The Influence of Audio Warning Urgency and Situational Urgency on Collision Avoidance Performance

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ABSTRACT: Audio warning system of collision warning system had been investigated extensively in previous studies; however, only a few of them focused on warning effectiveness under varied situational urgency. Their results suggested that warning signal should be tested under several situational urgencies to confirm its effectiveness. This leads to the objective of this study, which is to explore the effect of varied auditory warning urgency and varied situational urgency on collision avoidance performance. This paper performed an experimental evaluation for four audio warning conditions: high urgency, medium urgency, low urgency and none(no warning), with three situational urgencies: high, medium, and low situational urgency. The results indicate that varied situational urgency has some influence on the collision avoidance performance. In the aspect of brake reaction time, this study result suggests that warning with higher perceived urgency tends to improve brake reaction time in general. For brake profile, increasing the warning urgency up to the medium level improves braking behavior while high warning urgency tends to worsen it. In mean deceleration aspect, in low situational urgency, Mean deceleration tends to be decreased as the urgency of the warning increased up until the medium warning urgency, but high warning urgency increases the mean deceleration instead. Overall, medium warning urgency causes more stable and more appropriate braking response among all designed warning urgency.

KEY WORDS: Safety, Collision Warning System, Auditory Alarms, Driver Response, Time to Collision, Situational Urgency [C1]

1. Introduction

Audio Warning has been applied as notification systems in the automotive field due to its unique advantage over tactile and visual warning. This advantage comes from the concept that hearing is omnidirectional and cannot be shut off involuntarily while visual warning must be seen to be effective (1). Moreover, in contrast to the tactile warning, there is also no need to install any vibrating device on drivers. In previous studies, their participants tended to have negative opinions on the tactile warning; e.g. “annoying”, “distracting”, “not like” and “stressful”; whereas the tactile warning can provide better performance, e.g., a shorter response time (2,3).

Previous studies’ results revealed that acoustic parameters like sound intensity, sound frequency, and inter-onset interval have some influence on the perceived urgency of the auditory warning (4,5). Furthermore, this influence is also present in driving context as well (6). However, one study mentioned that the mental representation of the warning’s cause may override the acoustic parameter’s influence on perceived urgency when the workload becomes more severe (7).

In the principle of warning urgency, it was established that warning signal with higher perceived urgency tends to cause a faster reaction in general at least when the task is simple (8,9). In one study, its result revealed that higher warning’s perceived urgency tend to cause more quick responses and more accurate responses in a normal driving context (2). However, driving task during an imminent collision event should not be considered as a simple task. Drivers have to assess information concerning the critical situation from their surrounding quickly and precisely. After that, they have to perform a collision avoidance maneuver to prevent the collision accordingly.

Reaction time is known to be one of the crucial factors that determine the result of a collision avoidance. It was revealed in one study that even a small decrease in reaction time could lead to a high proportion of successful collision avoidance by using lateral maneuvers (10). From the point of view of warning signal’s perceived urgency, it implies that using higher warning urgency in a critical situation should reduce the number of the accident due to driver’s faster reaction. However, a previous study revealed that high urgency auditory warning and low urgency auditory warning cause higher accident occurrence than medium urgency warning when the necessary collision avoidance maneuver became more complex (11). This finding suggests that too high warning urgency of warning is not necessarily the best warning in driving context although it conveys more sense of emergency, which should be used to represent the imminent collision event. Furthermore, the result also indicated that too low warning urgency of warning is not effective.

The concept of the influence of situational urgency on driving responses in either with a warning or without a warning was reported in previous studies (3,12). Situational urgency can be described by using two types of parameters. The first one characterizes situational urgency by the initial state of the critical situation such as following distance, time headway, and Time to Collision (TTC). The other one characterizes situational urgency by the rate of deceleration of a leading vehicle or the rate of acceleration of an incoming object.

One study result showed that visual warning, audio warning, and tactile warning performance varied depending on the
situational brake urgency. It reported that tactile warning produced the shortest brake reaction time followed by audio and visual warning when the situational urgency was low (TTC 5 seconds). On the other hand, the clear difference between the fastest brake reaction time of tactile warning and other modalities, which could be observed in low situational urgency, could not be observed in high situational urgency condition (TTC 3 seconds) (12). In other study with no warning condition, shorter initial headway and leading vehicle’s hard brake tend to cause faster brake reaction time and harder brake profile. Conversely, longer initial headway and leading vehicle’s gradual brake usually causes slower brake reaction time and gradual brake profile or multiple-staged brake profile (12).

Several previous studies concerning the effects of warning effectiveness focused on the driver’s response times before braking by measuring the time required for switching from the acceleration pedal to the brake pedal. Although this index can provide information on what drivers do before braking, it does not reveal any data about what drivers do after pressing the brake pedal. One previous research has shown that braking behavior should be investigated in order to get more insight of the driver’s response under varied situational urgency (12). Therefore, brake reaction time, brake pedal time, and mean deceleration should be analyzed to obtain a better understanding of the driving response under the critical situation of varied warning urgency and varied situational urgency.

As mentioned above, to our knowledge, an interaction between Warning Urgency (WU) of the auditory warning and Situational Urgency (SU) in driving context have not been investigated in earlier works. In this study, different levels of WU and different levels of SU are considered, and the main effects of WU and SU and the interaction between WU and SU are investigated in terms of braking response time and braking behaviors.

2. Methods

2.1. Independent variable

A two-factor within-subjects design was used in this experiment. The independent variables were three levels of Situational Urgency (SU): high, medium, and low SU conditions and four audio Warning Conditions (WC): high WU, medium WU, low WU and none (no warning). The SU was expressed by using three different Time to Collision (TTC). TTC of 2.5, 3.5, and 4.5 seconds were chosen for high, medium, and low SU conditions respectively, resulting in total twelve experimental conditions. Each participant went through repeated measures through twelve experimental conditions in a counterbalanced order in this experiment.

In this experiment, the high SU condition is defined as the situation that needs an immediate response in order to avoid or prevent the critical situation. If the response is not fast enough, it is expected that the accident will occur.

2.2. Dependent variable

In this study, the dependent variables were brake reaction time, brake pedal time, and mean deceleration. They are defined as of the following:

1. **Brake Reaction Time (BRT)**
   Brake reaction time is measured from either the releasing of an auditory warning signal or the appearance of a pedestrian until the time at which driver of the test vehicle starts to press the brake pedal. The release of the warning signal and the appearance of the pedestrian were designed to occur at the same time.

2. **Brake Pedal Time (BPT)**
   Brake pedal time is measured from the initial depression to the maximum depression of the brake pedal. Lower values represent a more sudden brake, and higher values indicate a more gradual braking profile.

3. **Mean Deceleration (MD)**
   The mean deceleration is calculated from the initial depression of the brake pedal to either the test vehicle is stopped or the collision occurs.

A 9-point Likert Scale Questionnaire was used to assess subjective evaluation of driver’s feeling concerning the critical situation. The questions in the questionnaire are as of the following:

1. Please give a score on the easiness of collision avoidance.
2. Please give a score on the perceived urgency of audio warning urgency.
3. Please give a score on the perceived urgency during collision avoidance.

2.3. Participants

Twelve males (age 18-26 years, Mean = 20.92 years, SD = 2.35 years), who possessed a valid Japanese driving license, with 1 months to 4 years of driving experience, participated in the study. All drivers completed an informed consent and were compensated for their participation. All participants were healthy. They self-reported to have a normal or corrected-to-normal vision as well as a normal hearing. Ethical approval for this experiment was obtained from the Ethics Committee of Interfaculty Initiative in Information Studies, Graduate School of Interdisciplinary Information Studies, the University of Tokyo.

2.4. Apparatus

This paper presents an experiment utilizing a moving-based driving simulator, which is equipped with brake pedal, accelerator pedal, actuated steering wheel, instrument dashboard, and motion platform with six degrees of freedom. This driving simulator uses a 140-degree field-of-view to display a driving scenario. The visual scene was updated at the rate of 60 Hz. A set of computer speaker was installed on the left front and right front of a driver seat.

2.5. Auditory collision warning design

The auditory WU can be manipulated by adjusting acoustic properties (45,9). In this experiment, three types of sine wave warning signal were generated. Three of acoustic properties were used to control WU, including sound intensity, sound frequency, and Inter-Onset Interval (IOI). IOI is defined as the interval between onsets of stimuli The setting of acoustic parameters was designed by using various previous studies as a guideline (5,11). The setting of audio warning is as shown in table 1.

| WU    | Sound Intensity | Sound Frequency | Inter-Onset Interval |
|-------|-----------------|-----------------|----------------------|
| High  | 85 dB           | 2000 Hz         | 100 ms               |
| Medium| 77 dB           | 1000 Hz         | 200 ms               |
| Low   | 70 dB           | 400 Hz          | 300 ms               |

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2.6. Scenario design

The experiment scenario is illustrated in figure 1. Frontal pedestrian collision event was used for the scenario design. A row of parked buses was placed in the left lane, and each bus was 50 meters far away from each other. A pedestrian was randomly placed at the behind of the bus, which was a blind spot to the drivers. The pedestrian was programmed to suddenly move to the center of the right lane at the predetermined TTC of 2.5, 3.5, and 4.5 seconds. The speed of the pedestrian was set about 10 KMH. The appearance of the pedestrian and the release of the audio warning were designed to occur at the same time.

The Time to Collision in this study was designed so that the braking distance of high SU condition is barely enough for a full brake. On the opposite side of the road, various types of vehicle were placed and run at constant speed to make the experiment scenario more realistic.

Test Vehicle
Pedestrian

Fig. 1 Experiment scenario

Participants were asked to follow a leading vehicle, which runs at a constant speed of 60 km/h and drive along the right lane of the two-lane rural straight road. The background sound intensity during the experiment was adjusted to 60 dB.

During the critical situation, participants were instructed to press the brake pedal quickly and safely when they noticed either the auditory warning or the pedestrian. Steering maneuver was not allowed during the critical situation.

3. Experiment Procedure

3.1. Orientation phase

After the participants arrived at the driving simulator facility, they were explained general information about the research and asked to sign informed-consent documents.

After signing, they were requested to ride on the driving simulator and adjust the driver’s seat to a comfortable driving position. Then, participants were led to a prepared waiting room that is outside the driving simulator facility because auditory warning signal must not be heard during the sound intensity calibration process.

During the calibration process, participants were asked to complete a questionnaire covering demographics, driving experience, driving frequency, handedness, self-reported normal vision and normal hearing.

3.2. Driving simulator practice phase

After the calibration process, participants were called back to the driving simulator facility and rode on the driving simulator. They were given information about the practice scenario, which was designed to be the same as the real scenario, except that there were neither pedestrian nor warning signal in the practice scenario.

The purpose of this practice was to make participants get familiar with the driving simulator especially accelerating maneuver, braking maneuver and the task of following lead vehicle.

This practice session lasted about three minutes. The practice session was repeated, if the participant told that he was not familiar with operating the driving simulator. All the participants became familiar with the driving simulator by performing one or two practice session(s).

After completing the practice scenario, the participant was asked to listen the warning signal in a fixed order of high WU, medium WU, and low WU. Then, the participant was given the information concerning the questionnaire.

3.3. Experiment phase

After the practice session, participants were once again informed about the experiment instruction that they must brake the test vehicle quickly and safely when they noticed either the pedestrian or the warning signal, without using steering maneuver to avoid the imminent collision.

Each experiment scenario lasted at most two minutes. Each experiment scenarios was performed with a two-minute break in between. During this break, participants were asked to fill in the questionnaire.

4. Result

The raw data from the driving simulator were analyzed at the frequency of 120 Hz. The total number of analyzed scenarios from twelve participants was 144 scenarios. The statistical significance level was set at 0.05.

For the statistical analysis of brake reaction time, brake pedal time, and mean deceleration, Analysis of Variance (ANOVA) was performed regardless of some violations in normality assumption because of ANOVA’s robustness against the violation of normality assumption. The Shapiro-Wilk test of normality revealed a few violations in normality assumption in the data; e.g. Brake Reaction Time (p = 0.017), Brake Pedal Time (p = 0.006), and Mean Deceleration (p = 0.001). The Mauchly’s test of sphericity was performed, and it was confirmed that there was no violation concerning the sphericity. Consequently, a 2-way repeated-measures ANOVA with designed warning conditions and designed situational urgency as within-subject factors was performed.

For the analysis of questionnaire, the Friedman test was used because the Shapiro-Wilk test of normality revealed that most of the data of rated score in all questionnaire violated the normality assumption; e.g. p = 0.006 for the rated score of collision avoidance easiness, p = 0.003 for the rated score of perceived urgency of audio warning signal, and p < 0.001 for the rated score of perceived urgency during collision avoidance.

The amount of violation in normality assumption for subjective evaluation is higher than braking behavior result and thus is considered to be more severe. As a result, the nonparametric statistical test was conducted instead of parametric one. Then, the Wilcoxon signed-rank test with Bonferroni correction was used to analyze the difference between each experimental condition.

4.1. Brake Reaction Time (BRT)

The 2-way repeated-measures ANOVA revealed a significant interaction effect between Warning Conditions (WC) and SU on BRT (p = 0.01 < 0.05). The simple main effect was conducted, where the Greenhouse-Geisser correction was applied in the case where the sphericity was violated. The simple main effect means the main effect of one factor where the other factor is fixed at a certain level. It is common to evaluate the simple main effect, when the interaction between factors is significant. The simple main effect of WC was significant for high SU (p < 0.001),
and the significant mean differences in the multiple comparison with Bonferroni correction were as follows: high WU = None = -0.422, p = 0.005; medium WU = None = -0.383, p = 0.005; and low WU = None = -0.335, p = 0.01. The simple main effect of WC was significant for medium SU (p < 0.001), and the significant mean differences in the multiple comparison with Bonferroni correction were as follows: high WU = None = -0.696, p < 0.001; medium WU = None = -0.584, p < 0.001; and low WU = None = -0.522, p < 0.001. The simple main effect of WC was significant for low SU (p < 0.001), and the significant mean differences in the multiple comparison with Bonferroni correction were as follows: high WU = None = -0.748, p < 0.001; medium WU = None = -0.749, p < 0.001; and low WU = None = -0.663, p < 0.001. The simple main effect of SU was significant for none WU (p < 0.001), and the significant differences in the multiple comparison with Bonferroni correction were as follows: high WU = medium WU = -0.243, p = 0.014; and high SU = low SU = -0.391, p = 0.008. The simple main effects of WC and SU are listed in tables 2 and 3 respectively.

The descriptive statistics are graphically shown in figure 2. As shown in figure 2, in high and medium SU conditions, high WU design tends to cause the drivers to react faster than the other two WU settings. However, in low SU condition, there were four subjects who displayed a delayed response in high WU condition causing the BRT to be longer than the BRT result of medium WU condition. Furthermore, there were three subjects who exhibited a comparable brake reaction time to the medium WU condition. Thus, the mean and SD of BRT during high WU - low SU condition are comparable and wider than the mean and SD of BRT time of medium WU - low SU condition respectively.

Note: WU = Warning Urgency; SU = Situational Urgency; WC = Warning Condition; *; significant difference

### Table 2 The simple main effect of WC

| SU (TTC) | P-Value   |
|---------|-----------|
| 2.5 sec | P < 0.001 |
| 3.5 sec | P < 0.001 |
| 4.5 sec | P < 0.001 |

### Table 3 The simple main effect of SU

| WU  | P-Value |
|-----|---------|
| High| P = 0.311 |
| Medium| P = 0.642 |
| Low | P = 0.443 |
| None| P = 0.001 |

### 4.2. Brake Pedal Time (BPT)

The 2-way repeated-measures ANOVA revealed no significant interaction effect between WC and SU on BPT (p = 0.347 > 0.05). The main effects of both independent variables are also not significant; WU (p = 0.119 > 0.05), SU (p = 0.416 > 0.05).

The descriptive statistics are graphically shown in figure 3. In high and medium SU conditions, increasing the WU tends to make BPT become longer, which represents a gradual braking profile. But, that is not the case when the WU is high as shown in figure 3. The brake profile became more sudden instead causing a change in the tendency for all SU conditions.

![Fig. 3 Brake pedal time](image)

### 4.3. Mean Deceleration (MD)

The 2-way repeated-measures ANOVA showed that there is no significant interaction effect between WC and SU (p = 0.860 > 0.05). The main effect of WC is not significant (p = 0.067 > 0.05). The main effect of SU is significant (p < 0.001 < 0.05), and the significant mean differences in the multiple comparison with Bonferroni correction are as follows: high SU – medium SU = 0.538, p < 0.001; and high SU – low SU = 0.664, p = 0.001.

The descriptive statistics are graphically shown in figure 4. Figure 4 shows that MD tends to be decreased as the WU increased in general. However, in high WU condition, this tendency is changed from decreasing to increasing instead in all SU conditions. This change in trend is consistent with the BPT result that drivers tend to display harder brake profile in high WU for all SU conditions.

![Fig. 4 Mean deceleration](image)

### 4.4 Questionnaire

#### 4.4.1. Easiness of collision avoidance

The Friedman test showed that the rated score was
significantly different among experimental conditions ($\chi^2(11) = 84.554, p < 0.001 < 0.05$). Wilcoxon signed-rank tests were performed with Bonferroni correction; therefore, the corrected significance level was changed from 0.05 to 0.0056. The comparison results between with a warning condition and without a warning condition of each SU conditions are shown in table 4 with the median difference. The comparison with statistical significance difference is presented in bold number.

The descriptive statistics are graphically shown in figure 5. The figure 5 reveals that participants subjectively judged that it is easier to avoid a collision when the collision warning system was present.

In medium and low SU conditions, this rated score tends to be increased as the WU increased. However, during high SU condition, this rated score result does not show any clear difference among all WU designs.

4.4.2. Perceived urgency of the audio warning signal

The Friedman test showed that the rated score was significantly different among experimental conditions ($\chi^2(8) = 55.064, p < 0.001 < 0.01$). Wilcoxon signed-rank tests were performed with Bonferroni correction; therefore, the corrected significance level was changed from 0.05 to 0.00556. The comparison results between high WU - medium/low WU conditions and between medium WU – low WU conditions for each situational urgency condition are shown in table 5 with the median difference.

The descriptive statistics are graphically shown in figure 6. The rated score showed a clear tendency of increasing perceived urgency as the designed audio WU is increased as shown in figure 6.

The Friedman test indicated that the rated score was significantly different between experimental conditions ($\chi^2(11) = 38.124, p < 0.001 < 0.05$). Wilcoxon signed-rank tests were conducted with Bonferroni correction to see the p-value; as a result, the significance level was corrected to 0.00417. The results of the comparison between high WU - medium/low WU condition and medium/low WU – none condition are shown in table 6 with the median difference.

The descriptive statistics are graphically shown in figure 7. Figure 7 shows a tendency of U-shape in the result of perceived urgency during collision avoidance because the rated score of medium and low WU conditions usually tend to be lower than those of high WU condition and none condition.

| TTC 2.5 sec | Paired condition (Warning Urgency) |
|-------------|----------------------------------|
|           | High - None | Medium - None | Low - None |
| Z          | -2.512      | -2.952        | -3.088     |
| p          | 0.012       | 0.003         | 0.002      |
| Median Diff.| 3.0         | 2.5           | 2.5        |
| TTC 3.5 sec| High - None | Medium - None | Low - None |
| Z          | -3.104      | -2.844        | -2.429     |
| p          | 0.002       | 0.004         | 0.015      |
| Median Diff.| 2.0         | 2.0           | 2.0        |
| TTC 4.5 sec| High - None | Medium - None | Low - None |
| Z          | -2.953      | -2.848        | -2.055     |
| p          | 0.003       | 0.004         | 0.040      |
| Median Diff.| 2.5         | 2.5           | 2.5        |

4.4.3 Perceived urgency during collision avoidance

The Friedman test indicated that the rated score was significantly different between experimental conditions ($\chi^2(11) = 38.124, p < 0.001 < 0.05$). Wilcoxon signed-rank tests were conducted with Bonferroni correction to see the p-value; as a result, the significance level was corrected to 0.00417.

The results of the comparison between high WU - medium/low WU condition and medium/low WU – none condition are shown in table 6 with the median difference.

The descriptive statistics are graphically shown in figure 7. Figure 7 shows a tendency of U-shape in the result of perceived urgency during collision avoidance because the rated score of medium and low WU conditions usually tend to be lower than those of high WU condition and none condition.
Moreover, this influence of SU may also apply to none condition (no warning) too. Figure 2 shows that the BRT result of high SU condition (TTC 2.5 seconds) tends to be faster than those of lower SU designs (TTC 3.5 & 4.5 seconds). This result is consistent with one previous study’s result (12).

5.2. Brake Pedal Time (BPT)

Figure 3 reveals that increasing the WU tends to make BPT become longer, which represents a gradual braking profile. But, that is not the case when the WU is high. The brake profile became harder instead causing a change in the tendency for all SU conditions.

This change in tendency can be seen as a sign of inappropriate braking behavior because harder brake profile should be unnecessary when drivers could respond to the critical situation faster due to the presence of audio warning signal as shown in figure 2. For no warning condition, in low SU condition, BPT is longer than the BPT of high and medium SU conditions. This result indicates that when the braking distance is more than enough, drivers tend to judge that there is no need to compensate for their delayed brake response making the brake profile to be on the gradual side, unlike the other two SU conditions that drivers intuitively decided to brake harder in order to compensate their delayed reaction.

Ideally, BPT for safe braking behavior should be long since short BPT represents harder brake profile causing higher deceleration rate to the vehicle. Higher deceleration rate usually creates a sudden change in traffic flow and may lead to an accident from a rear vehicle if the driver in that vehicle could not respond to this change in time. In the aspect of possible skidding due to hard brake, although the system called Anti-Locked Braking System (ABS) exists to prevent the wheel from locking up (stopped rotation) resulting in skidding, gradual brake profile is still preferred over hard brake profile if possible.

Moreover, using more force to push brake pedal usually results in less movement’s accuracy. This reduction in precision may lead to pedal misapplication like foot slipping from brake pedal to gas pedal during the critical situation or even mistakenly pushing the gas pedal from start.

According to two previous literature concerning the possible cause of this harder brake profile, the first one defined the startle response types as a panic stop to avoid a collision. When an animal, vehicle, or pedestrian is in the driver’s immediate path, and the driver tries to slam on the brakes to avoid a collision (16). The other one mentioned that when drivers perceive a sudden stimulus as being life threatening and requiring an immediate solution. They tend to get startled response. The response usually exhibits in the form of an attempt to slam on the brake (17).

Therefore, when there is more braking distance due to the faster reaction time, stomping on the brake pedal during the critical situation should be considered as an inappropriate braking response.

5.3. Mean Deceleration (MD)

The result suggests that when brake reaction time is improved due to the presence of medium and low WU signal, the driver tends to use more gradual brake which results in lower MD. This behavior indicates that these medium and low WU designs improve collision avoidance performance in both aspects of BRT and how drivers pushed the brake pedal. On the other hand, in high WU setting, the trend of MD is changed from decreasing to increasing instead. This change suggests that further increased in WU from medium one may not provide further benefit anymore.

This result supports the discussion of startle response, which
is discussed previously in brake pedal time discussion. Drivers tend to slam on the brake when they perceive a sudden intense stimulus and become startled (16,17). Thus, in this study’s result, this change in mean deceleration trend when using high warning urgency may be caused by this response.

5.4 Mismatch in warning urgency and situational urgency

According to Sokolov’s comparator theory of habituation compares sensory information to a “neuronal model” of an anticipated stimulus (14,15), human tend to create a model of a stimulus after they receive a stimulus many times.

This theory proposed an assumption that when a sensory input (i.e., a perceived stimulus) matches the model, a response to the input is inhibited. However, if the sensory input and the model are mismatched with each other, the amplitude of the response to the input was said to be related to the magnitude of the difference between the sensory input and the model. This study observed a strong response when the mismatch between the sensory input and the model is large during early stimulus repetition. In late repetition, the model comes to represent the sensory input better; consequently, the strength of the response became weaker. From this theory, in driving context, the sensory input should be a warning signal, whereas the model should be something that warning signal try to represent and notify the driver; e.g. imminent collision event.

In general, a human can perceive a stimulus urgency intuitively. Moreover, they instinctively know that higher perceived urgency warning signal should represent something that they should pay their attention quickly or at least faster than usual. According to Sokolov’s theory, the mismatch between warning urgency and situational urgency should cause a stronger response than normal.

In the aspect of Psychophysiology, a response can be categorized into three types including orienting, defensive and startle response. Their definition can be described briefly as of the following (15):

1. Orienting response
Orienting response directs attention to stimuli and enhances sensory processing in order to understand the stimuli. This response can be described as “What-is-it?” response.

2. Defensive response
Defensive response protects living beings from any possible threat. This response activates physiological adjustment in order to prepare them for defensive action.

3. Startle response
Startle response is elicited by an intense stimulus. Its function is to interrupt and disengage from ongoing activity. The main difference between startle response and defensive response is response speed.

From the description of these responses, they implied that the amplitude of mismatch between the sensory input and the model for startle response should be higher than those of orienting response and defensive response.

Startle response usually is elicited from an intense stimulus, which should have higher perceived urgency in general. Moreover, startle response usually leads to an inappropriate driving response as mentioned in previous literature (16,17). In this study, the only clear inappropriate driving response due to the mismatch that can be observed is the delayed brake reaction time under high WU - low SU condition. Among all participants, there were four subjects who displayed such response.

Table 4 reveals that the p-value of high WU design is significantly different from none condition only in medium and low SU conditions while the p-values of medium WU design are all significantly different from none condition. This suggests that medium WU design works better than the other WU settings in this subjective evaluation.

The rated scores of no warning condition in all situational urgencies are lower than those of with warning conditions especially in no warning – high situational urgency condition, the score is the lowest among all experimental conditions because the number of the collisions, which occurred in this condition, is the highest when comparing to other conditions because drivers could not brake the test vehicle in time.

5.5.2 Perceived urgency of audio warning signal.

This result of the clear tendency of increasing perceived urgency as the designed audio WU is increased as shown in figure 6 is consistent with previous studies concerning on the influence of acoustic parameter on the perceived urgency of the audio warning signal. There is no clear sign of the influence of situational urgency on the perceived urgency of the warning signal.

5.5.3 Perceived urgency during collision avoidance

As shown in figure 7, this reduction in the rated score in medium and low WU condition suggests the possible benefit of the presence of auditory warning signal that made the driver’s braking response become faster resulting in the more braking distance. With more braking distance, the sense of SU should be reduced when comparing to no warning condition.

However, in high WU condition, the perceived urgency during collision avoidance tends to be given a higher score than those of medium and low WU conditions making it comparable to the rated score of no warning condition. This change indicates that the sense of urgency that driver could felt may come from the influence of acoustic parameters rather than the influence of SU. This scoring suggests that medium and low WU designs should be used as the warning setting since they effectively reduce the sense of urgency of the driver to the critical situation.

6. Conclusion

This study investigated drivers’ braking behavior during frontal collision event in a driving simulator experiment. Its objective is to evaluate how drivers respond to all designed WU under several SU conditions by analyzing the BRT, BPT, and MD.

It should be noted that the findings of this study were limited by the driving simulator paradigm. Although the driving simulator is equipped with six degrees of freedom motion platform to imitate real driving sensation, the mindset of the participants in this experiment may not similar to the real one since all critical situations took place in the simulating dimension and hence cause no harm even if the accident occurred. Moreover, the realistic critical situation most likely will not occur as frequently as this study. The number of participants in this study was twelve persons, which can be considered as low when compared to other studies.

Even though the results of this study may not be able to directly represent a realistic driving response, it should give some insights on the influence of the combination of situational urgency and warning urgency on the collision avoiding response. Although in this study, there is no significant difference in braking behavior from matching WU to SU could be found, the overall result indicates that the medium WU design tends to cause more stable and more appropriate braking response than the other two WU designs for all SU conditions.

5.5.1 Easiness of collision avoidance

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