Driver Reaction Time to Auditory Road Safety Alert: The Effect of Age-Related Deficits and Sound Parameters

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ABSTRACT - Recent technological advances made a vehicle more intelligent to increase safety and convenience for both drivers and passengers. Intelligent vehicle provides drivers with various driving safety warning information through audible sounds, visual displays, and tactile devices. However, elderly drivers using the advanced intelligent vehicle technology have been known to decrease the physical and cognitive ability such as hearing, eyesight, short term memory, and space perception. Therefore, serious possible age-related deficits such as hearing or eyesight should be considered to design an appropriate safety warning system. This paper presents response model for the auditory safety warning design by evaluating the impact of advancing age on response performance on vehicle safety warning alarms which are widely used for alerting driving hazards. In order to analysis the response performance among age groups: younger (20-29), middle (40-49) and older (over 60), 38 drivers were asked to drive a simulated rural road in driving simulator. It was found that the response model can be offered the response time characteristic with age groups to design for safety warning system.

1. INTRODUCTION

Recently, it is the most important issues to enhance convenience and safety for automobile drivers and passengers (1-2). Advanced driver assistance systems (ADAS) of intelligent vehicle assist in safe driving, and in-vehicle information systems (IVIS) provide a variety of information to drivers (3). ADAS components include adaptive cruise control (ACC), lane departure warning system (LDWS), blind spot detection (BSD) and the rear detection system (RDS). ADAS senses the situation around the car using vision and distance sensors (radar), and it controls some car functions such as reduction of speed to prevent accidents. In particular, ADAS provides auditory and visual warnings to the driver in case of danger, and new technology has led to tactile warnings and the combination of two or more types of warnings.

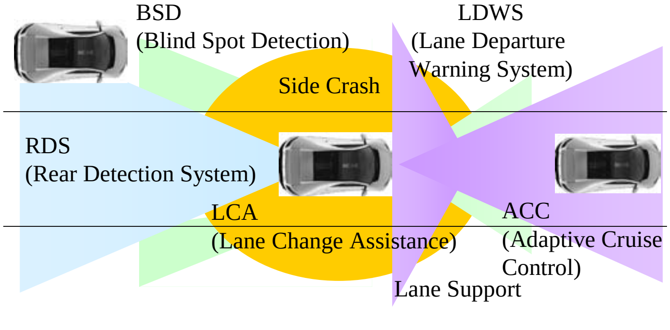

Figure 1: Advanced Driver Assistance System for intelligent vehicles.

Many studies related to warnings have been conducted (4). However, additional research is required into the design of new safety warning sounds to work with previous ones because existing studies targeted the average driver, even though most owners of high-end cars with high-technology ADAS functions are older drivers (4). In particular, safety system designers do not reflect age-related hearing loss and tend of various drivers including older driver because they do not have any the response characteristic information.

This paper presents response regression model for the auditory safety warning design by evaluating the impact of advancing age on response performance on vehicle safety warning alarms which are widely used for alerting driving hazards. The assessment of response performance was based on elapsed times for acceleration release response using a driving simulator. These dependent variables were examined for differences due to the frequency, tempo, and intensity of safety warning sounds. It was found that the response model can be offered the response time characteristic with age groups to design for safety warning sounds.

The rest of this paper is organized as follows. Section 2 introduces the experimental procedures used to assess the response performance of drivers to safety warning sounds. Section 3 shows the response characteristics and the response model for the auditory safety warning design. Section 4 provides conclusions and makes suggestions for further research.

2. EXPERIMENTAL METHOD

This study involved 38 participants recruited to analyze the response characteristics to safety warning sounds. Table 1 shows the age distribution of the participants. Because hearing loss is not gender specific, all the participants were male and selection was limited to those who drove more than twice a week, had more than three years of driving experience, and had driven more than 30,000 km. The participants selected were sufficiently healthy to drive more than 3 hr at a time and were free of mental illness and ear diseases such as tympanitis.

Table 1: Details of experiment participants.

Age range	Number	Average age and SD (yr)	Driving record and SD (yr)
20s	12	25.0 (1.86)	4.83 (1.64)
40s	11	44.3 (2.41)	17.9 (5.80)
60s	15	63.9 (2.87)	28.3 (6.77)

This study involved an experiment using a driving simulator (Figure 2) at the Daegu Gyeongbuk Institute of Science and Technology (DGIST, South Korea) to analyze the physical characteristic of older drivers to safety warning sounds. The driving simulator consisted of a digital projector, a 2400×1800-mm screen, PC controller, and a vehicle (Smart, Mercedes Benz). The software used in the experiment was STISM Drive^{TM} (Systems Technology Inc.), which provided pictures of the road and the car 20-30 times each second at a resolution of 1024×768 pixels. The simulator included an encoder on the accelerator and brake pedals to measure the times taken to push or release each pedal. The program measuring the response time was developed using Labview 8.6 (National Instruments), and the signals from encoders were obtained using a USB-6008 DAQ digital acquisition system.

Sounds based on the LDWS warning sound of the Hyundai “E” car were used to analyze the response characteristic of drivers to safety warning sounds. The basic LDWS 1.2 kHz warning sound was repeated every 800 ms during 400ms. The major independent variables used in the experiment were selected based on relevant international standards and the opinions of an otorhinolaryngologist and professional musicians (5). The warning sounds used in the experiments had various frequencies (0.5, 0.75, 1.0, 1.5, 2.0, 3.0, and 4 kHz), tempos (200, 300, 400, 500, and 1000 ms), and intensities (75 and 85 dB). 70 warning sounds combined with various frequencies, tempos, and intensities were created by sound expert and they occurred with random for counterbalancing in the experiment.

Figure 2: DGIST driving simulator.

The response time of the drivers were measured for each age group and examined for response regression model with the frequency, tempo, and intensity of the safety warning sounds. The response time was defined as the time from the moment when warning sound went off to the time that driver started to release the accelerator. The response assessment experiment had participants push the accelerator to the floor and drive on a straight road, and then release the accelerator and apply the brake when the warning sound occurred at two type of random table.

The experiment had three phases: before, during, and after driving. The 30-min phase before driving consisted of obtaining consent, presenting an overview, reviewing the subject’s eligibility, administering a preliminary questionnaire, and providing training on safety and the vehicle simulator. The driving phase in the simulator consisted of the response experiments, with a 5-minute break. The response assessment took about 30 min. The phase after driving was composed of a 10-min questionnaire about the subject’s mental state and stress level. Details of experiment setup referred reference [4].

3. RESULT AND DISCUSSION

3.1 Response characteristics

Figure 3 shows the responses of the drivers by age according to various safety warning sound frequencies. The figure shows that response time increased from 0.5 kHz to 2 kHz and slightly reduced from 3 kHz to 4 kHz, drivers had the shortest accelerator response time at 3 kHz with significant difference for the range of frequencies. Thus, drivers including older driver responded fastest to the 3-4 kHz safety warning, a result that can be explained by the resonance of external ear to amplify around the 3-4 kHz from equal-loudness curves, which indicate that people perceive sound best at a frequency of 3-4 kHz. Due to age-related deficits such as cognitive decrement, physical response decrement, and hearing loss, the average accelerator response time of older drivers was 160 ms longer than that of drivers in their 20s (minimum difference of 125 ms at 1.5 kHz, maximum of 184 ms at 4 kHz) and it was 100 ms longer than that of drivers in their 40s (minimum difference of 66 ms at 0.5 kHz, maximum of 147 ms at 4 kHz).

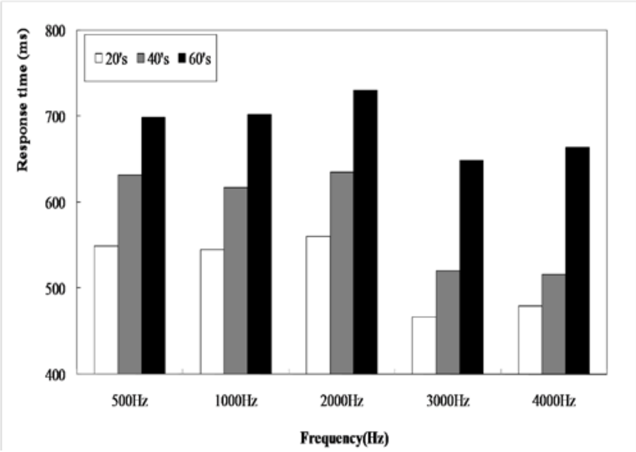

Figure 3: Response time for various frequencies according to age group

Figure 4 shows the responses of drivers by age for different safety warning sound tempos. The accelerator response times were faster for longer sound tempos, because longer sound tempos occurred for a long time with starting. The result of the tempo change test was similar to that of the frequency change test. The average accelerator response time of older drivers was 160 ms longer than that of drivers in their 20s (minimum difference of 150 ms for a tempo of 400 ms, maximum 180 ms for a tempo of 1000 ms) and 90 ms longer than that of drivers in their 40s (minimum difference of 79 ms for a tempo of 300 ms, maximum 110 ms for a tempo of 1000 ms).

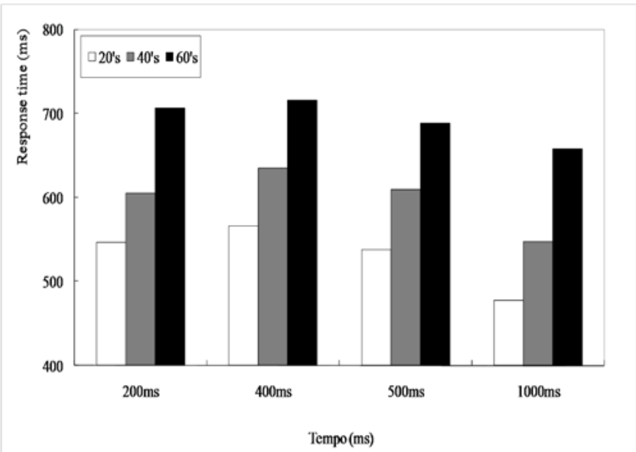

Figure 4: Response time for various tempos according to age group

Figure 5 shows the response of drivers by age for different warning sound intensities. Drivers in their 20s and 40s had shorter accelerator response times as the warning sounds became louder, whereas older drivers showed no significant difference. In other words, older drivers are less sensitive to changes in warning sound intensity. The average accelerator response time of older drivers was 170 ms longer than that of drivers in their 20s (minimum difference of 163 ms for 75 dB, maximum 178 ms for 85dB) and 86 ms longer than that of drivers in their 40s (minimum difference of 55 ms for 75 dB, maximum 118 ms for 85 dB).

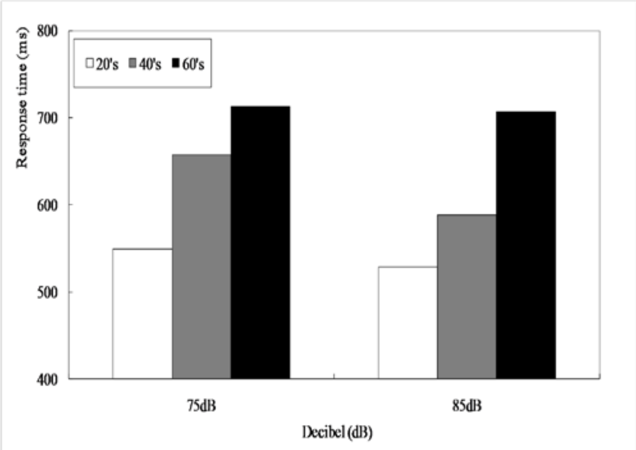

Figure 5: Response time for various decibels according to age group

3.2 Response regression model

Table 2 shows the physical response regression model of drivers by age for different warning sound frequency (Hz), tempo (ms) and intensity (dB) using version 14 of the SPSS statistical analysis software package (SPSS Inc.). The response regression model showed a statistically significant effect of age (*P*<0.05). Response regression model can be calculated response time of age group with sound parameters. For example, response time of older driver (62 years) for 2 kHz, 500 ms, and 75dB sound was calculated as 687.672ms using the response regression model. The response model can be applied to estimate the impact of advancing age on response performance on vehicle safety warning alarms which are widely used for alerting driving hazards.

Table 2: Response regression model.

Age range	Estimated regression model	R^2	R^2_{adj}	*P*
20s	774.937 - 0.020frequency – 0.087tempo – 2.044 intensity	0.098	0.094	0.000
40s	955.109 - 0.030frequency – 0.091tempo – 3.228 intensity	0.122	0.117	0.000
60s	939.369 - 0.012frequency – 0.058tempo – 2.458 intensity	0.054	0.049	0.000
Total	709.965 + 3.911age - 0.02frequency - 0.078tempo - 2.477intensity	0.282	0.281	0.000

Figure 6 shows the distribution of responses of drivers by age for different safety warning sound using real measure and regression model. In the figure, drivers in their 20s and 40s had wider distribution of real response times, whereas older driver concentrated around the 700msec. However, the result of the real response times except some case was similar to that of the model response time result. And, the trend line of model response time increased slowly with age. Comparison of real response and model response showed that suggested response regression model was appropriate method to estimate the response of driver.

4. SUMMARY AND CONCLUSION

This paper presents response regression model for the auditory safety warning design by evaluating the impact of advancing age on response performance on vehicle safety warning alarms. The response of older drivers to varying frequencies, tempos, and intensities was evaluated to establish response model. The conclusions derived from this research are as follows.

First, older drivers were significantly statistically different in the way they perceived warning sounds, depending especially on the frequency, but also on the tempo and intensity. Second, older drivers showed differences in response time model compared to drivers in their 20s.

Follow-up studies are required of the physical and emotional preference to sounds with various attributes to warn of head-on collision or lane deviation.

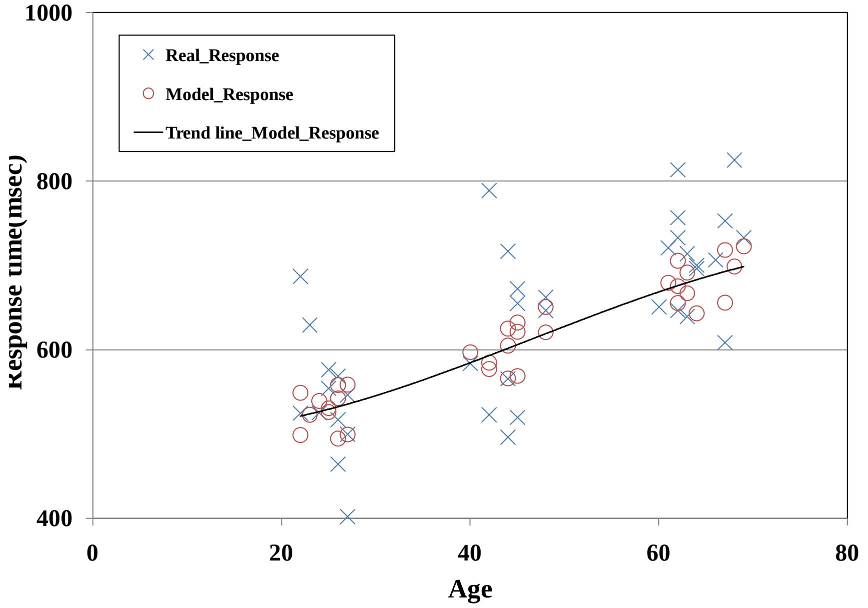

Figure 6: Distribution of response time using real measure and regression model.

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