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Paper:

Using Brainwaves and Eye Tracking to Determine Attention Levels for Auto-Lighting Systems

Junzo Watada, Yung-Chin Hsiao, and Hanayuki Kitagawa

Graduate School of Information, Production, and Systems, Waseda University
2-7 Hibikino, Wakamatsu, Kitakyushu 808-0135, Japan
E-mail: junzow@osb.att.ne.jp, eugene@triz.tw, kitagawa.hanayuki@yahoo.co.id

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To prevent car accidents, it should be possible for pedestrians and other drivers to detect oncoming vehicles. Many car accidents are caused because persons are not aware of approaching traffic, and this applies especially to visual awareness. The daytime running light (DRL) and the third braking light (TBL) were developed to significantly increase the visibility of vehicles, and their effectiveness has been verified through numerous studies. Usage of light-emitting diode (LED) lighting technology has also become popular in auto-lighting systems because of its advantages of energy efficiency, long life, and stylish appearance. However, LED lighting technology is very different from conventional incandescent or high-intensity discharge (HID) lighting technology. In this paper, we determine the effectiveness of LEDs as DRLs and TBLs. We measure human attention levels by observing brainwaves and performing eye-tracking experiments that shows the relationship between the theory of attention, brainwaves, and eye tracking. The results obtained show that it is feasible to evaluate automotive exterior lighting using the attention levels of subjects.

Keywords: eye tracking, brainwave, third braking light, daytime running light, light-emitting diode

1. Introduction and Motivation

Historically, the development of exterior lighting systems for automobiles has focused on the function of lighting systems as safety devices that illuminate the road. These lighting systems include headlamps, indicators, which signal a driver's intention to make a turn, brake lights, which indicate that the car is slowing down, hazard lights, which indicate danger, and tail lights, which are used as a reference for drivers that are behind a vehicle. The performance of these functions was subsequently improved with the development of daytime running lights (DRLs), third braking lights (TBLs), and adaptive lighting. The designs of these lighting systems have also been used to enhance the brand identity of some models of cars, which is sometimes a selling point, e.g., BMW vehicles have four round headlights and Mercedes Benz vehicles have oval-shaped headlamps. The TBL is relatively new in the automotive industry. Traditionally, all brands of vehicles have had only two dim tail lights. The TBL was not invented until the 1970s, when a psychologist conceptualized the idea of including a high mounted center brake light that would more effectively attract the attention of the driver in the vehicle behind [1, 2]. Nowadays, the TBL is a legal requirement on all vehicles worldwide. The DRL originated from a campaign in 1961 to turn on headlamps during the daytime in order to indicate the driver's intention to comply with the Texas governor's request to drive safely [3]. During the early years of its implementation, there were both advantages and disadvantages associated with the use of DRLs, which was aimed at reducing the number of car accidents. For example, DRLs were introduced in Scandinavian countries during the 1970s. In those countries, weather conditions do not always provide an environment with adequate lighting. This results in some drivers having difficulty detecting oncoming vehicles. In this scenario, DRL has proven to be useful. However, in North America, while there is often good weather with adequate lighting, DRL may not be as effective. The result of the latter study has concluded that DRL can improve the "clarity" sight of a driver by increasing the contrast between vehicles and the background during the day time. In addition, DRL makes it easier for pedestrians to detect approaching vehicles while they are still some distance away. Vehicles with DRL can also be more easily recognized by other vehicles, especially those coming from the opposite direction. DRL can be automatically activated when the engine is switched on. According to government regulations, low beam, high beam, or fog lamp settings can be dimmed while functioning as DRLs. While this approach to DRL is inexpensive and requires no additional lighting equipment, the glare problem remains a concern. In 2011, the EU countries set DRL as one of the standard vehicle safety devices after the introduction of LED lighting systems resulted in reduced glare for DRL. However, the use of DRLs has not been mandated by law as a standard safety device in all developed countries, e.g., DRL is optional in the United States [3–5]. The major improvements in the functional performance of TBL and DRL may be attributed to recent technological developments involving light sources, which have evolved from kerosene burners, incandescent bulbs, high-intensity

Table 1. Sight distances for road design.

Design speed	Intersection sight distance	Overtaking sight distance
40 km/h	80	160
60 km/h	120	220
80 km/h	170	340
100 km/h	230	480

discharge (HID) lamps, light-emitting diodes (LEDs), and lasers. Different light sources have their own technology and physical limitation with respect to their illumination and the color temperature, which limits their application on automobile lighting systems. LEDs were rediscovered in 1962. Early LEDs can only radiate visible red light spectrum with a low light intensity. Low-power LEDs can be used primarily in indicator lighting [4]. In the 1990s, innovations in the materials employed as the active layer, phosphor, the conducting pad, and the substrate, as well as crystal growth techniques, such as epitaxy enabled the development of bright white LEDs [6, 7]. Owing to the rapid advances in the development of LED technology, the application of LEDs in automobiles was expanded from interior lighting, such as the backlight of dashboards, to exterior lighting such as TBLs, DRLs, turning signals, taillights, and even headlamps.

The driving force of this expanded use is that LED lighting systems have many advantages over the other technologies in terms of their energy efficiency, lightweight, shock resistance, fast response time, simple optical system design, and long life [4]. Although LEDs have many benefits in auto-lighting, all automobile lighting systems must satisfy the same functional requirements, and should consider any glare problem that arises in their applications.

To guarantee the effectiveness of LED BLs and LED DRLs, it is necessary to study LED lighting systems using current automobile lighting regulations, which differ in different countries. For example, road-design sight distances specify the DRL illumination ranges as shown in **Table 1** [8]. Paine (2003) reviewed the functional and operational issues associated with DRLs [9]. The Society of Automotive Engineers (SAE) has a lighting committee that establishes vehicle lighting standards [10], but the lighting test process and methods may not be applicable for newer lighting technologies. For example, Audi has designed a new generation of organic LED (OLED) tail lights and BLs, as shown in **Fig. 1** [11].

While the BL in the figure is stylish, colorful, attractive, and the visible area is larger, it also raises the question of whether the functional performance of OLED BLs is as effective as other safety devices when compared with current TBL systems. Mercedes Benz has developed a new technology with an adaptive braking light, as shown in **Fig. 2** [12]. In this case, when the vehicle speed exceeds 60 km/h and the brake is suddenly pressed, the system will not only activate the BL, but will also flash the light to more quickly attract the attention of the driver of the rear vehicle. The concern here pertains to the need to measure and verify the claims made regarding the effectiveness of adaptive braking lights [13].

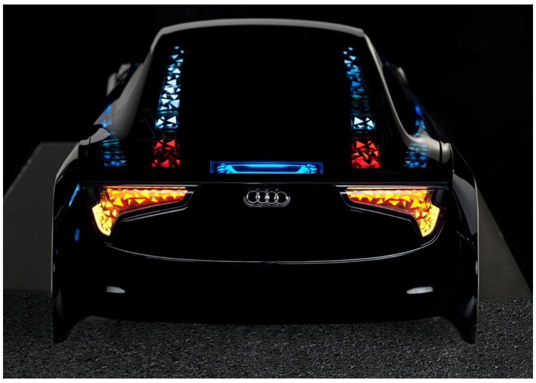

Fig. 1. Audi's OLED braking light.

Fig. 2. Adaptive braking light with two colors and dynamic flashing.

Figure 3 illustrates the evolution of the pattern of BLs, which was obtained from a survey of commercial braking lights. The evolution pattern was forecasted from the theory of inventive problem solving (TRIZ) [14]. From the trends observed during their evolution, all kinds of lighting systems have been developed. In addition, while driving on a road, we observe that even for a single model of cars, the BLs are different. We expect that more advanced lighting systems for automobiles will continue to be developed, and there will therefore be the need to address more issues and concerns that are raised. At the same time, current regulations may not remain current with the rapid development of auto-lighting technologies and designs. Therefore, we aim to investigate the effectiveness of automobile exterior lighting as a safety device.

The design principle of BLs as safety devices is focused on the need to improve the visibility of vehicles using lighting technology. These lights are designed to attract the attention of other drivers by creating a brightness contrast between the vehicles and the surrounding environment. From the viewpoint of the visibility of the BL, the design parameters should consider the light color, light intensity, lighting distance, viewable area, and the position of the BL. Regulations for these parameters may

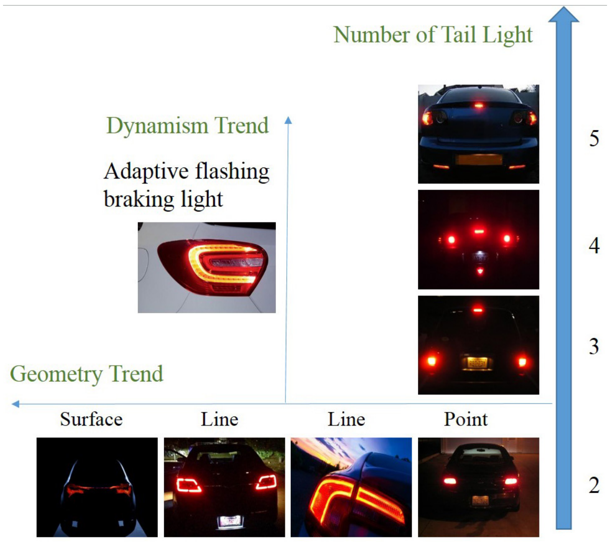

Fig. 3. The evolving patterns of tail lights and BLs.

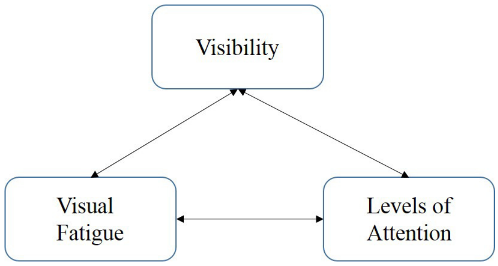

Fig. 4. Interaction between human factors.

be specified using in road codes, e.g., the California road code [15]. In this paper, we propose that additional human factors should be considered, in addition to the visibility, in order to improve the functionality of BLs and DRLs, because the human factors involved in real driving are very complicated. Drivers may experience visual fatigue if they continuously look at tail lights or BLs at nighttime. This visual fatigue may be due to poor visibility caused by glares. The realization of good visibility by using stylish designs with eye-catching effects may reduce visual fatigue, attract the desired attention, and increase awareness. For example, if an individual gazes at something of interest, such as beautiful pictures, there may be no visual fatigue, and there will be more engagement with the object in the picture. Likewise, if a driver becomes absent-minded, BLs may not attract their attention, and an accident may result. Therefore, high-visibility BLs will not necessarily lead to increased driver awareness, and they can be designed to quickly attract the driver's attention when suddenly activated. Based on the above discussion, there is a relationship between visual fatigue, visibility, and human attention levels, as shown in **Fig. 4**. We can improve the effectiveness of BLs by considering the design parameters that are related to the above-mentioned human factors. The attention level is the most important human factor because a high attention level may indicate

Table 2. Sight distances for road design.

Human Factor	Design Parameter
Visibility	Color of light
Visual fatigue	Range of lighting
Levels of attention	Number of lighting lamps
	Style of lighting lamp
	Luminance

better visibility and less visual fatigue.

Table 2 summarizes the relationship between human factors and design parameters, and we study this relationship by measuring a key factor, namely the attention/awareness levels, using brainwaves and the movements of eyes for various BL design configurations. We test the hypothesis that the effectiveness of lighting systems is related to the attention levels of the drivers. We perform a series of experiments to verify this hypothesis, and we expect that it will benefit the design of future BLs and DRLs with new technologies. Furthermore, based on this hypothesis, there is a need for new lighting regulations to be developed.

2. Theory of Attention and Related Brainwave Measurement

Attention is one of the major cognitive activities in the human brain. In selective attention, the brain can ignore background activity, while focusing on specific objects or events [16]. For example, a person may be focused on playing a computer game without feeling physical fatigue, students can daydream during classes, and drivers can be distracted while speaking on a cellular phone, eating, or thinking about something unrelated [17]. It is dangerous when a driver does not notice highlighted BLs because of temporary distractions. This attention can be studied from the perspective of different disciplines such as cognition science, visual theory, and psychology. Attention deficiency hyperactivity disorder (ADHD) is a disorder that can be diagnosed by analyzing brainwave patterns [18]. Brain waves, which are measured using electroencephalography (EEG) signals, are electrical signals that exist along the scalp. Different applications require different numbers of channels to collect the electrical signals at different scalp positions. In addition, electrical noise signals from blinking eyes, muscles, and power should be filtered. **Fig. 5** shows the two-channel electrical signals measured from the left and right sides of the forehead of the subject, which was obtained by Mindquest's EEG2000 [19]. The subject is viewing Van Gough's painting.

The plot showing the variation of the amplitude with frequency can be obtained by the Fast Fourier Transform (FFT), as shown in **Fig. 6**. The amplitude of the electrical signal is usually 1–200 μV. The normalized values from 0 to 2000 are shown on the x axis. The frequencies of

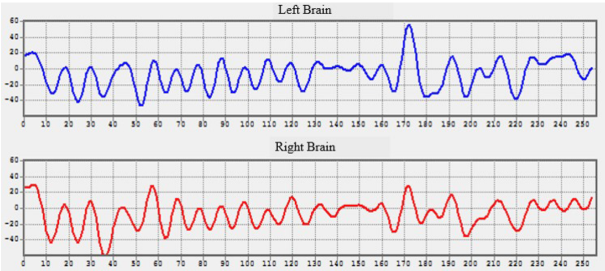

Fig. 5. Two-Channel EEG from left and right sides of the forehead.

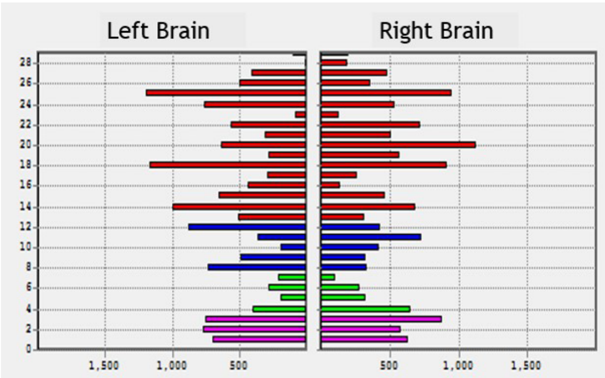

Fig. 6. Frequency spectrum of EEG.

Table 3. The brain states associated with different frequency bands.

Type	Freq. (Hz)	Amp (μV)	Brain states
δ	0.1–0.3	100–200	Deepest, dreamless sleep, unconscious state.
θ	4–7.5	<30	REM sleep, dreaming, intuitivity.
α	8–12	30–50	Relaxed, but non-sleepy state.
β	13–30	<20	Sensory and emotional influences, thinking, alertness.

the EEG along the y axis are classified into several bands, which are related to different brain states.

Table 3 shows the relationship between the frequency spectrum of the EEG and brain states. The profile of the spectrum can indicate the specific brain state. For example, if the subject is relaxed, the amplitude in alpha waves will be greater than in other frequencies [20]. The brain waves are constantly varying, and depend on age, gender, emotion, activity, etc. To investigate the relationship between brainwaves and cognitive activity, we should first establish the baseline brainwave of the subject. When the subject opens his eyes, looks at a white-colored wall, and relaxes without thinking about anything, the recorded brainwave is considered as the baseline. We recorded

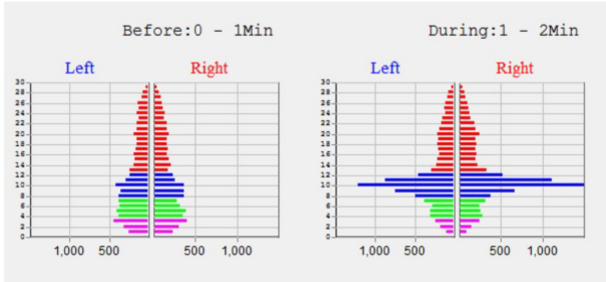

Fig. 7. Comparison of brainwave between the baseline and with closed eyes.

Table 4. Proportion of each frequency band in baseline and close eyes.

Left	Baseline	Right (%)	Left	Close eye	Right
11.7	β	12.6	11.3	B	11.4
28.3	α	28.8	53.6	α	57.8
32.0	θ	30.3	22.5	θ	19.1
27.7	δ	28.2	12.4	δ	11.5

the brainwaves for different cognitive loads such as performing mathematical calculations and looking at artistic paintings. Next, we compared the EEG features of the baseline and the specific cognitive loads. For example, for the spectrum of the baseline in the left part of **Fig. 7**, we can observe that there is a peak brainwave at 10 Hz when the subject closes the eyes, as shown in the right part of **Fig. 7**. The frequency spectrum can be further transformed as a proportion of the average amplitude of each frequency band, as shown in **Table 4**. When closing the eye, there is an increase in the proportion of alpha waves from 28.6% at the baseline to 55.7%. The change in the proportion of each frequency band may be used to indicate the state of the subject. However, for each subject, the cues of the attention levels may not be directly recognized from the frequency spectrum of the brain wave. After much research, NeuroSky developed its own algorithm, ThinkGear, which is used to extract the features of brainwaves as a measure of the levels of attention and relaxation called e-Sense. **Fig. 8** shows the e-Sense measurement obtained from a mobile phone App. Using NeuroSky's single-channel dry-electrode brainwave headset, the e-Sense meter does not require a baseline, as the range of values from 40–60 is equivalent to the baseline. A value from 60–80 is considered "slightly elevated," and may be interpreted as a higher level of attention or meditation, which may be higher than normal for a given person. Values ranging from 80–100 are considered "elevated," and strongly indicate heightened levels for e-Sense [21]. Many researchers use NeuroSky's portable brainwave headset and e-Sense meters for learning and gaming applications [22, 23]. The headset can send data back to the computer or mobile phone in real time via Bluetooth.

We assume that the e-Sense meters were used to obtain

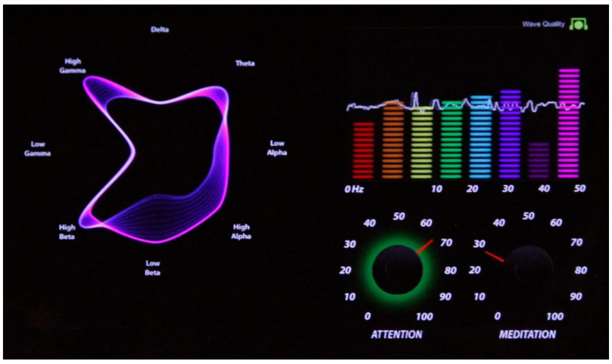

Fig. 8. NeuroSky's e-Sense meters.

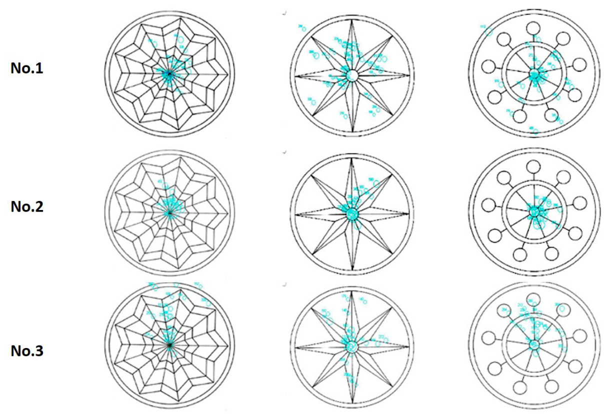

Fig. 9. Eye tracking of three subjects.

Table 5. e-Sense meters.

	A	B	C	D
Average of attention meter	80	60	40	30
Average of relaxation meter	80	40	60	20

measurements from 10 subjects with four types of BL, A, B, C, and D, and each subject viewed the BL for 3 min. The attention and relaxation meters fluctuate with respect to time. The time averages of both meters are recorded for each subject. The average scores of the e-Sense measurements for 10 subjects are as given in **Table 5**, where A is the best with the highest attention and meditation meters, while D is the poorest. B and C have performances that are similar to A and D. The performance measurement of the BL may be determined by the attention and relaxation meters of e-Senses. An event-related potential (ERP) and functional magnetic-resonance imaging (fMRI) can be used to evaluate the attention levels during the activation of the BL. The ERP and fMRI experiments are more complicated and expensive, and may be used as alternative methods after the EEG and eye tracker are tested.

3. Attention and Eye-Tracking

Eye-tracking can be used to measure different levels of attention. The positions of the eyeballs often indicate a person's focus of interest. For example, the sight line follows something dangerous or something of interest in front of a person. When speaking with someone, the absence of eye contact may indicate that the person is not concentrating on the conversation. One can also improve the attention levels by focusing on a single point. If this is done, the amplitude of the beta wave simultaneously increases. Therefore, it may be assumed that if the eyes remain focused on the same point for a longer period, the levels of attention on the viewed object are higher. Unfortunately, this assumption is not always correct. The exception is that some subjects are able to daydream without there being any changes in the positions of their eyeballs. In other words, although their attention has been lost, it is misinterpreted by eye tracking as having the opposite meaning. This situation can be avoided by using a self-report survey, as well as careful selection of the subjects prior to carrying out the test experiment. Eye tracking is a technique whereby an individual's eye movements are measured so that the researcher knows both where a person is looking at any given time and the sequence with which their eyes are shifting from one location to another [23]. For example, **Fig. 9** shows the eye-tracking results for three subjects while they are viewing monochrome geometric graphs. The results were measured using EyeLink [24]. The blue circle indicates the points at which the eyeballs are fixed, and the radius of the circle represents the time period. The figure shows that the sightline of the three subjects remains on the center of the graph. However, the data obtained from eye-tracking cannot explain their feelings and emotions, such as whether they are at peace, bored, or dislike the graphs. Now, we assume that the attention levels may be reflected by the parameter duration of attention (s) on the BL. This means that the eyes can remain on the BL for a longer period of time. In other words, the size of the blue circles from eye tracking should be larger and there should be more blue circles on the BL. Glare from the BL should be avoided as it will affect the levels of attention and cause visual discomfort. This factor regarding attention levels was excluded from our study. In other words, in our study, we assumed that there were no glare problems. To evaluate the performance of BLs in the dark, eye tracking should be performed in low-luminance conditions. This is usually a challenge for eye-tracking cameras.

4. Design of Experiment

In the previous sections, we discuss the proposed hypothesis considering the theory of attention and related measuring techniques. The hypothesis should be examined based on the experiment results. In this section, we discuss the design of the experiment used to evaluate the BL. It is very expensive and complicated to perform the experiment in an actual road test. At least two cars should

Fig. 10. Eyetracking BL obtained from the video.

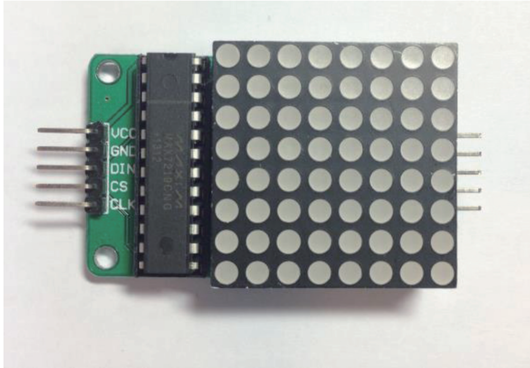

Fig. 11. LED matrix.

be arranged to be some distance from each other. The subjects in the rear car and the activation of the BL in the front car must be synchronized during the experiment. All of the measuring devices should be compact-sized because of the limited space in the car. An improved method is one in which both cars are at rest, and the measuring equipment can be set up in a spacious garage. Moreover, the daytime and night time conditions can be controlled easily using lighting devices. The same subjects can complete various testing conditions in a short time without considering variable weather conditions, time-of-day, and so on. Furthermore, the cars can be replaced by an on-road video for subsequent experiments. An ultrasonic distance sensor can be easily incorporated to ensure that there is a fixed distance from the front car. We recorded a video showing the activation of the BL from the front cars. The videos can include various types of BLs from different models of cars. The latter method is inexpensive and simple. **Fig. 10** shows the eye-tracking system that we used to measure the movements of the eyes with recorded videos. However, one major concern of laboratory tests is that drivers may have different behaviors in actual cars and in the laboratory. This is so because human factors are sensitive to the environment. Therefore, the data obtained from EEGs and eye tracking in a car may be different from what is obtained in laboratory conditions. This situation may lead to different conclusions. Therefore, a dimensional analysis should be performed before carrying out the experiment. The physical distance, luminance, color, and the related variables in the real environments should be carefully mapped to corresponding variables in the lab. For example, the ratio of the area of the BLs to the distance between cars should be the same as the ratio of the viewable area of the BLs on the screen to the distance between the eyes and the screen. The luminance of the BLs in real cars should be dimensionally homogenous in the lab. Then, we can use the data from the lab to determine the data from the real situation. For example, a small-scale ship model in a water tank can be used to predict the behavior of a real ship if dimensional homogeneity is implemented.

The abovementioned experiment is related to the verification of the effectiveness of existing BL models. In the preliminary design, a designer can create various BL designs in 3D models. With advances in virtual reality, virtual 3D prototypes can be shown on the screen as videos. Experiments that utilize a virtual prototype can help the designer to evaluate the design more cost-effectively. The designers can improve their design using fast feedback. From the above discussion, we propose that the test experiment in the lab be conducted first, after which it is performed in real cars. For basic research on establishing the relationship between design parameters and human factors, the empirical model will be helpful for the initial design of BLs. To clarify the relationship listed in **Table 2**, the design variables should be further controlled for the experiment. There are too many factors in commercial BL models that make a comparative study difficult. Therefore, for this study, we can develop a prototype. For example, the design variables, the position of the LED, and the number of LEDs with various values can be simulated using a prototype where other factors such as the light intensity and color temperature remain the same. An 8×8 LED matrix can be controlled by an Arduino micro-controller, as shown in **Fig. 11**. The software for the Arduino can simulate the pattern of the BL. Human factors that are related to BLs can therefore be studied in more detail.

The Kansei engineering (KE) methodology is often used to evaluate human factors such as sensory factors. Recently, the term “affective engineering” is used instead of KE. In being obtained from KE methodology, the survey was developed by using image words toward the products. We can evaluate the relationship between the psychological factors and design parameters of the product. The KE research report shows that the style of the car light may affect the response time of the driver behind when the BL from the front car is activated [25]. This may be simultaneously used together with eye tracking, and will help with the interpretation of the eye-tracking and brainwave results. All of the results can be cross-checked to verify the consistency of the data.

5. Conclusions

In this paper, we proposed that there is a need to consider human factors, other than the visibility, in the development of automotive exterior lighting such as DRLs and BLs, especially given the rapid advancements of LED technologies and the innovative designs of lighting systems. The attention level is a new factor we proposed that should be used to evaluate the performance of automobile exterior lighting. The performance is proportional to the attention levels, which may be evaluated by analyzing brainwaves and eye tracking. We discussed the relationship between the theory of attention, brainwaves, and eye tracking. We also discussed the design of an experiment using brainwaves and eye tracking. The results obtained show that it is feasible to evaluate automotive exterior lighting using the attention levels of subjects. In future, we will perform experiments to validate the assumption.

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Name:
Junzo Watada

Affiliation:
Professor, Graduate School of Information, Production, and Systems, Waseda University

Address:
2-7 Hibikino, Wakamatsu, Kitakyushu, Fukuoka 808-0135, Japan

Brief Biographical History:

1972- Senior Systems Engineer, Fujitsu Co. Ltd.
1983-2003 Lecturer and Associate Professor, Ryukoku University, and Professor, Osaka Institute of Technology
2003- Professor of Knowledge Engineering and Soft Computing at Graduate School of Information, Production, and Systems, Waseda University

Main Works:

- Data mining, text and web, soft computing, fuzzy data analysis

Membership in Academic Societies:

- Japan Society for Fuzzy Theory and Intelligent Informatics (SOFT)
- The Institute for Electrical and Electronic Engineers (IEEE)

Name:
Yung-Chin Hsiao

Affiliation:
Graduate School of Information, Production, and Systems, Waseda University

Address:
2-7 Hibikino, Wakamatsu, Kitakyushu, Fukuoka 808-0135, Japan

Brief Biographical History:

1990 Received the B.S. degree in naval architecture from National Taiwan University
1994 Received the M.E. degree in marine system management from Michigan University
1997 Received the M.S. degrees in mechanical engineering as well as ocean engineering from Massachusetts Institute of Technology

Main Works:

- His research interest includes optimal design, theory of inventive problem solving, and form design with computation. He is an independent consultant in the innovation of technology and problem-solving. He is awarded by Epistar Corp., Innolux Corp., and Salubris for his contribution in solving the challenging technical problems.

Name:
Hanayuki Kitagawa

Affiliation:
Graduate School of Information, Production, and Systems, Waseda University

Address:
2-7 Hibikino, Wakamatsu, Kitakyushu, Fukuoka 808-0135, Japan

Brief Biographical History:

2008-2012 Industrial Engineering, Islamic University of Indonesia
2011, 2014 Internship in PT. Bridgestone Sumatra Rubber Estate, Indonesia and Toshiba, Japan
2013- Master's Student, the Graduate School of Information, Production and Systems, Waseda University

Main Works:

• Ms. Kitagawa is the only one Japanese ancestry (Nikkei-jin) who got the scholarship selected from Asia given by the Association of Nikkei Japanese Abroad (2013-2016). Beside fed academic activities, Ms. Kitagawa is very active to join outside activities like youth conference, learn Japanese culture, volunteer and join the organization. During the research in the master program, she could freely explore potential areas of specialization in far greater depth than the expectation through most of our coursework.