Vibro-tactile Hazard Notification for Motorcyclists

Akimasa Suzuki

Dept. of Information Science
Iwate prefectural University
020-0693, 152-52, Sugo, Takizawa, Iwate, Japan
Email:suzuki_a@iwate-pu.ac.jp

Yuta Yamauchi

Ad-Sol Nissin Corporation
108-0075, Rivage Shinagawa, 4-1-8,
Konan, Minato, Tokyo, Japan
Email:Yamauchi.Yuta@adniss.jp

***Abstract*—This paper evaluates the effectiveness of vibro-tactile notifications for motorcyclists under external factors. Although many car manufacturers provide side and rear collision warning systems with auditory or visual alarms, such notifications may confuse a motorcyclist because they already need to be aware of many visual targets, such as mirrors and monitors, and of environmental sounds. We propose a vibro-tactile notification system using a vibration speaker installed in a motorcycle helmet between the outer shell and the cushion. The proposed system should enable motorcyclists to correctly identify the directions of five vibrating motors, three levels of risk, and three obstacle types (i.e., pedestrians, vehicles, and motorcycles). We evaluate the system under windy and engine vibration conditions and examine notification accuracy via experiment. Our results indicate that motorcyclists can correctly detect four directions and three threat levels using this system.**

***Index Terms*—vibro-tactile notifications; helmet actuators; vibration speakers; motorcyclists; noise tolerance.**

I. Introduction

This paper is an extension of our paper initially presented at the Ninth International Conference on Advances in Vehicular Systems, Technologies and Applications [1]. In this paper, we conduct additional experiments on several kinds of vibration pattern, and further demonstrate the effectiveness of our proposed system.

There has been considerable research into accident prevention systems for vehicles, particularly in relation to developing driving support systems that will transition to autonomous driving systems. Autonomous vehicles, such as Tesla [2], have achieved practical four-wheel vehicles with Level 2 autopiloting. Furthermore, the vehicles are collecting training data for realization of Level 4 autopiloting. However, to realize autonomous driving systems, we must overcome problems related to cyber-security measures and traffic laws (e.g., responsibility for accidents by autonomous cars [3]), which could take time. Additionally, as many people enjoy driving, the demand for manual driving as a hobby is unlikely to fade. Driving support systems will thus remain an important feature. Moreover, despite the high number of driving support systems used in Japan, many fatal vehicle accidents are caused by violations of safe driving practices, such as failing to keep eyes on the road, careless driving, and failing to make safety checks [4]. This highlights the need to develop more techniques that support drivers. Of the 288,995 road accidents in 2020 in Japan, 208,983 were caused by the violation of safe driving practices.

A support system for motorcycles is more important for driving protection than for other vehicles because when a motorcyclist is in a crash, they are more likely to die, owing to the reduce protection from the vehicle. Hazard notification is vital for motorcyclists because of their limited visibility, the diverse sounds they may hear, and their very high risk of accident. The fatality rate in crashes for motorcyclists is 1.22%, while it is only 0.35% for drivers of four-wheel vehicles [5]. Furthermore, motorcycles are small and difficult for other drivers to recognize. Motorcyclists therefore need to be highly aware of their surroundings, but this is difficult because of the blind spots caused by their helmet and small mirrors. To avoid incidents, an intuitive notification system that can specify direction and threat level would be beneficial. Therefore, we propose a system that uses haptic sensations to quickly notify a motorcyclist of possible hazards or obstacles around the vehicle.

Our proposed hazard notification system uses vibro-tactile actuators installed in a motorcycle helmet. The system notifications indicate the type of object, direction, and threat level surrounding the vehicle. We evaluate robustness against wind and motorcycle engine vibration. We also perform experiments to test the effectiveness of our proposed system. Section II reviews related research. Section III describes system architecture considerations. Section IV presents the system architecture. SectionV discusses the vibration intensity issue. Section VI presents the experimental methods and results under the influence of motorcycle engine vibration. Section VII describes the experiment methods and results under the influence of driving wind. Section VIII gives the conclusions.

II. Previous and related works

For vehicles such as four-wheel vehicles, many practical driving support systems employ image [6], radar [7], and ultrasonic sensors [8] to detect pedestrians and other vehicles with high accuracy. Around-view monitors are increasingly being used for automatic parking [9] and lane-detection systems are being applied using three-dimensional (3-D) laser imaging detection and ranging (LIDAR) [10]. Despite their weakness to noise, ultrasonic sensors can now be installed in driving support systems for a low cost, and the cost of 3-D LIDAR is also dropping. These devices can be used to detect not only the presence of an obstacle, but also the type of obstacle (e.g., pedestrian, vehicle, or motorcycle). In the current study, we focus on creating a notification method to alert drivers to potential hazards, rather than the development of a sensor system.

For preventing accidents on motorcycles, there are two main approaches: motorcyclists are assisted in checking their surroundings or drivers around a motorcycle are assisted in recognizing motorcyclist locations. For the latter approach, a helmet with brake lights has been investigated for practical use [11]. However, we focus on the former approach in this study. Hazard notification systems have been proposed for four-wheel vehicles [12] [13].

In addition, sensor systems, such as collision [14] or ground [15] detection methods, have been investigated for detection around a motorcycle. Many systems have focused on the sensor, however, we aim to not only sense issues, but also method for providing information more correctly to the motorcyclist. One study [16] proposed a smart helmet using a multimedia Internet of Things (IoT) sensor device and visual notifications. Many conventional notification methods for motorcycles rely on visual images in the motorcyclist's view [17] [18], such as front view, mirror, tachometer, speedometer, navigation system, and indicators. Therefore, there is the potential that excessive visual information may instead impact the motorcyclist's capacity to adhere to safe driving practices.

We focus on vibro-tactile notification as an option for non-visual information. Vibro-tactile notification is a possible candidate for providing information because early motorcycles conveyed engine failure to riders via irregular vibration. Some systems vibrate a motorcycle's steering, but this approach is limited to notifications in front of or behind the motorcycle [19]. We previously proposed a system for four-wheel vehicles that used haptic sensations to quickly notify drivers of possible hazards or obstacles surrounding the vehicle [20]. We examined the system's robustness against different material types and layers used for the driving seat cushions of four-wheel vehicles [21]. In this study, we also discussed vibrating waveforms by using a real 4-wheel vehicle, and illuminated higher accuracy on notification by using category-deformed and normalized waves between each actuator than real and certain vibration waves, respectively. Moreover, we discussed notifying accuracies of our system from an experiment combined with conventional notification system with a display and a sound speaker. From this experiment, we also discussed whether our system is obstructive or useful to driving.

The motorcycle seat is vibrated by the engine, although this may make it more difficult to notify the rider through vibration. In this study, we perform experiments under wind and engine vibration conditions to consider the viability of a highly intuitive notification system for motorcycles.

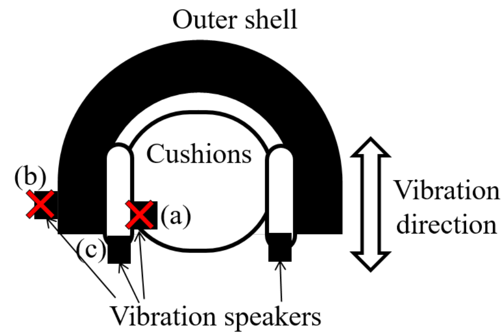


Figure 1. Proposed installation positions for actuators in a motorcycle helmet.

III. Mounting positions of actuators for motorcycles

In this section, we detail the system architecture.

A. *Locations of vibro-tactile actuator for notifications*

The proposed system aims to help motorcyclists correctly identify the directions of five vibrating motors, three intensity settings to indicate the level of risk, and three obstacle types (i.e., pedestrians, vehicles, and motorcycles). The position of vibration is important for giving critical notifications. We considered vibro-tactile actuators on the motorcyclist's arms, shoulders, or waist within a motorcyclist's suit or on the motorcyclist's head within a helmet. For locations on the body, the motorcyclist must use a wearable device. There are different types of suits for different motorcycles types (e.g., Cruiser or Sport) because the riding posture is different. Drivers may also experience limited mobility in a suit, which would impact accurate notification.

In contrast, helmets are usually fitted to the motorcyclist's head, and vibration positions are not affected by varying postures, although they are limited to facing forward. Helmets are also required in many countries. Therefore, we choose helmets for our proposed system. Figure 1 shows the possible installation positions within a motorcycle helmet. We cannot mount an actuator inside the helmet itself, as at (a), because direct contact with the driver's head would be unsafe. We considered the helmet's outer surface, as at (b), but our attempts showed that a very strong vibration would be needed. Therefore, we mount the actuators at the bottom of the cushion in the helmet, as at (c), so that the actuators vibrate vertically to each cushion.

We considered three types of vibration mechanisms: vibration motors, haptic reactors, and vibration speakers. Vibration motors can only produce sine waves and it is difficult to distinguish different categories, although they can achieve strong vibration. Although haptic reactors can realize a variety of vibrations, such as clicking, their vibration is too weak to produce notifications. We therefore propose a vibro-tactile notification system using a vibration speaker, which can realize the vibration with strong and varied expression. For our proposed system, we utilized a vibrating speaker with an Acoustic

TABLE I
SPECIFICATIONS OF THE ACOUSTIC HAPTIC™ACTUATOR

Shape inch method	⌀20x27.6 mm
Weight	39.29 g
Acceleration	6.1 m/s^2
Rise time	34.5 msec (0 to 90 %)
Drop time	34.5 msec (100 to 10 %)
Resonance Frequency	55 Hz (700 g, 2.83 V)
Impedance	8 Ω
Inductance L_e	0.66 mH
Power consumption	0.144 W (700 g, 2.83 V, 55 Hz)

Haptic™actuator developed by Foster Electric Company. The actuator, whose specifications are shown in Table I, is a type of woofer that comes into direct contact with the driver's helmet. The resonance frequency is 55 Hz, which makes it possible to generate strong vibrations in the low frequency range. To achieve uniform signal strength in any waveform, it is important to focus on the resonance frequency.

B. Mounting positions of actuators on a helmet

Motorcycle helmets have shields that can reduce visibility. They may also become fogged with weather and temperature, which further limits the motorcyclist's visibility. Motorcyclists also have blind spots behind the motorcycle where the mirror's field of view does not reach. Therefore, we consider the need for both backward and forward alerts. Figure 2 shows the planned layout of actuators in the helmet. This helmet has four cushions (i.e., front, rear, right, and left), as shown in sections (1) to (4) in Figure 2. To explore the vibro-tactile directional sense at the motorcyclist's head, we installed eight actuators as shown in Figures 2 (a) to (h). We mounted actuators (a), (b), and (h) on cushion (1), (c) and (d) on cushion (2), (e) on cushion (3), and (f) and (g) on cushion (4).

We conducted an experiment to evaluate the resolution of vibration on the human head. By determining the resolution of human-perceivable locations, we aimed to determine which directions are identifiable. We performed the experiment with the engine in idle at 1500 ± 300 rpm, which is frequently used as a typical speed range, on a Yamaha MT-01 motorcycle equipped with a V-twin cylinder 1670 cc engine. We had five participants (students), aged between 19 and 22 years old. We conducted four trials with each participant. We randomly induced vibrations at each position with strengths ranging from -2 dB to -12 dB and participants estimated the position in the helmet.

Figure 3 shows the correct answer rates for direction using all eight or only four actuators (one on each cushion: (a), (c), (e), and (g) in Figure 2). The vertical and horizontal axes denote correct answer rates and installation positions, respectively, and the green and orange bars indicate results for respectively all eight or only four actuators. The results demonstrate that there was confusion when multiple actuators were installed on a single cushion, leading to lower accuracy.

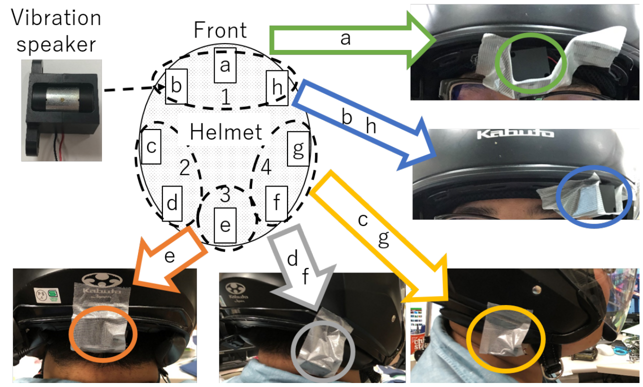


Figure 2. Experimental arrangement of mounted actuators.

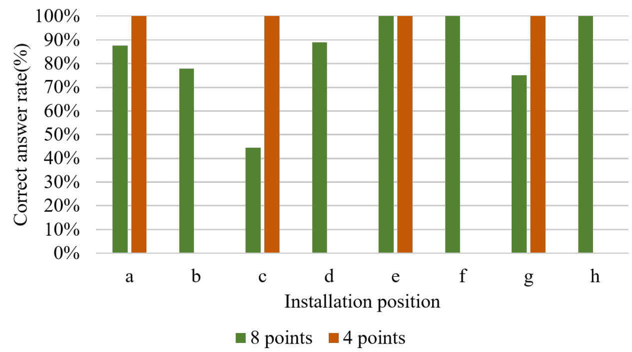


Figure 3. Correct answer rates according to the number and position of actuators.

By contrast, all participants had a 100% correct answer rate when four actuators were used. We therefore decided to utilize only one actuator per cushion.

IV. SYSTEM ARCHITECTURE FOR OUR PROPOSED SYSTEM

In line with the aforementioned experiment shown in Figures 2 and 3, we propose a vibro-tactile helmet as illustrated in Figure 4. Figure 4 (A) shows the positions of the actuators (or vibration speakers) on the helmet. Figure 4 (B) shows pictures of the different actuators in place; note that (b) and (d) are in the same position on the left and right sides of the helmet, so only one is shown.

The actuators shown in Figure 4 vibrate by transmitting sound data via the amplifiers. The sound data are deformed waves for three categories (i.e., pedestrian, four-wheel vehicle, and motorcycle) the same as in our previous study for four-wheel vehicles [21].

A. Waveforms for Categories

From our previous study [21], pedestrian notifications achieved higher correct answer rates than other obstacle types, owing to the more easily recognized notifications of the obstacle type than for other vibration waves. Thus, we aim to improve accuracy for the motorcycle and four-wheel vehicle obstacle types by making their waveforms more contrasting. Therefore, we utilize deformed waves for these obstacle types.

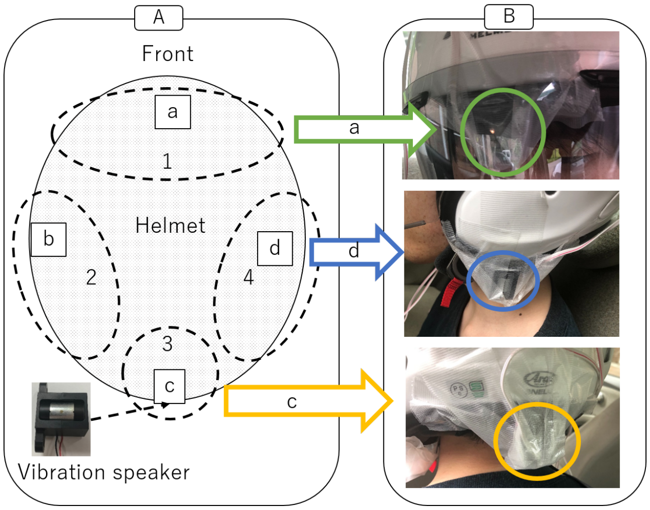


Figure 4. Overview of our proposed system.

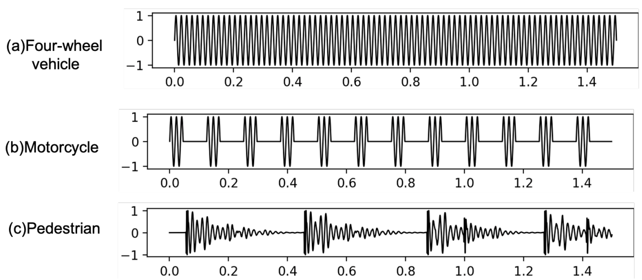


Figure 5. Waveforms for each category of object.

Figures 5(a), (b), and (c) show deformed waves based on the sound of a V6 engine revving up [22], the idling sound of a Suzuki GSX-S1000 motorcycle [23], and a real recording of footsteps with leather shoes [24], respectively. Note that, while a motorcycle is expressed by an intermittent deformed waveform, as in Figure 5(b), the interval is shorter than the waveform of the pedestrian shown in Figure 5(c). By contrast, the four-wheel vehicle is given a constant waveform to increase the contrast with the motorcycle waveform.

V. Vibration Strength

In this section, we discuss the strength of the vibrations for our proposed system.

A. Determination of optimum base sound level of each category

Our previous study in four-wheel vehicles [20] had three vibration strength levels (i.e., large, medium, and small) to indicate the level of risk. However, when riding a motorcycle, there is additional noise, such as from engine vibration or wind. Furthermore, we have not yet applied the vibration strength level concept to a helmet. Therefore, we consider the vibration strengths of the three levels.

We conducted an experiment with five participants aged between 19 and 22 years old, using an idle Yamaha MT-01.

TABLE II
Normalized vibration strength levels on Pattern B.

Category	large	medium	small
Four-wheel vehicle	-3 dB	-8 dB	-12 dB
Motorcycle	-2 dB	-8 dB	-12 dB
Pedestrian	-2 dB	-8 dB	-12 dB

The strength pattern is defined by the difference in the sound pressure. We considered two strength patterns. Pattern A has a small difference between the three levels. We can utilize a fourth level if we can detect the differences in Pattern A. Pattern B has larger differences than Pattern A, with the larger vibration for four-wheel vehicles adjusted so as not to prevent the motorcyclist from driving.

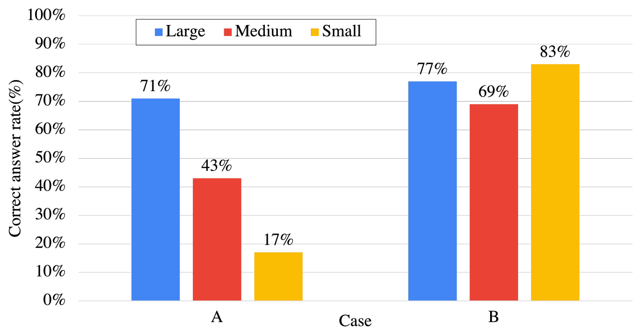
The strength levels of Pattern A, denoted large, medium, and small, were respectively -6 dB, -10 dB, and -12 dB from the original sound data based on the previous experiment [20], for all categories. The strength levels of Pattern B were different according to the category based on the normalization method [21], as shown in Table II.

We conducted this experiment using random directions, categories, and vibration strengths. Test participants answered ”large”, ”medium”, ”small”, or ”insensitive” as the levels of strength. In this experiment, we conducted the test in a stable room, and large, medium, and small strengths were randomly vibrated 51, 64, and 64 times, respectively, for 5 to 10 seconds. The experiment was conducted with the helmet shield closed. The test participants were taught three levels of vibration intensity (large, medium, and small) beforehand at actuator (d) in Figure 4, and then the experiment was conducted.

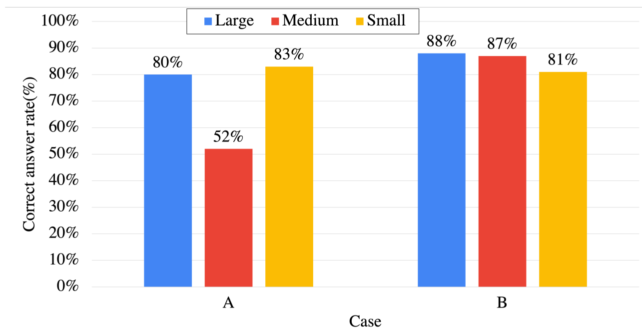
Figure 6 shows the experimental results for both patterns. The vertical and horizontal axes denote correct answer rates and strength levels, respectively. The blue and brown bars respectively indicate Patterns A and B. Pattern A had low correct answer rates for medium and small, and as well as instances of ”insensitive” shown as 0 percent in6(a). Pattern B had correct answer rates of over 69% for each strength level. Figure 6(b) and (c) show the percentage of correct answers for each pattern A and B in the comparison experiments for pedestrians and motorcycles, respectively. Figure 6(b) shows that 80%, 52%, and 83% of the participants rated the vibration intensity as ”large”, ”medium”, and ”small”, respectively, for Pattern A. Figure 6(b) shows that the percentages of correct responses for large and medium were much higher for Pattern B than for Pattern A. Figure 6(c) also shows that the percentages of correct answers for medium and small were much higher for Pattern B than for Pattern A. Thus, we adopt a notification method of three strength levels with large intervals like Pattern B.

B. Normalization by head sense

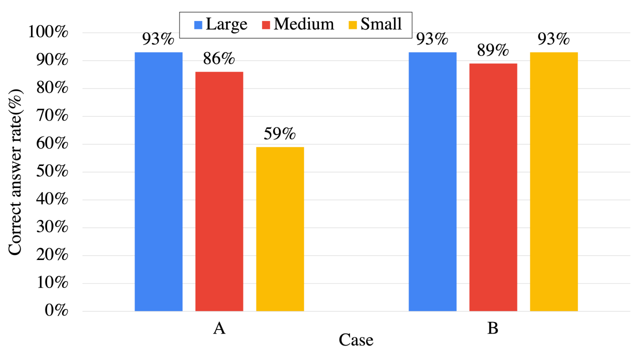
In this study, we apply normalized and exaggerated waves to improve notification accuracy because many motorcyclists pointed out that the vibration strength felt uneven depending



(a) Fourwheel



(b) Pedestrian



(c) Motorcycle

Figure 6. Correct answer answer rates for strength patterns A and B.

on the installation position. Here, we normalize the vibration strength for the different parts of the head via an experiment on the motorcycle, in addition to normalization by category with Pattern B in Figure 6.

For normalization, we utilized three actuators, (a), (b), and (c), on the front, rear, and left cushions, respectively, in Figure 4. Actuator (d) in Figure 4 is considered to have the same tendency as actuator (b). First, via a questionnaire, we determined the maximum and minimum strengths motorcyclists can detect with no effort. The results indicated that the gap between the maximum and minimum strengths for actuator (b) was greater than that for the other positions. Thus, we used the maximum and minimum strengths that participants felt for (b) for all the actuators. We denoted the maximum and minimum strengths as large and small, respectively. We defined the medium strength level not as the midpoint value

TABLE III
VIBRATION STRENGTH LEVELS AT EACH POSITION.

position	large	medium	small
a	−6 dB	−10 dB	−14 dB
b	−8 dB	−12 dB	−19 dB
c	−6 dB	−10 dB	−13 dB

(in decibels) between large and small, but instead according to how participants identified "medium" between large and small vibrations. In this normalization, we utilized the vibration of the four-wheel vehicle category [21]. Finally, we adjusted for strength as shown in Table III, which presents the strength levels for each actuator position, noting that the side position is more sensitive than the front and back positions.

VI. EXPERIMENT OF IDLING SCENARIO

We conducted an experiment to verify the correct answer rates when using actuators mounted on a helmet when there are external factors, including wind and engine noise.

A. Experimental Trials by t-test

We used t-tests to determine statistically significant results. We conducted an independent t-test for each strength level on actuators (a), (b), and (c) to compare the differences in correct answer rates under different wind and idling noises. We adopted a significance level of 5%, a moderate effect size of 0.5, and a detection rate of 80%. Possible answers were "large", "medium", "small", and "insensitive". Sample sizes for the answer of "large" and the other strength levels were determined from one-sided and two-sided tests, respectively. From the t-test, sample sizes from which we could obtain a significant difference were 51, 64, and 64 samples for "large", "medium", and "small" answers, respectively.

B. Correct answer rates during idling

We conducted an experiment in the idling state to evaluate the robustness under engine vibration, as illustrated in Figure 7. Six test participants on the motorcycle answered when they felt a vibration. This experiment was conducted with the engine off, at 0 rpm, and rotating at 1000 rpm, 1500 rpm, and 2000 rpm. In the case of 0 rpm, the experiment was considered a situation of engine stopped. For each engine speed, including 0 rpm, we performed 51, 64, and 64 trials for large, medium, and small, respectively, at random. The vibration categories used were those applied to four-wheel vehicles in our previous study [21].

Figure 8 shows the correct answer rates during idling rpm at 0 rpm, 1000 rpm, 1500 rpm, and 2000 rpm, respectively. The blue, red, and yellow bars respectively indicate "large", "medium", and "small" as answered by the participants. The vertical and horizontal axes of each figure denote the correct answer rate and the three levels of signal strength, respectively. For example, 10% of participants answered "medium" for the "large" strength level given by an actuator at 1000 rpm, as shown in Figure 8(b).

Figure 7. Overview of the experiment during idling.

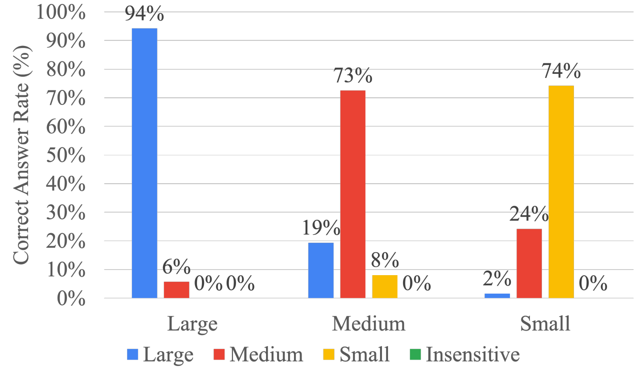
We defined the correct answer rate as the percentage of matches between the answers of participants and the actual level of vibration strength. For example, in Figure 8(b), the correct answer rates for ”large”, ”medium”, and ”small” were 90%, 72%, and 83%, respectively. Let us focus on the medium strength level in Figure 8(b). We confirmed that participants experienced stronger vibration at this level because they answered ”large” more often than ”small”. The correct answer rates were lowest in the case of Figure 8(d). This may be due to the high engine rotation causing stronger vibration and noise from the motorcycle, obscuring the vibration from the actuators.

VII. Evaluation of driving scenario

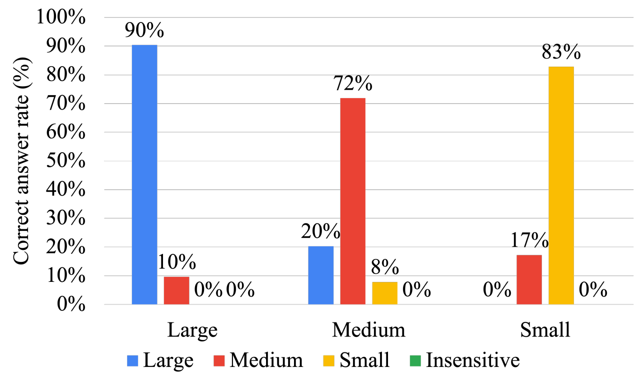
We conducted an experiment with six participants using a car to evaluate accuracy degradation due to wind. We used a car for safety and because of the difficulty in collecting answers. Although the strength of the traveling wind is little different between cars and motorcycles, the effect of the wind can be measured. We compared the wind noise between the car and the motorcycle, and found that the wind noise on the motorcycle was almost the same as on a car with all windows open.

A. Experiment on the vibration categories of a four-wheel vehicle

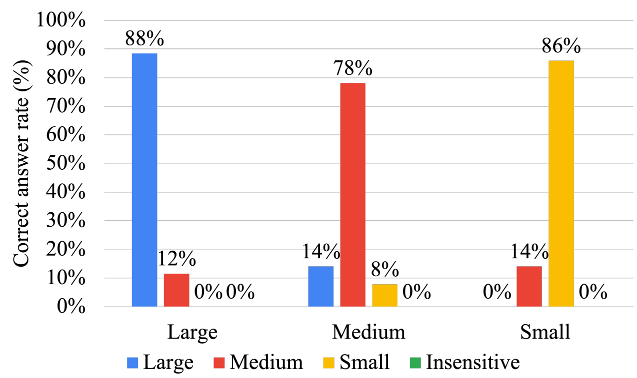
First, we experimented with the vibration categories of a four-wheel vehicle. Each participant performed the experiment at the four speeds of 0 km/h, 60 km/h, 80 km/h, and 100 km/h. At each speed, we performed 51, 64, and 64 trials with large, medium, and small strength levels, respectively, at random. The actuator vibrated for 5-10 s at random for each trial. In the case of 0 km/h, we conducted the experiment in a situation with engine stopped, as in Section VI-B. In the other cases, we used a highway. Figure 9 shows the experimental highway route. This route has two lanes in each direction limited to 100 km/h, and three entrances and exits shown



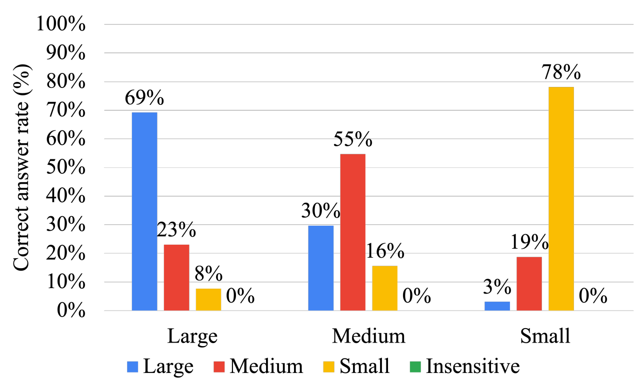
(a) 0 rpm



(b) 1000 rpm



(c) 1500 rpm



(d) 2000 rpm

Figure 8. Correct answer rates for different strength levels at (a) 0 rpm, (b) 1000 rpm, (c) 1500 rpm, and (d) 2000 rpm.

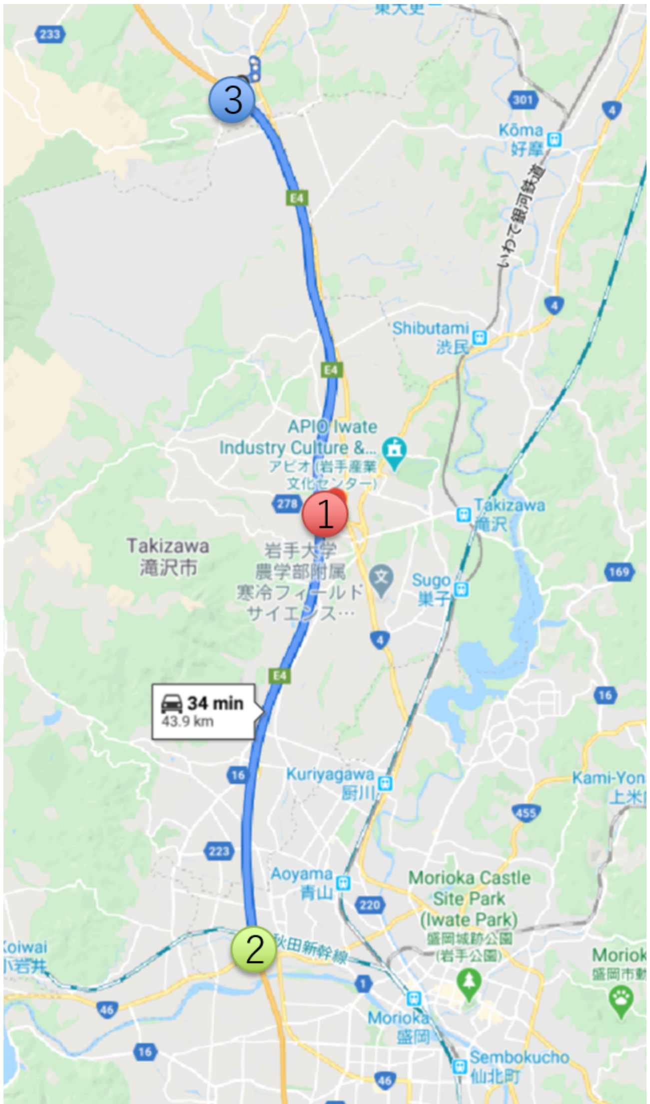


Figure 9. The course of the experiment on a highway.

as ①, ②, and ③. We set up sections of 11.1 km between ① and ②, 20.3 km between ② and ③, and 9.2 km between ③ and ①.

The experiment was conducted at speeds of 80 km/h, 100 km/h, and 60 km/h between ① and ②, ② and ③, and ③ and ①, respectively. Figure 10 shows the seating positions of the participant in this experiment. All windows of the car were open and the helmet shields were closed. Before the experiment, participants were provided with examples of the three strength levels at position (b) of Figure 4. We limited the experiment to the four-wheel vehicle category. The experimental results were saved as movie files and evaluated via post-processing.

Figure 11 shows the correct answer rates at driving speeds of 0 km/h, 60 km/h, 80 km/h, and 100 km/h. The vertical and horizontal axes of each figure denote the correct answer rate and the three levels of signal strength, respectively. In Figure 11(a), the correct answer rates were in 94%, 73%,

Figure 10. Seating position of participants in the vehicle.

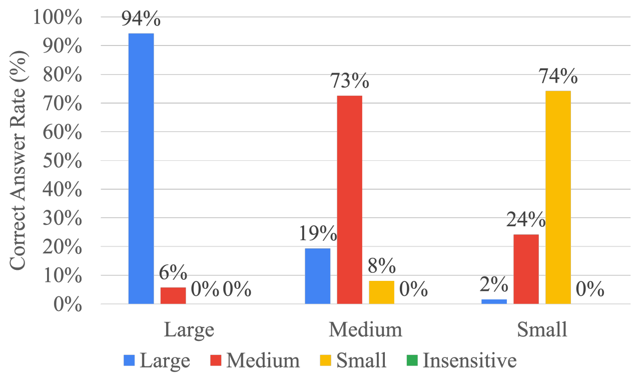
and 74% for large, medium, and small vibration strengths, respectively. Figure 11(b) indicates a high correct answer rate for large vibration. Test participants tended to be more likely to select strong vibrations. In the case of Figure 11(c), the correct answer rates were increased and decreased, respectively, for medium and large vibrations as compared to Figure 11(b). In Figure 11(d), a high correct answer rate was obtained even for small vibrations. From Figures 11(c) and (d), the medium strength level showed only small differences in the incorrect answer rate compared with large and small. Therefore, we consider the medium strength level to be appropriate in the high-speed case. We expect a higher notification accuracy can be achieved by adjusting the strength automatically depending on outside noise. We also found that notification accuracy was more degraded by engine rotation than by wind noise, which should be a consideration for practical implementation.

B. Experiment on the other categories

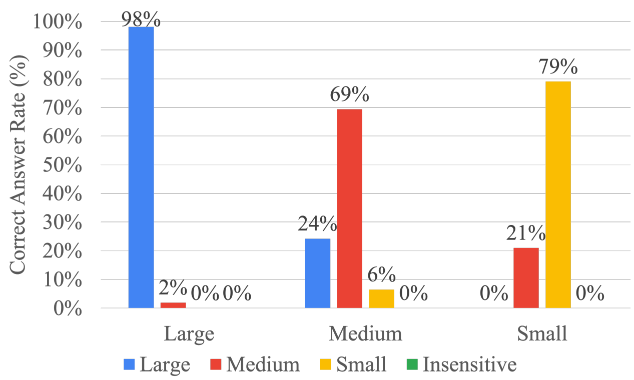
Next, we performed the experiment for other vibrations for motorcycle and pedestrian categories. The experimental settings were the same as Figures 9 and 10. However, each participant evaluated the experiment at the speeds of 0 km/h, 60 km/h, and 80 km/h, because the speed limit had been changed on the target highway by the time of the experiment.

Figures 12 and 13 show the correct answer rates in the vibration patterns for pedestrians and motorcycles, respectively, at the different driving speeds. In the case of pedestrians, the percentage of correct answers for medium and small increased as the wind speed increased from Figures 12(a) to (c). On the other hand, the percentage of correct answers for large was the lowest in Figure 12(c). A lower medium strength might be required, because the number of incorrect "large" answers was higher than the number of "small" answers for the medium vibration, as shown in Figure 12(a). However, Figures 12(b) and (c) show that the difference in the number of "large" and "small" answers in the evaluation of the medium vibration was slight. Thus, the medium intensity is suitable for 60 km/h and 80 km/h as vibrations for the pedestrian category.

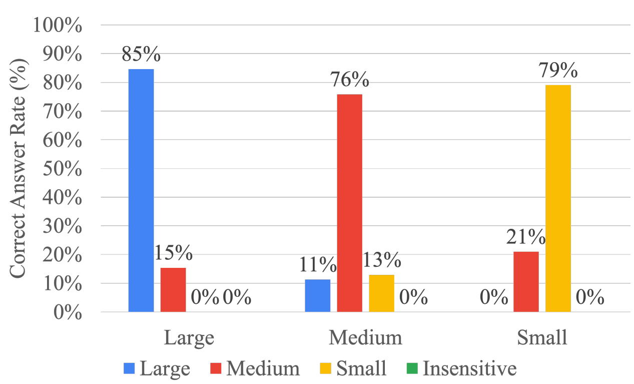
For the motorcycle category, the percentage of correct answers for small increased as the traveling wind became stronger, as shown in Figures 13(a), (b), and (c). These results



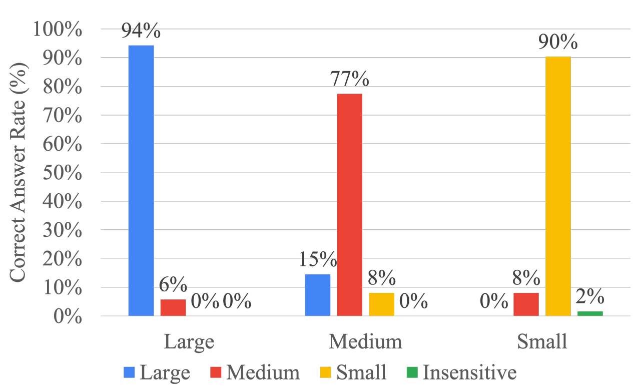
(a) 0 km/h



(b) 60 km/h

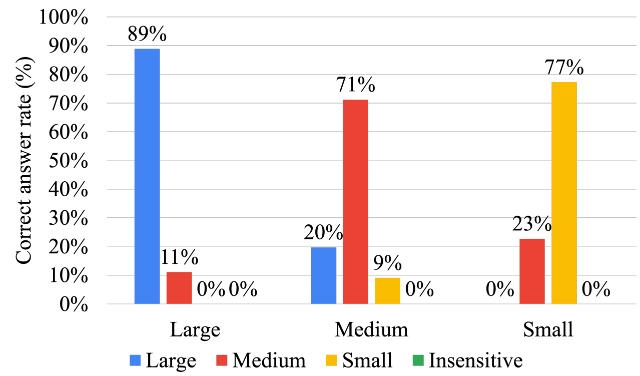


(c) 80 km/h

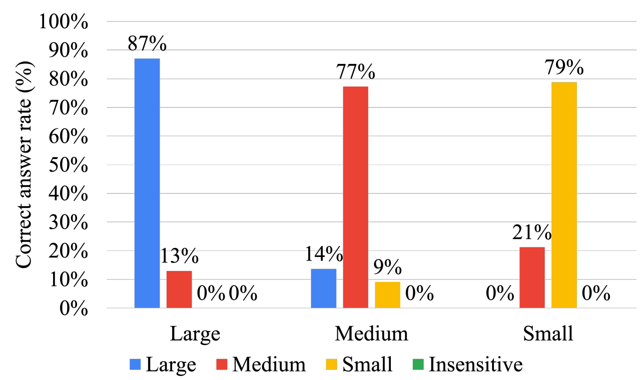


(d) 100 km/h

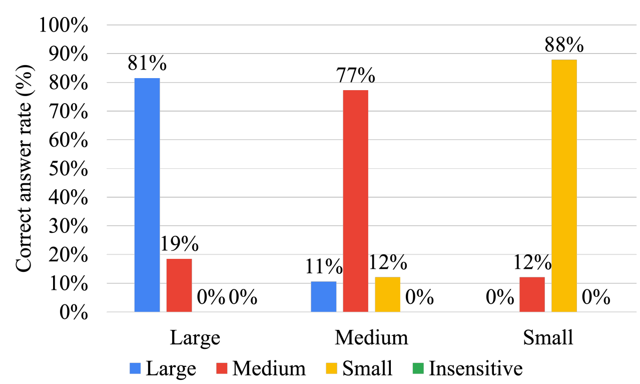
Figure 11. Correct answer rates for strength levels at each speed (four-wheel vehicle).



(a) 0 km/h



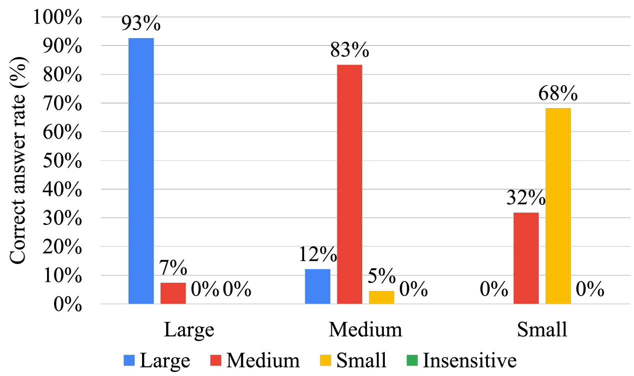
(b) 60 km/h



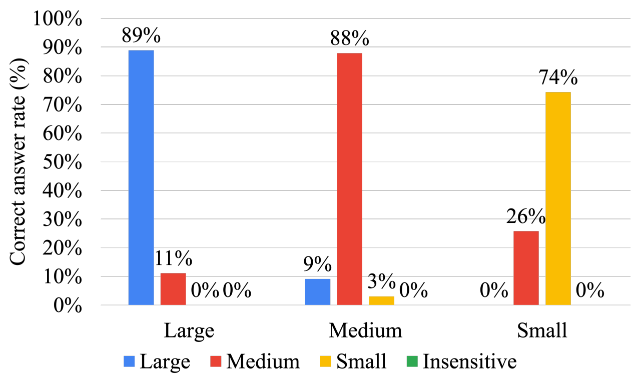
(c) 80 km/h

Figure 12. Correct answer rates for strength levels at each speed (pedestrian).

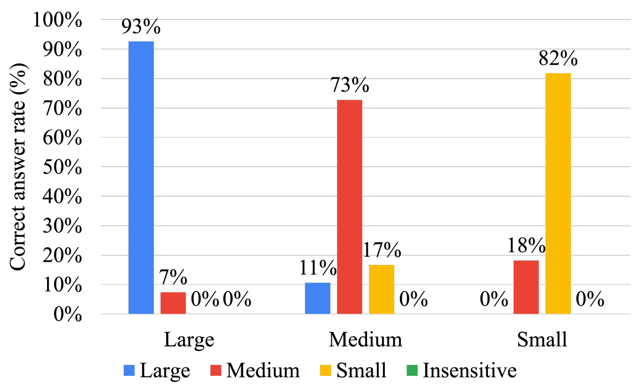
also show that the percentage of correct answers for large remained high in all speed ranges. Figure 13(c) has the lowest percentage of correct answers for medium. The difference in the number of "large" and "small" answers for the medium vibration was smaller than that for the small vibration in the case of Figures 13(a) and (b). Furthermore, in Figure 13(c), the difference between the number of "large" and "small" answers in the evaluation of the medium vibration was small, indicating that the medium intensity is suitable only for 80 km/h. We expect a higher notification accuracy can be achieved by adjusting the strength automatically depending on outside



(a) 0 km/h



(b) 60 km/h



(c) 80 km/h

Figure 13. Correct answer rates for strength levels at each speed (motorcycle).

noise, as in the case of a four-wheeled vehicle.

VIII. Conclusions

It is difficult for motorcyclists to recognize objects in their surroundings because of the many blind spots from their helmets and their smaller mirrors. Furthermore, accidents are more serious and have higher mortality rates for motorcycles than for four-wheel vehicles. We therefore proposed a notification system for motorcycles based on previous works for four-wheel vehicles. In our system, parts of the helmet vibrate corresponding to the direction of a hazard, the category of an object, and the level of risk. We used the strength of vibration to indicate three strength levels. We evaluated the accuracy of our proposed notification method for motorcycles using haptic actuators in windy and idling situations. We demonstrated the effectiveness of our notification method even for winds of $80\ \mathrm{km/h}$ on each waveform category. We expect improved notification accuracy can be achieved by adjusting vibration strength according to the motorcycle's speed. Various helmet types will be studied by quantitative assessment in future works.

Acknowledgment

This work was supported by MEXT KAKENHI Grant Number JP 16723884 and Foster Electric Company, Limited. We would like to thank Uni-edit (https://uni-edit.net/) for editing and proofreading this manuscript.

References

[1] Y. Yamauchi and A. Suzuki, "Vibro-tactile notification in different environments for motorcyclists," in The Ninth International Conference on Advances in Vehicular Systems, Technologies and Applications (VEHICULAR 2020), 2020.

[2] M. Dikmen and C. Burns, "Trust in autonomous vehicles: The case of tesla autopilot and summon," in 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC), 2017, pp. 1093–1098.

[3] A. Hevelke and J. Nida-Rümelin, "Responsibility for crashes of autonomous vehicles: an ethical analysis," Science and Engineering Ethics, 2015.

[4] e-Stat (Japanese Government Statistics), "Statistics about road traffic / annual report," Feb. 2020, [accessed: 2021-07-13]. [Online]. Available: https://www.e-stat.go.jp/en/stat-search/files?page=1&layout=datalist&toukei=00130002&tstat=000001027457&cycle=7&year=20200&month=0

[5] ——, "Statistics about road traffic / annual report," Feb. 2018, [accessed: 2021-07-13]. [Online]. Available: https://www.e-stat.go.jp/en/stat-search/files?page=1&layout=datalist&toukei=00130002&tstat=000001027457&cycle=7&year=20180&month=0&stat_infid=000031800894

[6] Subaru of America, "Subaru eyesight," Jun. 2019, [accessed: 2021-07-13]. [Online]. Available: https://www.subaru.com/engineering/eyesight.html

[7] B. Major, D. Fontijne, A. Ansari, R. Teja Sukhavasi, R. Gowaikar, M. Hamilton, S. Lee, S. Grzechnik, and S. Subramanian, "Vehicle detection with automotive radar using deep learning on range-azimuth-doppler tensors," in Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV) Workshops, Oct. 2019.

[8] L. Alonso, V. Milanés, C. Torre-Ferrero, J. Godoy, J. P. Oria, and T. De Pedro, "Ultrasonic sensors in urban traffic driving-aid systems," Sensors, vol. 11, no. 1, 2011, pp. 661–673. [Online]. Available: https://www.mdpi.com/1424-8220/11/1/661

[9] J. K. Suhr and H. G. Jung, "Fully-automatic recognition of various parking slot markings in around view monitor (avm) image sequences," in 2012 15th International IEEE Conference on Intelligent Transportation Systems, 2012, pp. 1294–1299.

[10] Q. Li, L. Chen, M. Li, S.-L. Shaw, and A. Nüchter, "A sensor-fusion drivable-region and lane-detection system for autonomous vehicle navigation in challenging road scenarios," IEEE Transactions on Vehicular Technology, vol. 63, no. 2, 2014, pp. 540–555.

[11] Indiegogo, "Brake free helmet light. digital image. indiegogo," 2020, [accessed: 2021-07-13]. [Online]. Available: https://www.indiegogo.com/projects/brakefree-the-smart-brake-light-for-motorcyclists#/

[12] W. Chang, W. Hwang, and Y. G. Ji, "Haptic seat interfaces for driver information and warning systems," International Journal of Human-Computer Interaction, vol. 27, no. 12, Dec. 2011, pp. 1119–1132. [Online]. Available: https://doi.org/10.1080/10447318.2011.555321

[13] Y. Gaffary and A. Lécuyer, "The use of haptic and tactile information in the car to improve driving safety: A review of current technologies," Frontiers in ICT, vol. 5, Mar. 2018, p. 5. [Online]. Available: https://doi.org/10.3389/fict.2018.00005

[14] M. Muzammel, M. Z. Yusoff, and F. Meriaudeau, "Rear-end vision-based collision detection system for motorcyclists," Journal of Electronic Imaging, vol. 26, no. 3, May. 2017, p. 033002. [Online]. Available: https://doi.org/10.1117/1.jei.26.3.033002

[15] G. Gil, G. Savino, S. Piantini, and M. Pierini, "Motorcycles that see: Multifocal stereo vision sensor for advanced safety systems in tilting vehicles," Sensors, vol. 18, no. 2, Jan. 2018, p. 295. [Online]. Available: https://doi.org/10.3390/s18010295

[16] M. I. Tayag and M. E. A. D. V. Capuno, "Smart motorcycle helmet: Real-time crash detection with emergency notification, tracker and anti-theft system using internet-of-things cloud based technology," International Journal of Computer Science and Information Technology, vol. 11, no. 03, Jun. 2019, pp. 81–94. [Online]. Available: https://doi.org/10.5121/ijcsit.2019.11307

[17] V. H. Tran, D. Muscat, J. R. Cruz, A. M. Carrillo, D. A. A. Alonso, and E. Chavez, "Motorcycle and helmet providing advance driver assistance," U.S. Patent Application No. 13/897,570, 2013.

[18] Crosshelmet, "Cross helmet x1 - transform your riding experience," 2020, [accessed: 2021-07-13]. [Online]. Available: https://crosshelmet.com/

[19] C. Inc., "Blind spot detection & lane change assist," 2020, [accessed: 2021-07-13]. [Online]. Available: https://www.continental-automotive.com/en-gl/2-Wheeler/Safe-Mobility/ARAS/Blind-Spot-Detection

[20] A. Suzuki, Y. Murata, and M. Hayashi, "Notification of hazards around a vehicle using seat actuators," in 25th ITS World Congress. Copenhagen, Denmark: ERTICO, Sep. 2018, pp. AP–TP1335.

[21] A. Suzuki, K. Horie, S. Otobe, Y. Murata, and S. Fujimura, "Hazard notifications around a vehicle using seat actuators," The International Journal on Advances in Intelligent Systems, vol. 13, no. 1 and 2, 2020, pp. 59–68, iSBN:978-1-61208-720-7,ISSN:1942-2679.

[22] GYANTARO, "Vellfire v6 3.5l 0-138km/h full acceleration test (alphard 30 series)," Jan. 2016, [accessed: 2021-07-13]. [Online]. Available: https://www.youtube.com/watch?v=WI4voS7YF6Y

[23] ahotakuro, "Suzuki gsx-s1000 normal idling sound, motorcycle," Dec. 2016, [accessed: 2021-07-13]. [Online]. Available: https://www.youtube.com/watch?v=c6pK2z9ANRk

[24] M. studio official Channel, "Recommended sound effects, human sound foot and leg, footstep, leather shoes 04," Apr. 2014, [accessed: 2021-07-13]. [Online]. Available: https://www.youtube.com/watch?v=A5fGVbsHOfI