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A human factors study on a modified stop lamp for motorcycles

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Abstract

In an effort to increase the detectability of a motorcycle's brake signal, this study evaluated the effects of a modified stop lamp for motorcycles. With this modified stop lamp, both turn signals would flash simultaneously to supplement the regular stop lamp. The major concern with this design is the confusion between regular turn signals and the modified stop lamp with both turn signals flashing. Two experiments were conducted to evaluate this design using a PC based driving simulator equipped with three motorcycle taillight assemblies. The results suggest that the reaction time to a brake signal can be significantly reduced by 200 ms on average ($p<0.001$) with a modified stop lamp, especially during the night when a taillight is on ($p<0.05$). Although the normal use of a turn signal was affected by the use of a modified stop lamp by approximately 122 ms ($p<0.001$), this adverse influence does not exist for a motorcycle that is straight ahead ($p<0.01$). When regular turn signals are present, they do interfere with the use of a modified stop lamp by an average of 134 ms ($p<0.05$). However, even with such interference, this design still requires a shorter reaction time than a conventional stop lamp by about 120 ms ($p<0.05$). Overall, it can be concluded that even with the interference, the reaction time to modified stop lamps is still shorter than the reaction time to the conventional stop lamps in laboratory settings.

Relevance to industry

The results of this study benefit the tail lamp assembly design for motorcycles. The findings suggest that the modified brake lamps may be a promising device to improve the visibility of the motorcycle, and to provide easier identification for following motorists. However, the effect of this modified tail lamp on the original function of turn signals, as discussed in this article, should be considered in the design process.

Keywords: Brake lamp; Motorcycle; Rear-end collision; Turn signal; Safety

1. Introduction

Based on the World Road Statistics 2000 (IRF, 2000), by the year of 1998, the numbers of registered motorcycles in Taiwan, Japan, and China were more than 10 million while there were less than 5 million in the United States and less than 3 million in Germany. In terms of the density of motorcycles on the roads, represented by the ratio between the number of motorcycles and the total length of roads, Japan has 23 times the density of the United States and Taiwan has over 500 times the density of the United States. Thus, the motorcycle accident rates in Asian countries are generally higher than that in the United States. For example, according to Taiwan Ministry of Transportation and U.S. Department of Transportation, motorcyclists accounted for approximately 20% and 6% of total traffic fatalities in 1999, respectively. In fact, the highest death rate to date in automotive transportation is associated with two-wheeled motor vehicle users. According to European Transport Safety Council (2003), motorcycle or moped travel death risk is 17.5 (when measured by elapsed time of the road) to 20 (when measured by distance traveled) times higher than that for travel by four-wheeled vehicles. Therefore, a better design to ensure motorcycle safety is crucial (MSF, 2000), in addition to improving other factors such as motorcyclist training, motorist awareness, law enforcement, and roadway characteristics.

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The visual angle to a typical motorcycle is about one-fourth of a passenger vehicle at the same distance from a following vehicle's view. The emphasis on styling simplicity and the lack of space often dictate a single-point, single-bulb taillight for a motorcycle. Since visual inputs account for 90% of information required for driving a vehicle (Sivak et al., 1981), a small visual angle potentially may increase the risk of motorcycle accidents. For example, if a following driver misses the moment when a brake from the motorcycle ahead is first applied, he/she must rely on absolute brightness discrimination to determine the meaning of the tail lamp ahead. This is something that people do not do with 100% reliability. To prevent a rear-end collision, stop lamps of motorcycles should provide fast, distinct, and sufficient information, so that motorists or riders behind can make a timely response to such events as making an emergency brake. Numerous studies have been conducted regarding rear-end collision prevention for automobiles (e.g., Dingus et al., 1997; Shinar et al., 1997). The most well known case is the center high mounted stop lamp (CHMSL) that would increase the detectability of the stop lamps (Farmer, 1996). In a recent study, Kuge et al. (2002) hypothesized that the geometric shape arranged by stop lamps of a vehicle would affect the brake response time of the driver in the following vehicle. For example, a traditional arrangement of two stop lamps and one CHMSL forms a triangle that provides more cues on visual angle changes while the front vehicle decelerates. The research suggests that some stop lamp arrangements outperform others in terms of response time, mainly due to a better distinction of visual angle changes. Kuge et al. (2002) further suggest that flashing the stop lamps within a suitable frequency range can make the deceleration easier to be recognized. This design has been installed on the Nissan ASV-2 for further study.

Although there are numerous studies on collision prevention for automobiles, collision prevention studies for motorcycles are relatively few. The single-bulb taillight design for a motorcycle prevents Kuge's concept or a CHMSL from being adopted. Among all studies on motorcycle safety, the most comprehensive one is the "Motorcycle Accident Cause Factors and Identification of Countermeasures" also known as "Hurt Report" (Hurt, 1981). The report investigated motorcycle accidents from different aspects such as human factors, vehicle factors, environmental factors, and social factors. Since 1979, motorcycles sold in the United States have been regulated to be equipped with automatic-on headlights. Some modern motorcycles are equipped with "position lights" in their front turn signals. These devices may help motorists be aware of the following motorcycle based on their side or rear mirrors. However, for automobiles behind a motorcycle, there is no similar device to increase the detection of the brake signal from the leading motorcycle.

Because brake signals are generally considered one of the most important information provided by the front vehicle during a vehicle following task (Luma et al., 1997), increasing the detectability of a motorcycle's brake signals provides better information for the motorist in the following vehicle. This may improve the visibility of the motorcycles when on the road, and provide easier identification for following motorists in the countries where motorcycles are not as prevalent, such as United States (MSF, 2000). In contrast, since motorcycles are quite common in many Asian and European countries, drivers in these regions, especially in urban areas with high traffic density, often encounter circumstances where the distances between automobiles and motorcycles too close for adequate reaction time. Since automobiles have obstructions and blind spots (such as door pillars) that can hide a motorcycle from the drivers' view, it becomes essential that motorcycles have stop lamps with high detectability.

This study investigates a novel design of a modified motorcycle stop lamp. With this modified stop lamp, both turn signals flash simultaneously to supplement the regular stop lamp while the turn signal retains its original function. Thus, as depicted in Fig. 1, while riding a motorcycle with a modified stop lamp, when a brake is engaged, the stop lamp will be actuated and at the same time both turn signals will flash (Fig. 1, bottom left case). If a turn signal is turned on when making a turn or changing lanes without engaging a brake, only the corresponding turn-signal lamp will be actuated and flash (Fig. 1, upper right case). However, when a motorcyclist makes a turn, he or she will typically reduce speed (usually by means of engaging a slight to moderate brake) and turn on the corresponding turn signal. In this case, the regular stop lamp will be actuated and the corresponding turn signal

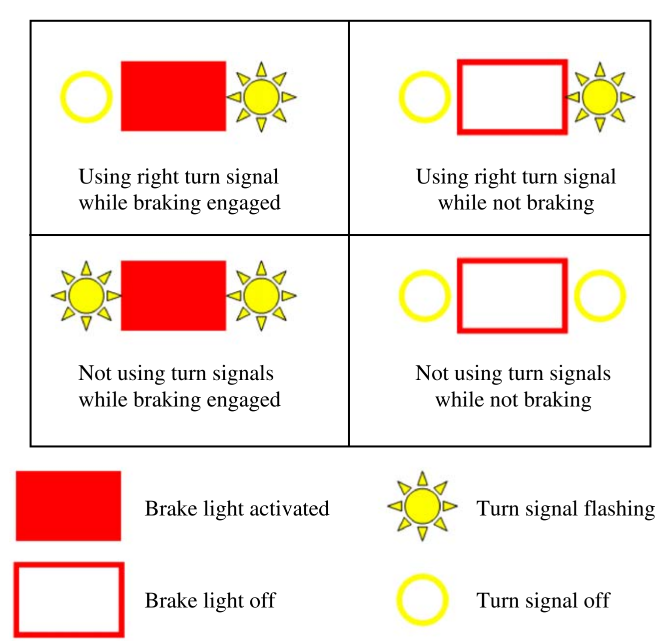

Fig. 1. The proposed functionalities for the supplemental brake lamp of motorcycles. Note that only the right turn signal on or off scenarios are depicted in this figure. The left turn signal on or off scenarios have the same effect.

will flash (Fig. 1, upper left case). The rationale is that the deceleration is usually at a small to moderate degree when a motorcyclist intentionally makes a turn. At this level of deceleration, following vehicles should have adequate time to respond. In the event that a leading motorcycle engages an emergency brake, an immediate response is needed by a following vehicle. Because turn-signals are not turned on in this occasion, the modified stop lamp will be actuated to prevent a rear-end collision. Many motorcycles in Taiwan have already adopted this design, although its primary purpose is for cosmetic appeal.

The idea of flashing both signals as a supplement to a brake signal seems advisable due to the light color and flash rate. Experiments conducted by Reynolds et al. (1972) show that when using the central vision and in a low signal-to-background brightness, a red signal is the most preferable, followed by green, yellow, and white. However, the color of a fovea-centered object may appear different if seen peripherally (Ancman, 1991; Dudek and Colton, 1970) and in many cases, a motorcycle needs to be detected using peripheral vision when traffic density is high and a motorcycle is close to the side of a vehicle. For color perception in the peripheral vision field, Dudek and Colton (1970) found that with any given background, or environmental light level, the blue and yellow test lights gave the best results for the greatest recognition of color and the number of errors made.

Flashing signals provide discriminable stimulus in situations with a great deal of temporal and spatial uncertainty and a potential increase in the information content of the system (Ima and Mann, 2002). Because of this rationale, they have been used to increase the detectability of a warning signal under the conditions where the view angles are limited (Teichner and Krebs, 1972). In this respect, Markowitz (1971) suggested the optimal flash rate and the duty cycle for visual flashing indicators, and reported that a range of 1 to 2 flashes per second, which is presently used on automobiles and airplanes, is compatible with human discrimination capabilities. Kuge et al. (2002) also suggested that flashing brake signals reduced response time in a study based on a driving simulator.

In an effort to verify this design, Tang (2003) conducted a field study to test the modified stop lamp in actual urban and suburban traffic where traffic density and interfering lightings along the roads such as neon signs may affect the detectability of stop lamps. The study also tested the modified stop lamp at different levels of illumination. Overall, the results from this study suggest the modified stop lamp outperformed the conventional stop lamp when sunlight is bright as well as during the night. The analysis also shows that while the average reaction time to a modified stop lamp was generally shorter than that to the conventional stop lamp during the night, the modified stop lamp was particularly useful in the urban traffic. Although this design reduces the braking response time, the confusion between regular turn signals and turn signals used for a modified stop lamp may increase the response time to turn signals. Also, when the turn signals are used for their original function, the reaction time to the modified stop lamp may be increased as well due to the confusion.

In order to further investigate the effect of this modified stop lamp, two experiments were conducted in the laboratory settings. The first experiment was to investigate whether the reaction time to a brake signal will be different between a modified stop lamp and a conventional stop lamp. Because this modified stop lamp would flash both turn indicators simultaneously as a supplement, one concern is that the response time to a stop lamp may increase when turn signals are used for their original function. Thus, in the first experiment, the normal use of turn signals (i.e., flashing one turn signal alone without engaging a brake) was considered as an interference factor. This was designed to find out whether the use of turn signals would affect the reaction time to stop lamps, either modified or conventional ones. On the contrary, the second experiment was designed to find out whether the reaction time to a turn signal would be affected by a modified stop lamp. Although brake signals are generally considered more important than turn signals, the use of modified stop lamps should not compromise response time to turn signals.

2. Experiment One

2.1. Subjects

Twelve paid subjects with at least one year of driving experience participated in this study. Five subjects were female and seven were male. The average age of the subjects was 22 years old, with a standard deviation of 1.3 years. All subjects had a normal or corrected to normal eyesight.

2.2. Equipments

A 120-inch screen was set up in the front at 5 m away from a subject and the image of the virtual car was projected on the screen with a LCD projector. Three sets of a typical motorcycle taillight assembly were mounted at the lower left corner, central bottom, and lower right corner of the screen as shown in Fig. 2. The bottom of the screen was 75 cm above the floor. The visual angle from the center taillight assembly to either the left or right taillight assembly was 30°. Each motorcycle taillight assembly included a brake/tail lamp and two turn-signal lamps located at the left and right sides of the stop lamp. The height and width of the rectangular brake/tail lamp was 10 and 15 cm, respectively, while the diameter of the two turn-signal lamps was 8 cm. The luminous intensity of the stop lamp, tail lamp, and turn-signal lamp were 75, 35, and 65 cd, respectively. The flash rate of the turn signal was 90 per minute and the duty cycle was 55%. All of these specifications were within the current US and Taiwan

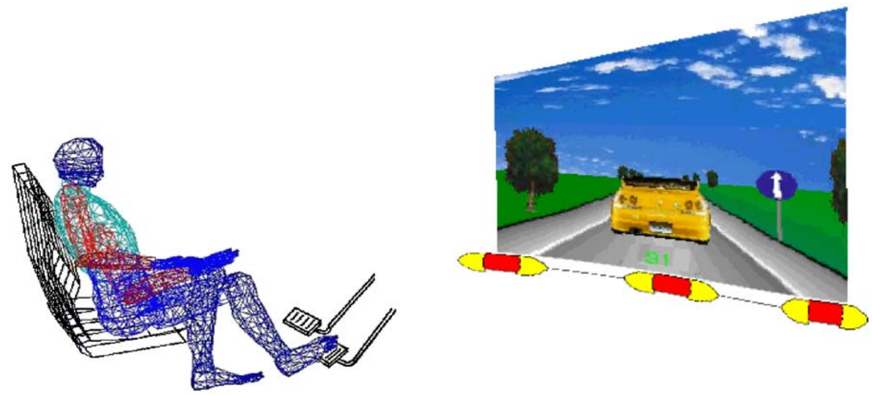

Fig. 2. A schematic diagram of the subject's view, a screen capture of the driving simulator was shown in this figure.

standards (FMVSS No. 108 and CNS D20202, respectively). The study simulated these motorcycle taillight assemblies being viewed from 20 m away. To achieve this simulated geometry with the actual viewing distance, a black cardboard with corresponding dimensions of apertures was placed in front of the taillight assembly (Sivak et al., 1994). The taillight assemblies and the response button were connected to a control panel with three digital timers so that the reaction times can be recorded with millisecond accuracy.

The study simulated both daytime and nighttime conditions. For the daytime condition, incandescent photoflood lamps and overhead fluorescent lights were used to illuminate the taillight assemblies at approximately 4000 lx. For the nighttime condition, the only light source was the reflection from the screen illuminated by the LCD projector. The tail lamps were turned on throughout the experiment for the nighttime condition.

2.3. Tasks

Subjects performed two tasks simultaneously. One task was to press a button as soon as the test subject detected a stop lamp. The other task was to carry out a vehicle following task with a virtual driving simulator designed to approximate the perceptual workload of driving. The driving simulator was developed using Microsoft Visual Basic. Fig. 2 shows a schematic diagram of the experimental setting and a screen output of the vehicle following task. A passenger car seat and a set of gas and brake pedals from Ford Liata model were used in this experiment. The gas and brake pedals were modified so that serial signals can be generated to indicate the movement of the pedals. These signals were then transmitted to serial ports of a PC running the simulation program from which the acceleration and deceleration can be calculated. The virtual car shown in Fig. 2 traveling at different speeds, different rates of acceleration or deceleration, was controlled by a preset program. The test subject sat on the driver's seat and controlled the gas and brake pedals just like driving a normal passenger car. When the virtual car decelerated, the subject had to brake accordingly to avoid a collision. When the headway distance was increased, the subject could accelerate to get closer to the virtual car. The stop lamps of the three taillight assemblies would not go on if the test subjects did not drive the car within the zone of the 2-s following distance. The change of the visual angle of the virtual car at different distances and speeds has been calculated to resemble the real situations. The subject used a set of gas and brake pedals to perform the task to avoid possible conflicts with the first task at the motor output stage (Wickens, 1992).

2.4. Design

This experiment investigated the following factors: stop lamp style, level of illumination, turn-signal interference, and location of the taillight assemblies. A $2 \times 2 \times 2 \times 3$ within-subjects design compared two types of stop lamps, daytime and nighttime conditions, with or without using turn signals in the experiment, and three locations of the taillight assemblies, namely, left, center, and right. The dependent variable was the reaction time to the stop lamp signal measured in milliseconds.

With or without using turn signals in the experiment was considered as an interference factor in order to find out whether the use of turn signals would affect the reaction time to stop lamps. Without using turn signals means that only brake signals were presented throughout the experiment, while "interfered" (with turn signals being used) means that the normal use of a turn signal would happen in the session. In the latter case, the subjects had to distinguish between the normal use of turn signals and a modified brake signal with both turn-signal lamps flashing.

2.5. Procedure

Each subject was tested individually on four consecutive days and each day one of the four combinations of two stop lamp styles and two levels of turn-signal interference was presented. The assignment of the stop lamp styles and turn-signal interference to the subjects was counterbalanced across the experiment. Each day the daytime and nighttime test blocks were randomized and subjects were allowed a 30-min rest between the daytime and nighttime test blocks so they could adapt to the change of light.

On the first day, after receiving instructions on how to operate the vehicle following task, each subject was allowed ten minutes to become familiar with the virtual driving simulator as well as the gas and brake pedals. The subject then started with one of the daytime or nighttime test block. Thirty trials for three locations of the taillight assemblies were randomized in a test block and the interval times between two consecutive trials followed a uniform distribution ranging from 10 to 90 s. For test blocks interfered with the use of turn signals, one of the six turn-signal lamps was randomly selected and energized based on a uniform distribution ranging from 10 to 90 s. However, while the two events were controlled with independent random number generators, if either a stop lamp or turn-signal lamp was energized, the next event was controlled at least 5 s apart. For either stop lamps or turn-signal lamps, the energized time was 3 s. Subjects were informed of the stop lamp style as well as whether the test block was with or without using turn signals as interference to avoid confusion.

2.6. Results

A four-way repeated measures ANOVA was used to analyze the collected data and revealed four significant main effects: stop lamp style, $F(1,11) = 53.02$, $p<0.001$; turn-signal interference, $F(1,11) = 5.42$, $p<0.05$; level of illumination, $F(1,11) = 7.38$, $p<0.05$; and location of the taillight assemblies, $F(2,22) = 18.84$, $p<0.001$. Table 1 presents the mean reaction time to the brake signal for the different levels of these four main effects and their standard deviations.

Table 1 shows that the reaction time to a modified stop lamp was less than that to a conventional stop lamp with the mean difference of about 200 ms. For the turn-signal interference factor, a test of the main effect revealed that the use of the normal turn-signal function did increase the mean reaction time by about 64 ms. A test of the main effect on the level of illumination factor indicated that it took longer to detect the brake signal during the night than during the day. A Tukey HSD test with $\alpha = 0.05$ on the taillight location factor revealed that the signals from a central stop lamp was easier to be detected than the stop lamp at two sides while no difference exists between the right and left ones.

There were two significant two-way interaction terms: stop lamp style and turn-signal interference as shown in Fig. 3, $F(1,11) = 5.21$, $p<0.05$, and stop lamp style and level of illumination as shown in Fig. 4, $F(1,11) = 8.44$, $p<0.05$. None of the higher-order interaction terms were significant.

Fig. 3 illustrates the time required to respond to a brake signal for two different types of stop lamps, with or without using the normal function of turn-signals. The trend suggests that using the normal function of turn-signals has a larger impact on a modified stop lamp than a conventional stop lamp. This observation was confirmed by a priori contrast tests ($p<0.01$). While there was virtually no difference between using and not using turn signals as interference for a conventional stop lamp in terms of measured reaction time, the use of turn signals did increase the reaction time in the case of a modified stop lamp. However, Fig. 3 shows that while using a turn signal increases the reaction time in the modified stop lamp case, it is still less than that in the case of a conventional stop lamp. A test of main effect on the combinations of these

Table 1
Mean reaction time (ms) to the brake signal for the different levels of four main effects and their standard deviations (in parenthesis)

Factors	Levels		
Locations of the taillight assemblies	Center	Left	Right
	573(262)	816(297)	785(314)
Brake lamp style	Modified	Traditional	
	625(250)	824(333)	
Turn-signal interference	Yes	No	
	757(303)	693(315)	
Level of illumination	Day	Night	
	688(229)	761(372)	

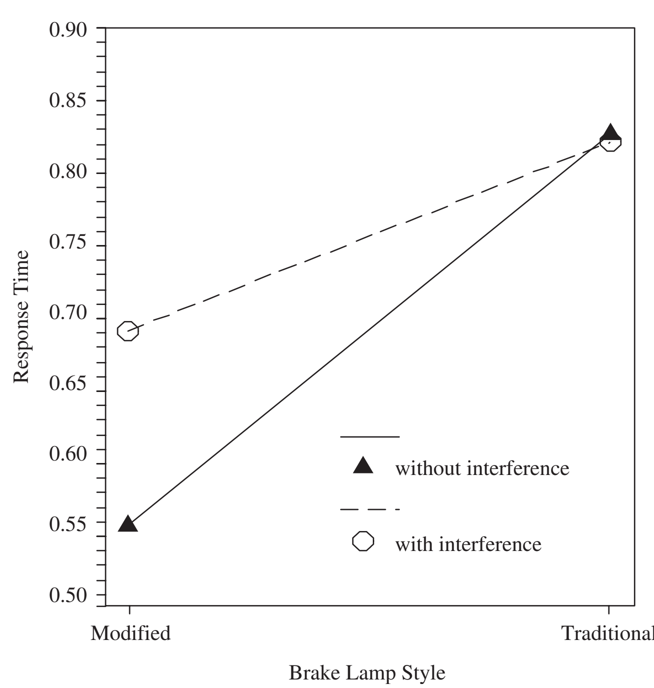

Fig. 3. Reaction times (s) to brake signals for two different types of brake lamps, with or without using the normal function of turn signals.

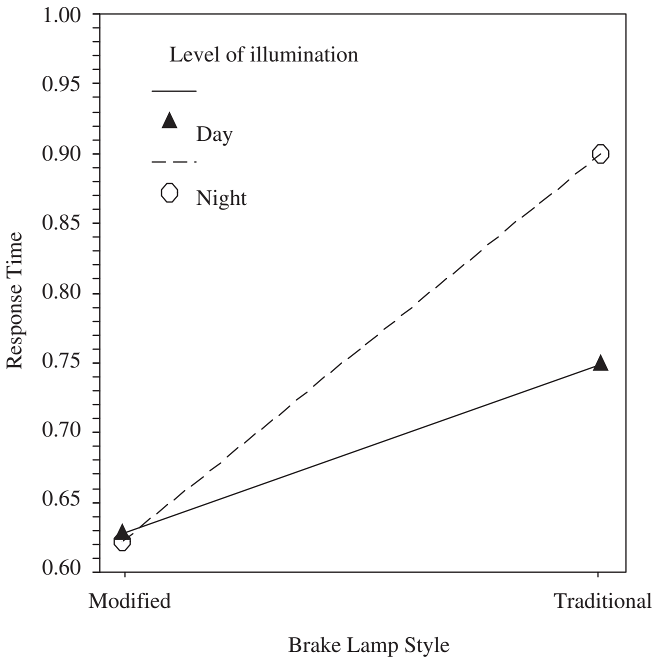

Fig. 4. Reaction times (s) to brake signals for two different types of brake lamps at different levels of illumination.

two terms using Tukey HSD test confirmed that a modified stop lamp without using turn signals outperformed a modified stop lamp using turn signals, while the latter outperformed a conventional stop lamp, with or without using turn signals. There was no significant difference between the conventional stop lamp with or without using turn signal as interference.

Fig. 4, indicates that the reaction time to the conventional stop lamp during the night is the longest. A test of main effect on the combinations of level of illumination factor and stop lamp style factor using Tukey HSD test revealed that while there was no significant difference between modified stop lamp during the day or night, these two cases outperformed a conventional stop lamp during the day, and a conventional stop lamp during the night had the worst performance among the four scenarios.

2.7. Summary

The results from Experiment One suggest that the modified stop lamp helped subjects respond to a brake signal faster than the conventional stop lamp. This effect was more significant during the night, presumably due to the turned-on tail lamps. With the tail lamp turned on, signaling a brake application by making the tail lamp brighter requires the subject to make absolute brightness discrimination if the subject missed the transition. If the contrast between two levels of brightness is not strong enough, the subject may need a longer response time. With a modified tail lamp, the flashing signals provide extra information to avoid missing the transition.

On the other hand, the use of turn signals in a normal fashion seemed to have adverse effects on the reaction times to a modified stop lamp to some degree. However, the reaction time in this scenario still outperformed the case of a conventional stop lamp. Thus, the modified stop lamp is preferred in terms of the reaction time to stop lamps.

3. Experiment Two

The Experiment One investigated how the reaction time to brake light was affected by various factors of interest. This experiment investigated how different types of brake lamps (i.e., modified and conventional stop lamps) affected the reaction time to turn signals.

3.1. Subjects

Twelve subjects participated in this study. None of these subjects had participated in the previous experiment. Four subjects were female and eight were male. The average age of the subjects was 20 years old, with a standard deviation of 1.5 years. Other characteristics of these subjects were similar to those in Experiment One.

3.2. Method

The apparatus and laboratory settings used in Experiment Two were the same as Experiment One. However, the experiment adopted a $2 \times 2 \times 3$ within-subjects design that compared two types of stop lamps, daytime and nighttime conditions, and three locations of the taillight assemblies, namely, left, center, and right. The dependent variable was the reaction time to turn signals measured in milliseconds.

The experiment task is similar to Experiment One. The test subjects still performed the vehicle following task, but this time, they responded to turn signals instead of brake signals. In this experiment, the use of brake signals was considered interference to the reaction to turn signals. The control of the frequency and interval time of turn signals was the same as the brake signal in Experiment One, and the control of the brake signal in Experiment Two was the same as that of turn signals in Experiment One. The brake signal and turn signals were still controlled at least 5 s apart. There were also thirty trials in each test block controlled by the same method as described in Experiment One.

3.3. Results

A three-way repeated measures ANOVA was performed on reaction times to turn signals and revealed three significant main effects: stop lamp style, $F(1, 13\,11) = 33.27$, $p<0.001$; level of illumination, $F(1, 11) = 4.01$, $p<0.1$; and location of the taillight assemblies, $F(2, 22) = 19.68$, $p<0.001$. Table 2 presents the mean reaction times to the turn signals for the different levels of these three main effects and their standard deviations. The results suggest that a modified stop lamp

Table 2
Mean reaction time (ms) to the turn signal for the different levels of three main effects and their standard deviations (in parenthesis)

Factors	Levels		
Locations of the taillight assemblies	Center	Left	Right
	602(243)	763(242)	751(237)
Brake lamp style	Modify	Tradition	
	766(254)	644(233)	
Level of illumination	Day	Night	
	727(249)	683(252)	

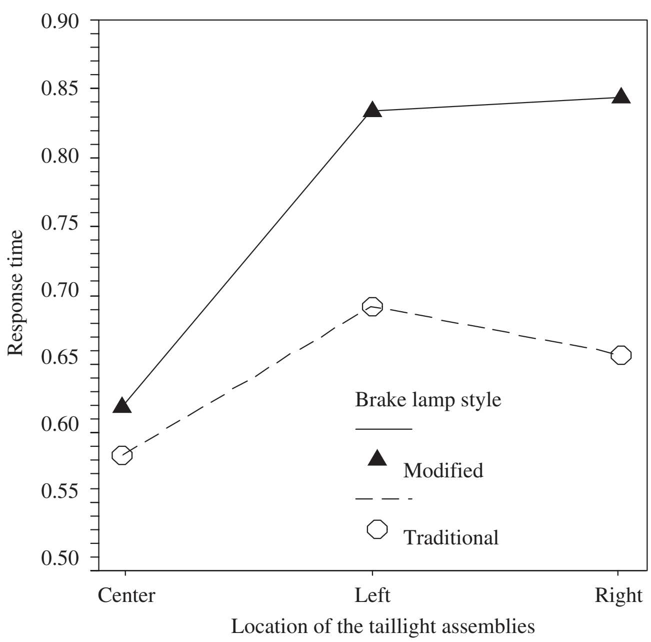

Fig. 5. Reaction times (s) to turn signals for two different types of brake lamps at three different locations.

required a longer time to respond to turn signals than a conventional stop lamp by about 122 ms. In terms of illumination, it took longer during the day by about 44 ms than that during the night. The difference between daytime and nighttime conditions, however, was marginally significant ($p = 0.052$). Also indicated in Table 2, the reaction time to the turn signals from the central taillight assembly was still shorter than when they were on both sides. This result is similar to Experiment One. A Tukey HSD test on taillight location factor revealed that turn indicators from the central taillight assembly was easier to be detected than the taillight assembly on two sides, and there was no difference between the right and left ones.

There was one significant two-way interaction terms: stop lamp style and location of the taillight assemblies as shown in Fig. 5, $F(2, 22) = 6.20$, $p < 0.05$. None of the higher-order interaction terms were significant. A test of the main effect on the combinations of the location and stop lamp style using Tukey HSD test revealed that among the six combinations, while there was no significant difference among the modified stop lamp at the center as well as all of the three locations for a conventional stop lamp, this group outperformed the modified stop lamp at left and right sides, where no difference existing between these two.

3.4. Summary

The results from this experiment seem to suggest that the reaction time to turn signals may be affected by applying the modified stop lamp at a moderate level. The impacts, however, are more noticeable for the turn indicators from taillight assemblies at two sides. For turn indicators from central taillight assembly, there are virtually no difference between the modified stop lamp and conventional stop lamp.

4. Discussion

This study evaluated a new brake light design for a motorcycle and determined how this design reduces brake response time. The major concern in this study is the confusion between regular turn signals and a modified stop lamp with both turn signals flashing.

One concern about this design is how a modified stop lamp would affect the regular use of turn signals. The results from both experiments suggest that while the modified stop lamp saved 200 ms for braking on average, it also increased 122 ms for responding turn signals on average. The response time to a motorcycle taillight assembly located straight ahead of test subjects did not seem to be affected by this adverse influence. This result also suggests that the following vehicles may benefit from the modified stop lamp when a front motorcycle that is straight ahead brakes. However, for the motorcycle taillight assembly mounted at two sides, because the vehicle following task requires foveal attention, the distinction between regular turn signals and turn signals used for a modified stop lamp may be lowered due to the insufficient resolution in peripheral vision.

Another concern is how the use of the turn signals affects the modified stop lamp. The results suggest that when regular turn signals are present, they do interfere with the use of a modified stop lamp by an average of 64 ms. However, even under the situation where modified stop lamp is being interfered, it still has a shorter reaction time than conventional stop lamp by about 120 ms as shown on Fig. 3. Overall, it can be concluded that although the interference exists, the modified stop lamps outperform the conventional ones.

Although the stop lamp design for motorcycles has less often been discussed, the results regarding this modified stop lamp can be mostly explained by information theory. The modified stop lamp provided multiple coding dimensions including brightness, color, flashiness, and configuration (spatial arrangement). It is well known that the use of multiple dimensions, in a form of redundancy, can decrease response time in perception and decision making (Sanders and McCormick, 1993). For example, a study conducted by Luma et al. (1997) also showed that a redundant color coding of a turn signal reduced the reaction times to the break signal.

However, while the empirical research supports the effects of this modified stop lamp design, we need to see how it works under less controlled conditions before it can be accepted by the public. Although a field study has been conducted (Tang, 2003) for this design, it is still deemed as a controlled situation because all participants were aware of the experiment. In the actual traffic with a mix of both traditional and modified stop lamps, drivers may not know which stop lamp has been installed on the preceding motorcycle. In such a situation, the effect of a modified stop lamp would probably be smaller than that in the current study. This requires more research in which subjects have no knowledge of the kind of stop lamps they are dealing with.

Another thing that needs to be noted is that only young subjects are included in this study. If drivers' visual performance is an important factor in an experiment, elderly subjects should be included as well because they may not perform as well on the driving task either in the driver's central or peripheral viewing area (Benekohal et al., 1994). It can be reasonably assumed that elderly drivers may have longer reaction times than those reported in this study.

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