purpose

We set a visual search task using the key images that we selected as described in the previous chapter. The purpose of the task was to verify whether reaction time is affected by the emotion evoked by the stimulus material.

B. Method

The test was conducted on nine university students in their 20's (six males, three females; mean age: 21.7; age range: 20-24)

The stimulus material comprised the three types of key images. Of these, we used the expressionless face as the distractor, and the friendly face and threatening face as the targets. We set an image (hereinafter, "visual stimulus") consisting of points directing in a circle subtending $3.44°$ visual angle centered around the fixation point, along which the key images would be positioned. Figure 7 shows a target-present stimulus, in which one of the key images within the visual stimulus is the target, and a target-absent stimulus, which is entirely comprised of distractors.

(a) Target-absent Visual Stimulus (b) Target-present Visual Stimulus

Fig. 7. Visual Stimuli

The participants were required to answer as quickly as possible (by pressing a response key) whether or not the target appears within the visual stimulus they were presented with. We instructed the participants to press the response key with the index finger of their dominant hand as quickly and as accurately as possible. We randomized and counterbalanced the left-right allocation of the response key among the participants.

There were 240 rounds each for the target-present stimulus and target-absent stimulus. In the case of the target-present stimulus, there were six potential positions where the target could appear. Because there were two types of target (friendly face and threatening face), it was possible to obtain measurements for 20 rounds of a single visual stimulus per participant. We presented the visual stimulli in a random order. Figure 8 shows the actual procedure in the test.

We set the size of the key images shown on the monitor so that when viewed from 1.2 meters from the monitor, they would correspond to the size of actual vehicles 30 meters ahead. We also used a chin support to control physical movement. The test was conducted in a darkened room, and the stimulus material was presented on an LCD monitor (EIZO ColorEdgeCG210). The LCD monitor was recalibrated for each test.

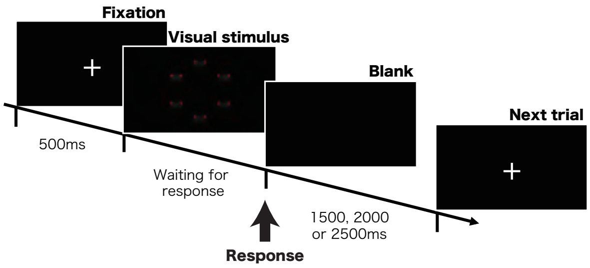
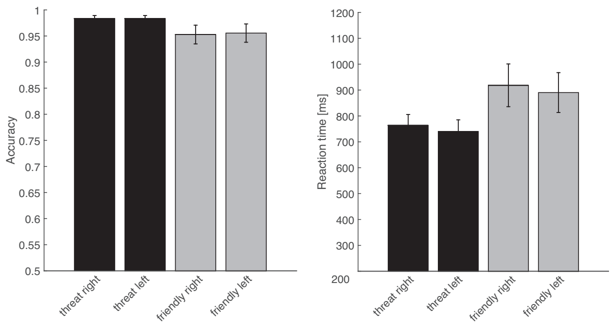


Fig. 8. Experiment Procedure

After being briefed, the participants waited in the darkened room for five minutes so that their eyes would grow accustomed to the dark, undertook a practice session consisting of 24 rounds, and then undertook the actual test. To limit the burden on the participants, we set a rest period after the 240th round.

C. Results

The results of the test are shown in Figures 9. Regarding values that pertain to improper/defaulted rounds or to rounds where the reaction time was 3SD or more from that participant's mean reaction time, we deemed such values as abnormal values and excluded them from the analysis (excluded round rate = 1.94%).



(a) Response Accuracy (b) Response Time

Fig. 9. Experimental results

We subjected each of the results obtained to a two-factor repeated measures ANOVA in which the two factors were target type and target position.

With regard to response accuracy, the ANOVA did not indicate any statistically significant results for either factor. With regard to response time, the ANOVA indicated a main effect for target type ($F(1,8) = 9.738$, $p < .005$) but not for target position, and it did not indicate an interaction effect.

D. Discussion

Looking at response accuracy, the fact that there were no statistically significant results for either factor demonstrates that in this visual search task, there was no discrepancy in difficulty level among the target types or among the target positions. With regard to response time on the other hand, given that there was a main effect of target type, the results imply that in vehicle rear designs, an angry expression has perceptual preeminence as is the case with human faces.

V. Conclusion and Future Outlook

In this study, we examined how visibility varies according to differences in rear design in order to enhance motoring safety. We conducted tests with a view to proposing a tail lamp design that offers better visibility. Specifically, focusing on perceptual sensitivity in human face recognition, we conducted an subjective evaluation experiment and visual search task using images of vehicles.

The results revealed that a human's impression of a rear design of a vehicle is structurally similar to their impression of a face, and that the tail lamp design affects search time. The results also revealed that when a tail lamp design conveys an angry expression, the response time will be shorter compared to tail lamp designs that convey other expressions. This finding suggests that a vehicle tail lamp will have better visibility if it evokes angry emotion.

An ongoing challenge concerns the design of the visual stimulus used in visual search task. In particular, it will be necessary to further examine the influence of the morphological elements of rear design constituents other than the tail lamps. Furthermore, we plan to verify the validity of our hypothesis by using physiological indices in addition to behavioral indices such as response time.

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