Study on Adaptive Driving Assistant System for Elderly Drivers

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CHAPTER 1

INTRODUCTION

1.1 Driving and the mechanism of traffic accidents

A car as a means of transportation is very useful to human, and is a machine for movement indispensable to social life. However, since a machine for the general driver who has not received special training, physical ability and ability to process information for drivers as the user may be frequently exceeded. Consequently, fatigue of drivers, occurrence of traffic accidents due to long-time driving are induced [1]. The negative aspects of cars are becoming a serious problem.

Many of traffic accidents are occurred by the error of driver's performance, i.e., through a series of consciousness and cognition, judgment, and operation. That is, a driving performance is to control a car through the process of cognition-judgment-operation of a driver by considering environment information inputted. Moreover, the driving performance is functioning as human- car-environment system which always feeds back between external information and a self-vehicle movement state.

Figure 1.1.1 shows a dimension progress, which results in a traffic accident, regarding driving behaviors, spatial and temporal relations [2]. In the three-dimensional space of a figure, driving environment (situation) is located in X-axis, driving time is located in Y-axis, and driver performance is located as Z-axis. Regarding the driving environment in X-axis including road environment with the difficulty of driving tasks, such as a going-straight run, a curve way and a lane change, passing and also obstacle avoidance, the marginal performance of a car and the control capacity of a driver are factors in the control failures. Next, regarding the driving time in Y-axis, when driving for a long time, in case of elderly drivers, exceeding the limit of safe driving will cause an accident. Furthermore, regarding driver performance in Z-axis, it requires the correctness of driving action from the cognition-judgment-operation based on the age of a driver, gender, a level of skill, and a custom, and driving safety will be hindered if this action deviates from safety operation.

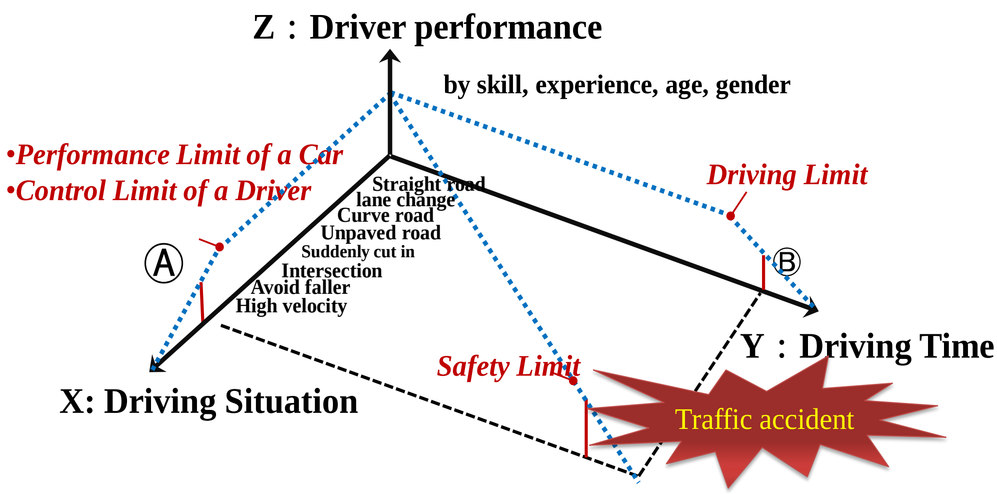

Figure 1.1.1 A dimension progress which results in a traffic accident

Therefore, it is thought that a traffic accident occurs in relation to a certain work load for the change of driving situations, driving beyond the limit of driver.

1.2 Physical Characteristics of Elderly drivers

1.2.1 The functional limitation by aging

The functional limitation related aging, when driving most, is those which relate to the vision and cognition. There are almost no signs in which a decline in the function of vision and cognition of part of normal aging has negative result at read safety [3],[16]. The serious decline in functional limitation as resulting aging involves in traffic accidents significantly [6], [7].

(1) Vision

Vision is the most important sense for the driving. Most of the necessary sensory to drive a car is visual sense. However, eye disorders such as declines of visual acuity, weakened accommodation force, narrowed visual field, macular degeneration and blurred vision like a cataract are occurred by ageing. The disorders effect on driving performances as shown in Table 1.2.1.

Nevertheless, visual functions generally considered in driver licensing are binocular visual acuity and visual field. Not only the minimum license requirements, but also ocular or neurological pathology related ageing should be investigated.

Table 1.2.1 Functional limitation by ageing and the effect on driving

Functional limitations by ageing	Driving limitation accompanied by functional limitations
Declines of visual acuity	Difficulty to confirm traffic environment and in-vehicle indicators
Weakened accommodation force	Increase of required time during eye movement
Narrowed visual field	Difficulty for distinctions of mixed colors on a display
Macular Degeneration	Restrictions in the places of indicators
Delay of dark adaptation	Poor visibility after entering tunnels
Blurred vision	Dazzling by a headlight of other cars

(2) Dynamic visual acuity

Dynamic visual acuity is the ability to discriminate the fine parts of a moving object. Obviously, Dynamic visual acuity is very important ability to detect movement for safe driving, not only for being able to detect on-coming vehicles on intersecting roads and to estimate their speed, but also for being able to detect changes in the speed of vehicles in front, i.e., stopping, slowing down, speeding up, and reversing. However, the decline in the dynamic visual acuity with increasing age appears to be mainly the result of age-related changes to neural mechanisms.

(3) Night-time visual acuity

Impaired night-time visual acuity is the result of two age-related changes that reduce the amount of light reaching the retina: reduced pupil size and yellowing of the lens. A consequence of reduced retinal illumination is that sources must be of higher intensity to be seen at night. Sensitivity to glare, which increases between the ages of 40 and 70, leads to a slower recovery from headlights and other.

(4) Contrast sensitivity

As far as contrast sensitivity is concerned, elderly drivers have more difficulties detecting objects that are not outlined clearly or that do not stand out from their background. Its deterioration is probably attributable to changes in the eye itself as well as neural factors. Contrast sensitivity is necessary for the perception of (the information on) traffic signs. Besides this, contrast sensitivity is also believed to play a role in distance perception and the estimation of the speed of moving objects.

1.2.2 Cognitive Function

Age-related declines in sensory functions such as vision and hearing have an impact on the input the driver receives from other road users and from the road environment (e.g., traffic signs and signals, road markings). To select the appropriate information, interpret it and make decisions which must then be translated into an appropriate driving action, and to compensate for sensory limitations, various perceptual and cognitive functions come into play. Some of these functions show effects of ageing. Cognitive functions for which appreciable effects of ageing are described [19], are fluid intelligence, speed of processing, working memory, and executive functions like inhibition, flexibility and selective and divided.

The speed, at which information is processed, is important to making safe decisions as a driver [5]. Fundamental to this aspect of the driving task is the time taken by a driver to respond to the demand placed upon him or her by the traffic environment (often referred to as ‘perception-reaction’ time).

Research studies have generally found that reaction times to simple stimuli do not deteriorate dramatically with age. Reaction times of elderly drivers only slow down when drivers have to make decisions in complex situations.

1.3 Current state of elderly drivers

1.3.1 Traffic accident data by OECD Statistics report

According to a traffic situation investigation of the member nations by OCED in 2013 [1] Korea had the number of 206.8 cars per 1km of traffic road, and ranked top. Next, Italy possessed 100.9 cars per 1km of traffic road, Japan was shown with 68.5 cars and the United States was shown with 39.2 cars shown in the Figure 1.1.1. Here the number of cars in both Japan and Korea were higher than the OECD country average, 44.2 cars.

Figure 1.3.2 shows a result of the number of traffic accidents per 100,000 people. In this graph, the numbers of traffic accidents in Japan are shown as the 541.8 accidents per 100,000 persons. And the number of traffic accidents in Korea is shown with 445.4 accidents. According to this result, the numbers of traffic accidents in both Japan and Korea are shown highly than an average of OECD, 313.1 accidents, and that of Japan is extremely serious.

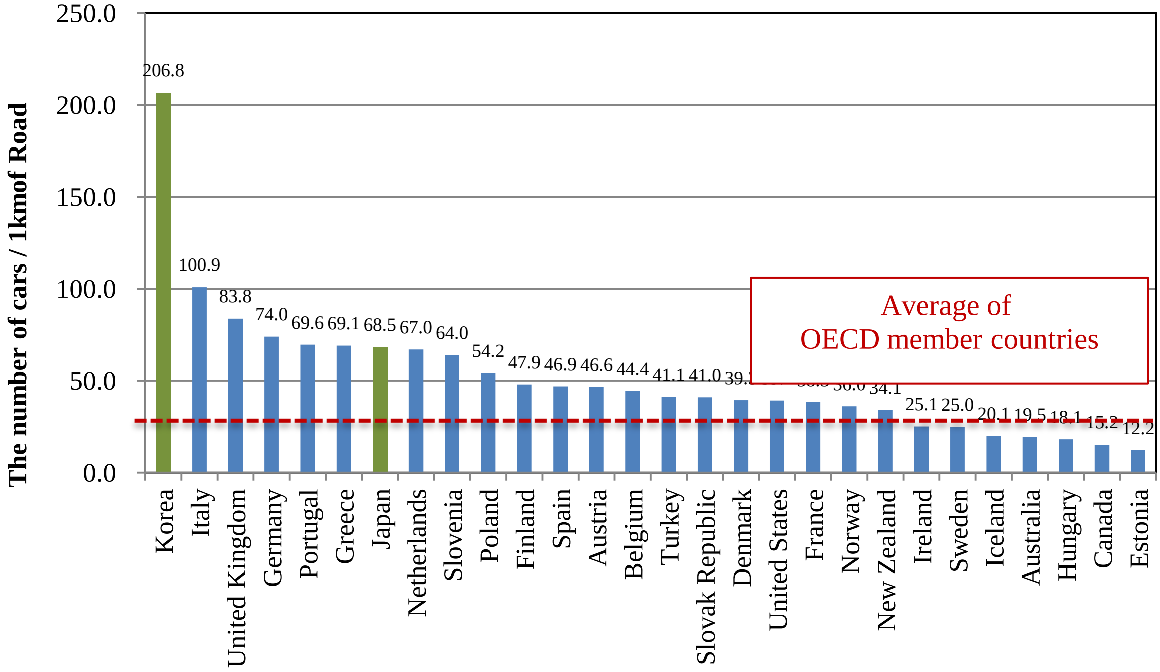

Figure 1.3.1 The number of cars per 1km of road

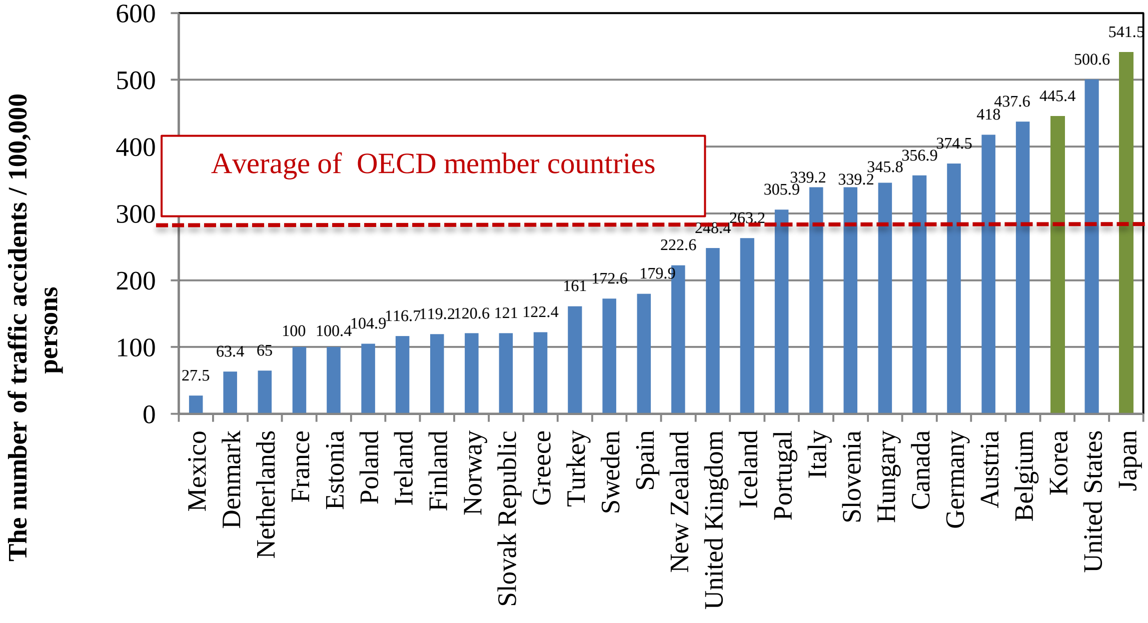

Figure 1.3.2 The number of traffic accidents per 100,000 persons

Figure 1.3.2 shows a result of the number of traffic accidents per 100,000 people. In this graph, the numbers of traffic accidents in Japan are shown as the 541.8 accidents per 100,000 persons. And the number of traffic accidents in Korea is shown with 445.4 accidents. According to this result, the numbers of traffic accidents in both Japan and Korea are shown highly than the average of OECD, 313.1 accidents, and that of Japan is extremely serious.

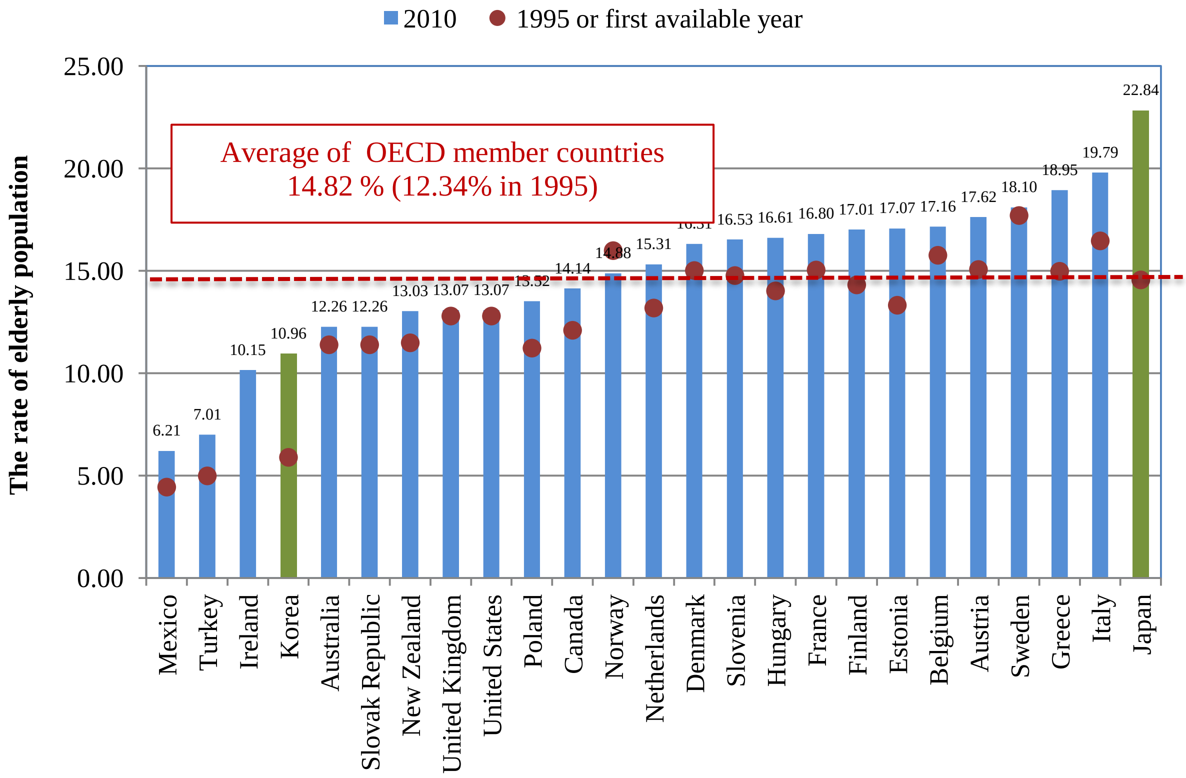

Figure 1.3.3 Elderly population (As a percentage of total population)

Figure 1.3.3 shows percentage of the elderly population in 2010, compared with 1995. As shown this figure, the percentage of elderly persons in most of nations increased than 1995, while, the number in Norway declined only. Remarkably, the percentage of elderly persons in both Japan and Korea increased with 30%, so the percentage shows 19.79 percentages in Japan and 10.96 percentages in Korea.

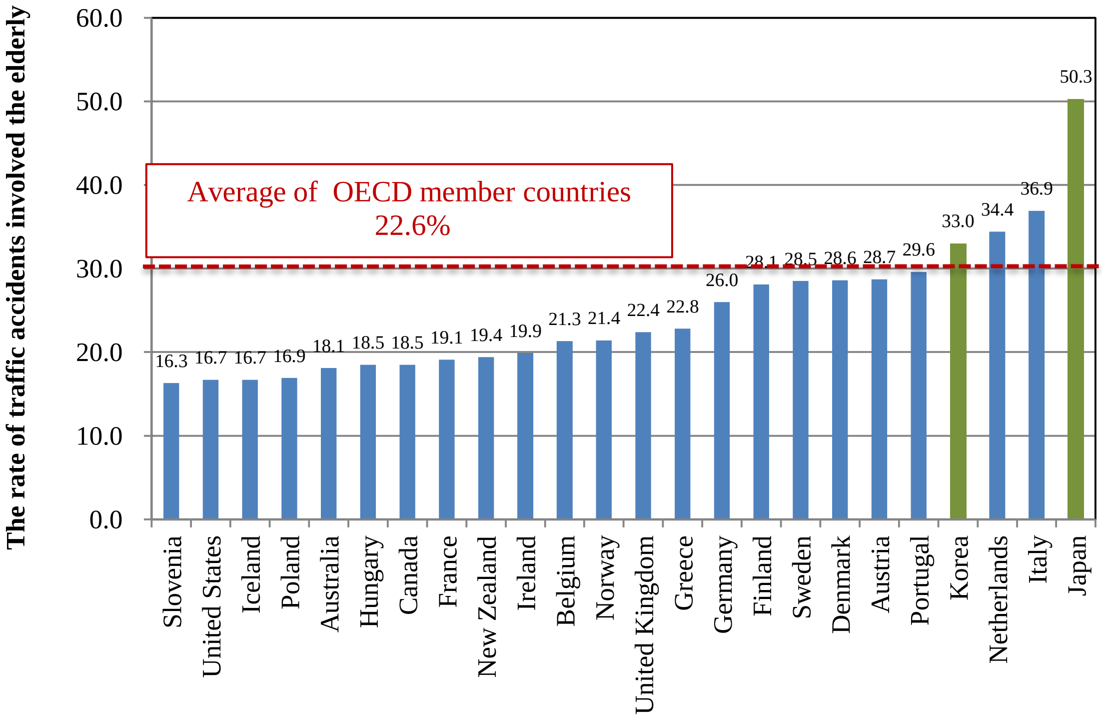

Figure 1.3.4 The rate of traffic accidents involved the elderly

Figure 1.3.4 shows the rate of traffic accidents involved the elderly. As a result, Korea (33.0 percentages), Netherlands (34.3 percentages), and Italy (36.9 percentages) exceeded the average, 22.6 percentages, of traffic accidents by the elderly in OECD countries. Remarkably, Japan has a much higher percentage as 50.3 percentages. Therefore, each Japan and Korea has higher risk of traffic accidents by elderly drivers.

Next, Figure 1.3.5 shows the facilities of elderly on traffic accidents per 100,000 persons who are over 65 years old. As the results, the average of OECD member countries was 10 persons per 100,000 persons who are over 65 years old. Greece (11.9), United stated (13.0), Poland (13.7), Portugal (13.7) and Korea (30.5) exceeded the average. Korea is extremely higher than the other countries. However, although in case of Japan, the rate of accidents involved elderly drivers is the highest, the number of facilities of the elderly is lower than the average of OECD countries.

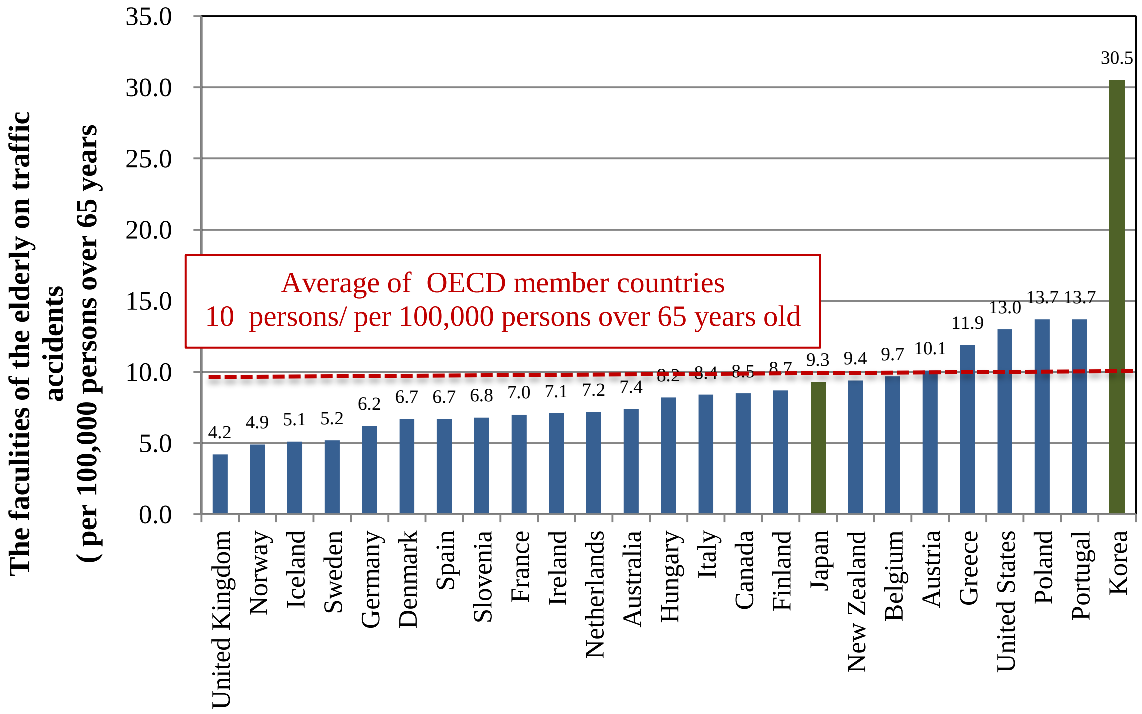

Figure 1.3.5 The faculities of the elderly on traffic accidents (per 100,000 persons over 65 years old)

1.3.2 Comparison between Japan and Korea

Figure 1.3.6 shows the situation of total number of casualties by traffic accidents and fatalities' numbers in Japan. And Figure 1.3.7 shows the situation of total number of road casualties by traffic accidents and fatalities' numbers in Korea. As the investigated result, the number of fatalities in Japan is 9,073 persons in 2000 and 4,373 persons in 2013. The value has been declining. Equally, the value for fatalities in Korea have been declining 2000 to 2011, however, the number in 2012 was increased.

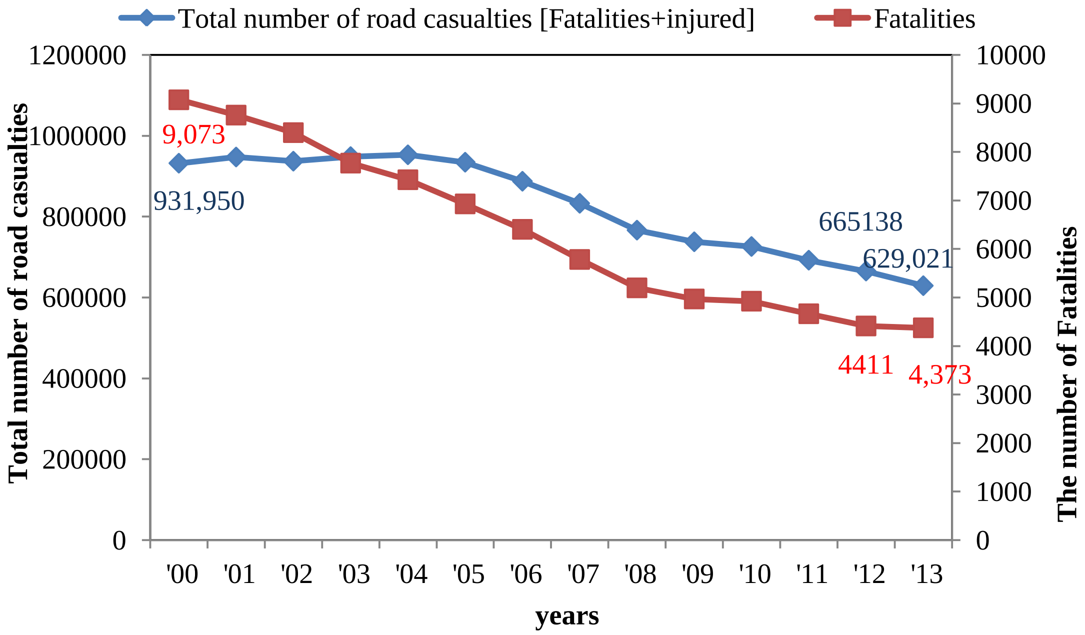

Figure 1.3.6 The traffic accidents situation in Japan

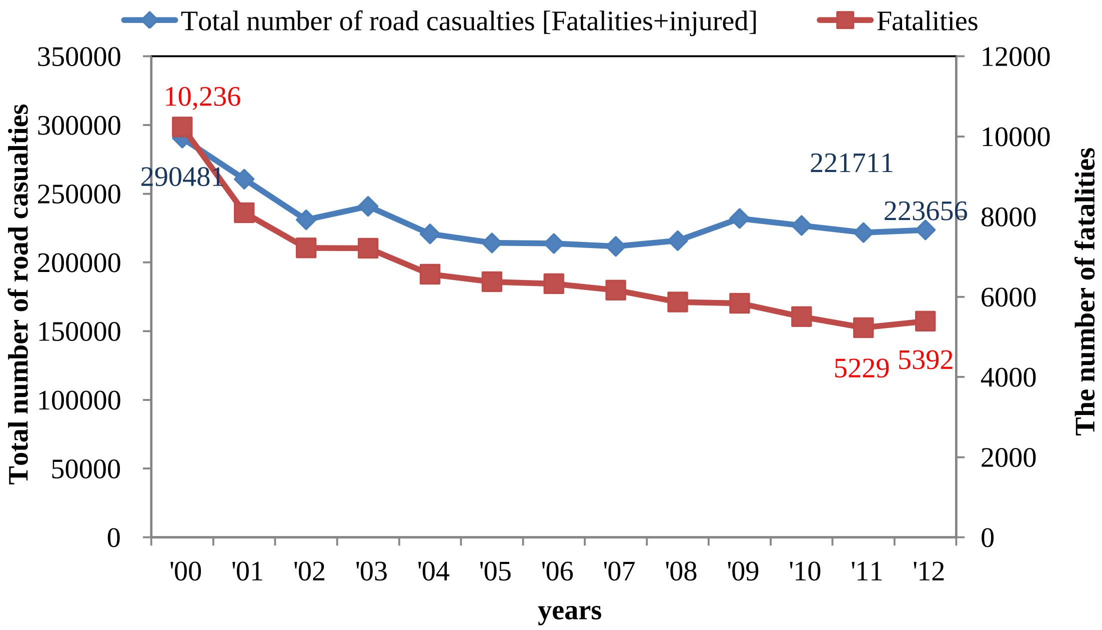

Figure 1.3.7 The traffic accidents situation in Korea

Figure 1.3.8 shows the rate of traffic accidents involved with elderly people. In case of Japan, the rate increased from 42.5 percentages in 2005 to 50.6% in 2012. Korea, the rated increased from

26.7 percentages in 2005 to 34.6 percentage in 2012 and had been increasing steadily. The rate exceeded with half of all traffic accidents. But above all, it is a serious condition which accounts for over 50 percent of traffic accidents in Japan. The measures to minimize the rate of traffic accidents involved elderly people are urgently needed.

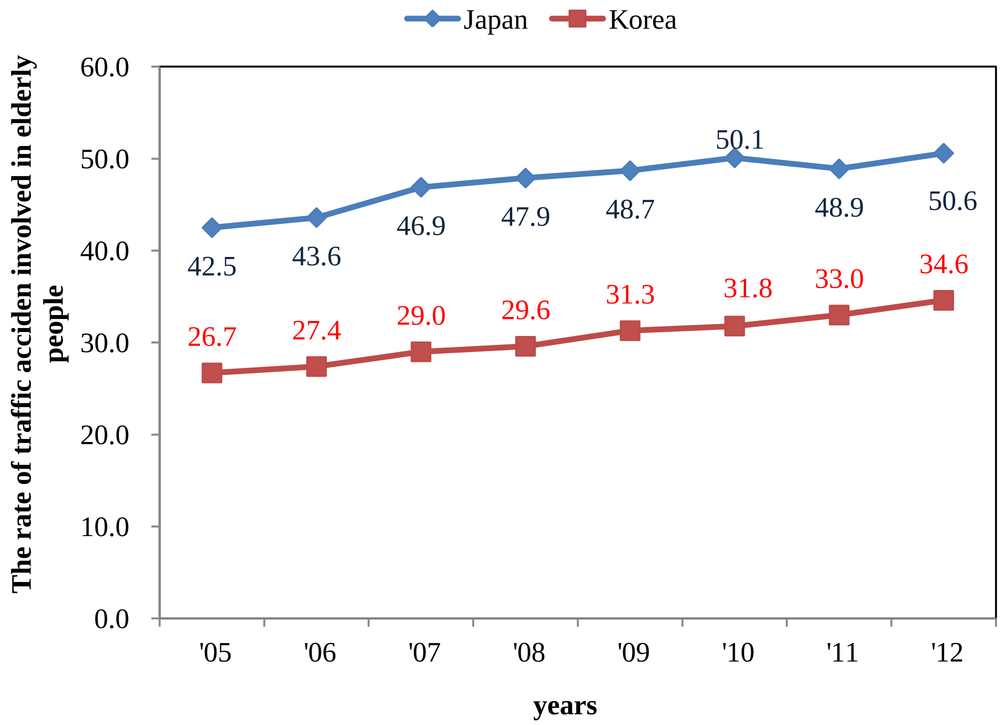

Figure 1.3.8 The rate of traffic accidents involved in elderly people

1.4 Advanced driving assistance system Theoretical framework for support for elderly drivers

Advanced driver assistance systems (ADAS) are systems developed to enhance safety and better driving. Safety features are designed to avoid collisions and accidents by offering technologies that alert the driver to potential problems, or to avoid collisions by implementing safeguards and taking over control of the vehicle. Adaptive features may automate lighting, provide adaptive cruise control, automatic braking, incorporate with GPS/ traffic warnings, connect to smart phones, alert driver to other cars or dangers, keep the driver in the correct lane, or show what is in blind spots.

1.4.1 Sensing Technologies

Advanced Driving Assistance System (ADAS) is the system to detect the traffic situations around vehicles or pedestrians, etc. and prevent traffic accidents through using sensor devices at the front, the side and the rear of cars. Therefore, the realization of ADAS is possible since there are the advanced sensing technologies.

The sensing technologies detecting surrounding traffic state are a radar technology (Radio Detection and Ranging), are a ladar technology (Laser Detection and Ranging), a photography technology (picture processing and picture recognition) and a wireless data communications technology.

The radar technology is easy for metallic material detection as well as detection in bad weather, but there is a weakness in which the level of resolution is low more than a ladar camera.

The ladar technology which has a spatial resolving ability of very high level is possible for a phenomenon distinction of an object. However, it's affected in the weather state, and there is a weakness on which a laser beam is scattered.

The photography technology is possible to detect a distance based on a relation between a picture and an object using two cameras. Because the level of its resolution is excellent, the recognition and distinguish of objects are possible. However, in case of a optical light camera, the detection in the area where a night headlight can't light up is difficult. On the other hand, the wireless data communications technology using a road map and information in terms of traffic flow or congestion is little influenced by the weather conditions and driving time.

Currently, for the recognition related traffic objects, the fusion of multiple sensor, camera based sensors, deepness cameras, vehicle sensors as well as radar and ladar sensors data has been used and reported [20].

1.4.2 The types of advance driving assistance systems

(1) A type of universal driving assistance systems

Active safety systems like ABS and ESP improve traffic safety by assisting the driver. In addition, advanced driver assistance systems (ADASs) have the potential to significantly reduce the number of road accidents. An ADAS which is a vehicle control system improve driving comfort and traffic safety by assisting the driver in recognizing and reacting to potentially dangerous traffic situations as shown Figure 1.4.1.

The following types of the intelligent vehicle systems can be distinguished [21]:

Driving information systems

Driver information systems provide basic driving information in terms of driving to drivers, and enhance the driver’s situation awareness. For instance, there is advanced route navigation systems.

The navigation system appeared in the market because wireless communication progressed significantly. In the 1960s, the US Federal Highway Association developed the Electronic Route

Guidance System (ERGS), aiming to provide route guidance to vehicles. Next, Since 1990, Global Positioning System (GPS) and Geographic Information System (GIS) technologies have progressed significantly and have been widely used to improve navigation systems.

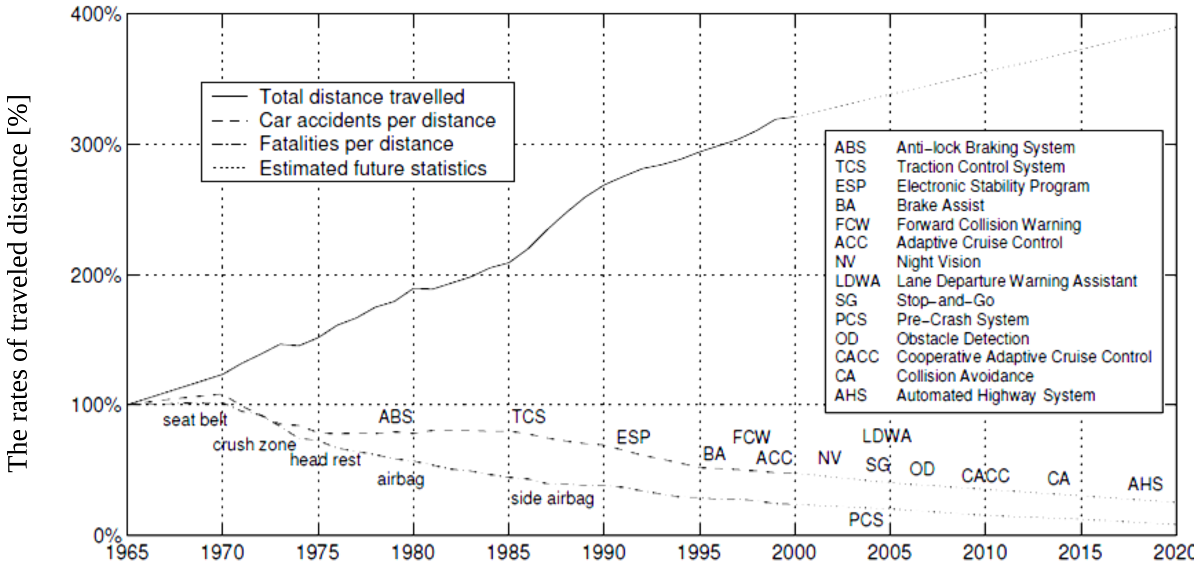

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Figure 1.4.1 Passive safety systems which reduce fatalities in case of an accident

Recently, there has been a lot of research on route guidance and path finding, particularly investigating dynamic traffic situation such as congested section. A substantial number of studies have been conducted to make a driver model dealing with users' behaviors under Advanced Traveler Information Systems (ATIS), a well-known RGS. To this end, under intelligent transportation systems, the dynamic route guidance system (DRGS) has received wide attention such as climate condition that it can't be expected, road closing and collision situations. This system can provide routing suggestions to users in accordance with current traffic conditions.

Driver warning systems

Driver warning systems warn the driver in terms of a potential danger in driving. Its systems, there are a lane departure warning system, a blind spot warning system and forward collision warning (FCW) systems.

The lane departure warning system warns a driver when the vehicle begins to deviate from its lane. In 2009 the U.S. National Highway Traffic Safety Administration (NHTSA) began studying whether to mandate lane departure warning systems and frontal collision warning systems on automobiles

Recently, a real-time and various illumination invariant lane detection methods for lane departure warning system in bad weather conditions and at night time were suggested. As the results, an average detection rate show sufficient performance with 93%. Moreover, regarding driver behavior models of the directional sequence of piecewise lateral slopes (DSPLS), the system has a detection error with as low as 17%.

The blind spot warning system (BSWS) warns a driver when there are prospective collision risks using a vision-based BSD system with dynamic camera calibration and image pre-processing methods.

The forward collision warning (FCW) systems are based on camera or radar sensors monitoring the road ahead. They provide object recognition and detect relative speeds between a vehicle and objects on the road. If the approaching speed represents a risk of collision, drivers can be alerted through a number of warning methods.

Intervening systems

The intervening systems provide active support to the driver. As one example of this system, there is an adaptive cruise control (ACC) system. ACC is a comfort system that maintains a set cruise control velocity, unless an environment sensor detects a slower vehicle ahead. The ACC then controls the vehicle to follow the slower vehicle with safe distance. ACC is intended for speeds above 30 km/h, but is currently being extended to a stop-and-go application for automated longitudinal control in low-speed complex environments, such as traffic jams and urban areas.

Integrated passive and active safety systems

In addition to passive safety systems that are activated during the crash, a pre-crash system can mitigate the crash severity by deploying active and passive safety measures before a collision occurs. Pre-crash safety measures, such as brake assist and seat belt pre-tensioners, have recently been introduced on the market.

Fully automated systems

Fully automated systems are the next step beyond driver assistance, and operate without a human driver in the control loop. Automated highway systems, using fully automated passenger cars, are expected to significantly benefit traffic safety, but are not considered for short-term introduction.

1.4.4 Advanced driving assistance systems

To prevent accidents of elderly drivers, it is effective to present driving supports with regard to the characteristics of each driver. Moreover, consumers' price consciousness regarding a car is high, and the cost for driving assistance system should be regarded. That is, we have to consider so that a system may be realized as low cost as possible. Conversely, spreading systems to more users can bring social meaning than offering systems as low cost for the first time.

Both Japan and Korea are already aged societies so, safe and comfortable movement is a mission of a car, moving will be the social life itself. Therefore, a supporting technology to safe and comfortable operation will become increasingly important.

The driving support in consideration of the driver's characteristic is needed for coexistence of the safety of road traffic and convenience accompanying computerization of these days. In other words, supporting certain information for drivers when driving is exactly realizing "coexistence with cars, and human beings under all environment". On the other hand, as mentioned above, driving performance is functioning as human beings, cars and environment system. Therefore, an understanding of the human characteristic relevant to the feature of cognition leading to certain driving behaviors becomes indispensable for development of driving support systems. That is, prevention of errors accompanying introduction of information systems like a navigation system is important. However, the interface designs which reduce work loads of drivers still not enough. Furthermore, driving behaviors including psychological elements, such as cognition, judgment and operation decision-making, have been studied. Investigation of the driving behavior in real traffic roads, observation of driving operation behaviors under the simulated environment in the virtual space using a driving simulator, field researches using in-vehicle electronic counting system, etc. have been carried out. Regarding the research trends, investigations of near miss collisions using drive recorders, and conformity assessment of driver characteristic and the driving support technology in a real vehicle driving experiment have been progressing quickly with remarkable development of sensor technology [22].

Considering a future society, a research for an ecological car utilizing natural resources is advanced. At the same time, prevention of traffic accidents against a super aged society is needed. Focusing on the traffic environments in which elderly drivers are driving, many elderly drivers' accidents have been occurring at intersections [23], and straight single ways and curve roads. Regarding previous studies for elderly drivers at the intersection, there were the results that they caused an error (e.g., the failure of detecting signal change, vehicles, and pedestrians) when the elderly drivers did not show the proper operation at the intersection. Metropolitan Police Department of Japan reported that the reasons of causes of accidents occurred at intersections are delay or failure on detection of vehicles, stop signs or intersections (67.1 %), error when judging a certain driving performance (10.0 %), error when operating (5.9 %), and collisions of unknown cause (17%). It is mentioned that there is not an uniform measures to avoid accidents because of wide individual difference. However, in a simple reaction and selective reaction, reaction times are linger that of non elderly drivers. In addition, elderly drivers usually have miss many operation in the target selective task. Therefore, an effective driving assistance system which decreases elderly drivers' accident is needed.

Based on the above-mentioned background, this study was set up on the theme of a design method of a driving assistance system with regard to an interaction of man-machine system, and we summarized the result of research. Especially aiming at the traffic accident prevention in a future aged society, a practical design method of a driving assistance system for elderly drivers is constructed and applied. A foundational structure of driving assistance system aimed at this research is shown in Figure 1.4.2. Driving behaviors are known as a series of recognizing a surrounding driving environment, judging safety and carrying out steering or braking operation by considering the driving environment as an input according to the internal behavior model of cognitive judgment for each driver. If the complex driver performance (cognition-judgment-operation) is simplified, it is helpful to elderly drivers. For instance, when approaching intersections, presenting external information to increase attention to elderly drivers using a driving monitoring technology is designed. Next, when braking operation presents second information to induce proper timing and stopping position using an audiovisual device in terms of a stopping operation process at intersections.

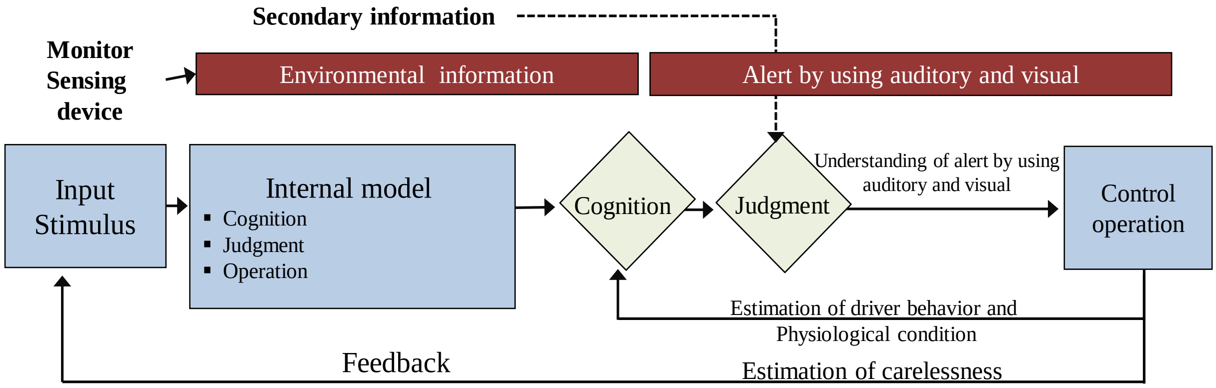


Figure 1.4.2 Driver behavior model with pre-information & alert system for driver

1.5 Scope of the dissertation

This paper is composed with 6 chapters as follows.

Chapter 1: Introduction

Chapter 2: Investigation of elderly drivers' driving behaviors at intersections

Chapter 3: Study on the composition of advanced driving assistance driving assistance system and it's effects based on physical

Chapter 4: Adaptive driving assistance system for elderly drivers considering individual characteristics

Chapter 5: Application of the driving assistance system for elderly drivers

Chapter 6: Conclusions

The contents of each chapter and mutual relation for examinations are displayed by a block diagram as shown in Figure 1.5.1.

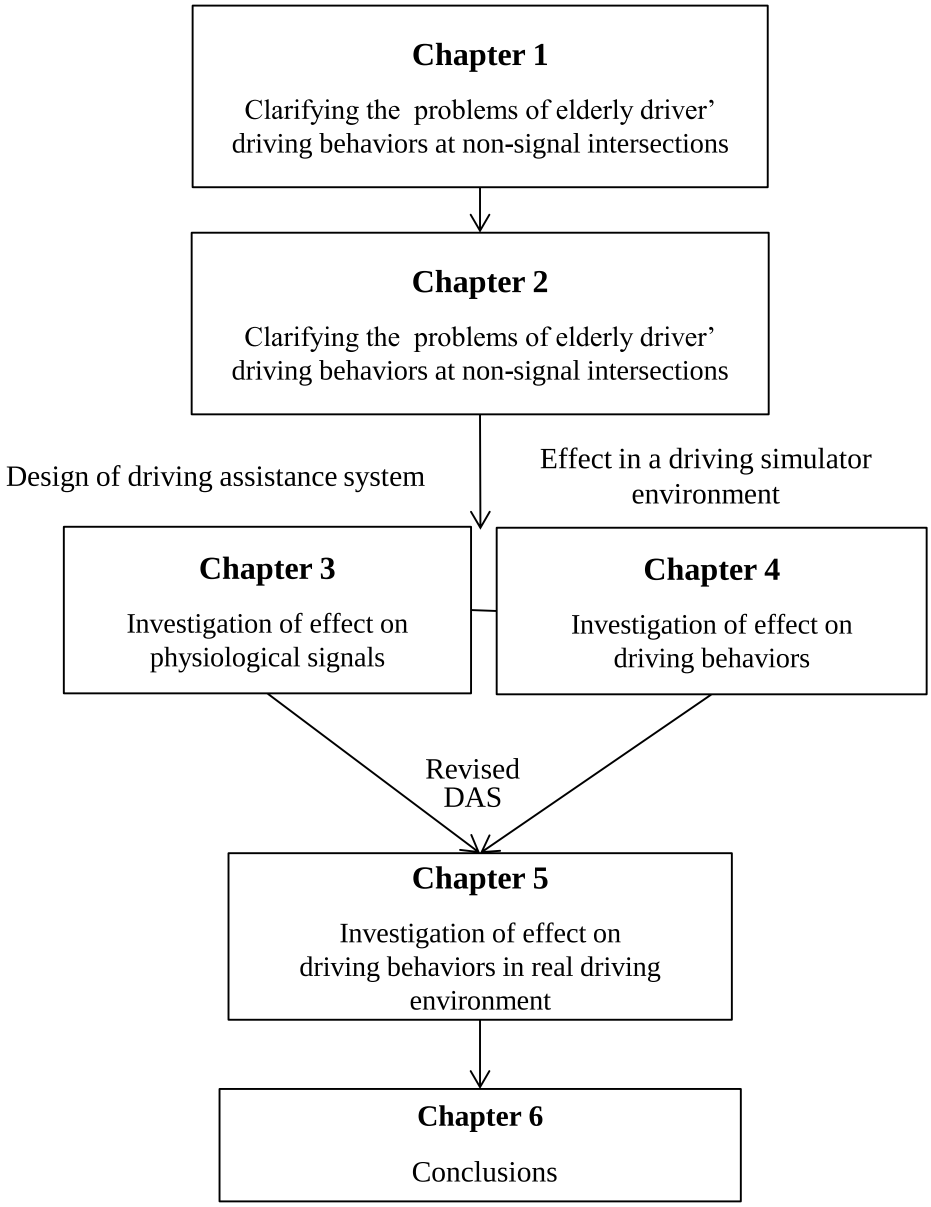


Figure 1.5.1 The flow chart of this study

In Chapter 1 "Introduction", characteristics of elderly drivers are defined. Progress of traffic accident prevention safety technology and the present condition of developing of driving support technology are surveyed, and the composition of the background of research, the research purpose are shown.

In Chapter 2 "Investigation of elderly drivers' driving behaviors at intersections", driving behaviors in terms of braking of elderly drivers were investigated. Here, the characteristics of the elderly driver's driving behavior were observed. Therefore, it was clarified that requirements of a system to assist braking behavior was needed.

In Chapter 3 "Study on the composition of advanced driving assistance driving assistance system and it's effects based on physical", the driving assistance systems, using combinations of audiovisual alarms, to prevent many traffic accidents by elderly drivers were designed. To verify the effect of suggested system, physiological index like a driver's cardiac beats, a cerebral blood flow, and a body surface pulse wave were measured. As a result, it was clarified that the individual difference of physiological reaction of elderly drivers was wide, and requirement of an optimal alarm system concerning this individual difference is confirmed.

In Chapter 4 "Adaptive driving assistance system for elderly drivers considering individual characteristics", change of braking behaviors of elderly drivers with a driving assistance system in a driving simulator environment was observed. Moreover, although individual difference brought by the ability of cognition and judgment, the positive effects on braking behaviors was clarified. Especially, the system is more effective to elderly drivers whose physical ability had fallen.

In Chapter 5 “Application of the driving assistance system for elderly drivers", I verified effect of the driving support system though field tasks. Generally, assistance warning by a beep sound had the highest effect to enhance early brake behavior for an elderly drivers' group who had the inferior cognition function. However, a voice condition as to induce stopping has high effect on increasing the rates of full stopping. In contrast, a voice condition was very effective for elderly drivers' group whose cognition function was not inferior.

In Chapter 6 "Conclusions", I summarized this research; and a future research task is described.

CHAPTER 2

INVESTIGATION OF ELDERLY DRIVERS' DRIVING BEHAVIORS AT INTERSECTIONS

2.1 Definition of driving process at intersections

Driving behaviors when approaching at intersections consist of several steps in driving process, cognition-judgment-control. At first, the driver approaching at intersections recognizes there are intersections with stop signs or stop lines, etc.. And the driver selects the timing putting on a braking pedal and operates a brake pedal by appropriate force and method. At the same time, the driver should check other vehicles, pedestrians or other traffic objects. Finally, the driver stopped at intersections operates slowly an accelerate pedal while confirming oncoming other traffic objects.

This driving process at intersections is a multitask, and elderly drivers have trouble for carrying out appropriate driving operations. Therefore, traffic accidents related elderly drivers occur frequently. Figure 2.1.1 shows braking steps and driving performances which were mentioned above.

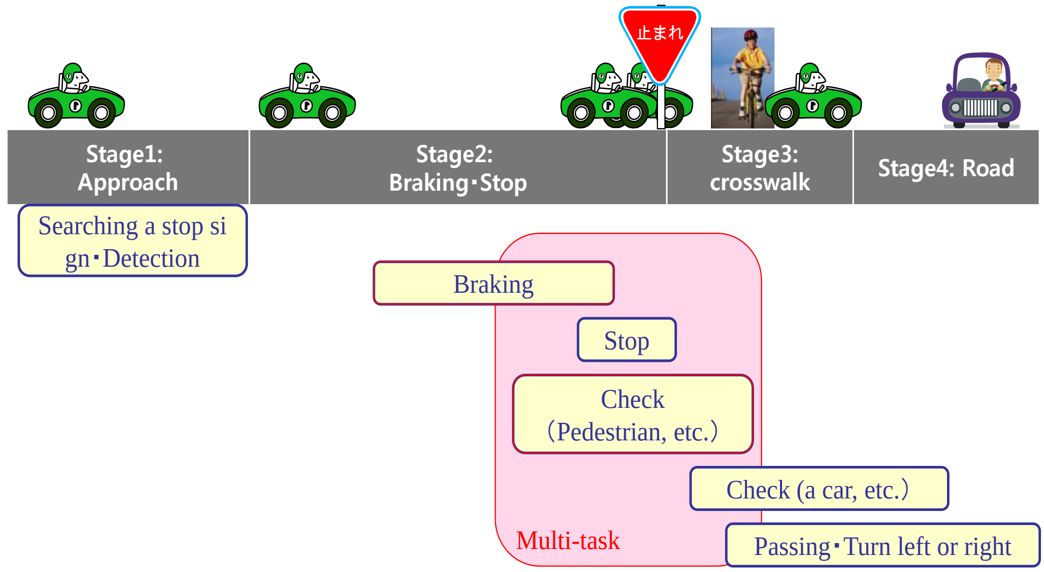


Figure 2.1.1 The process of driving performances from the recognition of intersections to stopping

2.2 Driving behaviors of elderly drivers at intersections

Driving behaviors have been reported as a very complex task in sequential operations with the information of visual aspects among sensory aspects of a human. The many preceding studies suggested that the number of accidents near intersections occur frequently.

According to a report of Japan Metropolitan Police Department in 2014-1st half, traffic accidents occurred at intersection (28.0%) and at near intersections (24.1 %) as shown in Figure 2.2.1. Hence, regarding the types of traffic accidents occurred elderly drivers, the face to face accidents was 480 cases in total of 916 cases as shown in Figure 2.2.2.

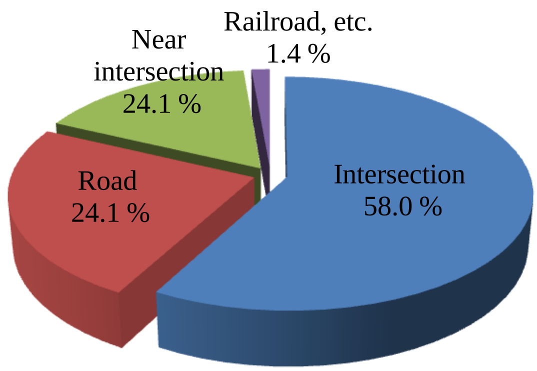


Figure 2.2.1 The traffic accidents in 2014-1st half in termd of road types

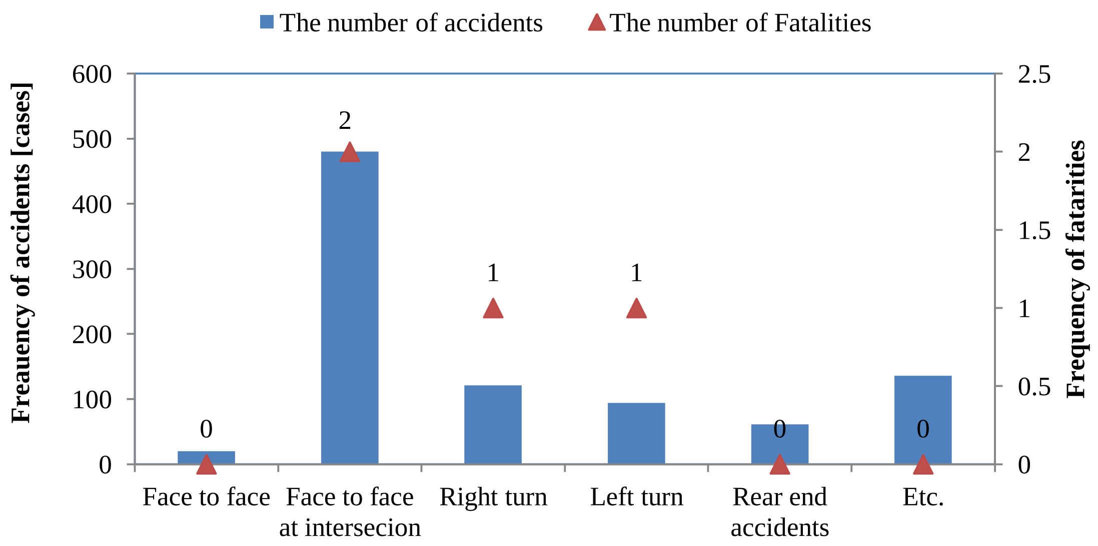


Figure 2.2.2 The traffic accidents occurred by elderly drivers in 2014-1st half in termd of road types

Past researchers examined the effects of attention failures at intersections on driving behaviors. Failures of drawing attention may result from the improper distribution of attention, difficulties of visual recognitions, and/or inappropriate selective attention. Therefore, if the visual ability of a driver is deteriorated and damaged [12] [18], he or she has to select the limited driving behavior or give up the driving [11]. Considering these aspects, the behaviors of elderly drivers pertains to the important variable in driving behavior. When they selected an inappropriate timing on driving behaviors compared to younger drivers, they cause traffic accidents. Many studies reported that the physical ability of elderly drivers deteriorates, because of the limitation of visual function related aging influenced on driving behavior [10]. Therefore, elderly drivers, who make wrong decisions in terms of braking timings [14] or the force putting a brake pedal due to severe deteriorations by ageing, cause traffic accidents [7], [27].

2.2.1 Evaluation of elderly drivers' driving characteristics at intersections on field study

In this Chapter, the driving characteristics of elderly drivers during approaching and stopping to the intersections were investigated through field tests. The characteristics of driving performances between young drivers and elderly drivers were compared. A flow of the driving experiment is shown in Figure 2.2.3.

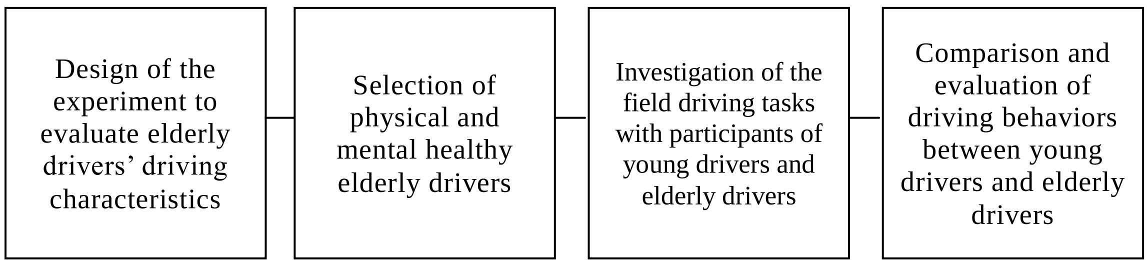


Figure 2.2.3 Experiment process model to evaluate elderly drivers' driving characteristics at intersections

I designed an experiment to investigate elderly drivers' driving characteristics at intersections, comparing with young drivers. At first, I needed to select physical and mental healthy elderly participants. Therefore, I recruited healthy elderly drivers through a local job center, and investigated physical and mental ability of elderly drivers. Next, the selected elderly drivers and young drivers joined the field driving tasks, and the driving tasks were evaluated and analyzed.

2.2.2 The experimental apparatus and the design of experimental intersections`

(1) Subjects of the experiment and selection of elderly drivers

Ten elderly drivers over 65 years old and ten young drivers were participated in the driving tasks. The young drivers (men; 7, women; 3, 22.3~24.0 years, mean age; 23 years) having more than one year of driving experience joined the experiment.

For selecting elderly persons having no trouble in driving, I asked a local job center to recruit healthy elderly participants. I recruited 45 elderly participants. At first, elderly drivers were joined a listening survey of personal information, a visual acuity test, a color vision test, Mini Mental State Examination (MMSE) and Usual Field of Visual (UFOV). The results of the test, I selected healthy 10 elderly drivers (males; 5, females; 5, 69 ~ 78 years).

(2) Experimental vehicle

Figure 2.2.4 shows a car used at the driving tasks and the configuration of the experimental devices. In this car, a GPS sensor, an optoelectronic switch, four cameras and computer devices were installed. The GPS sensor obtained data regarding the lateral and longitudinal velocity and the position of the car.

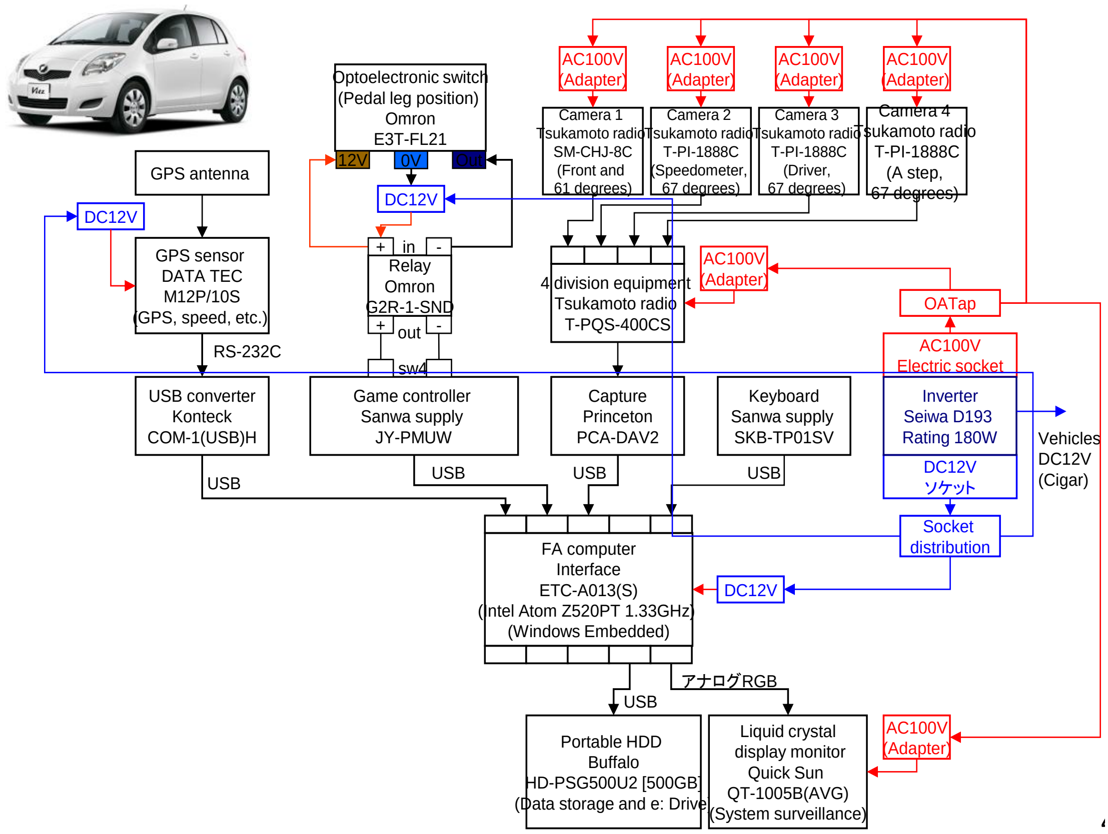


Figure 2.2.4 A driving car and the configuration of the experimental devices

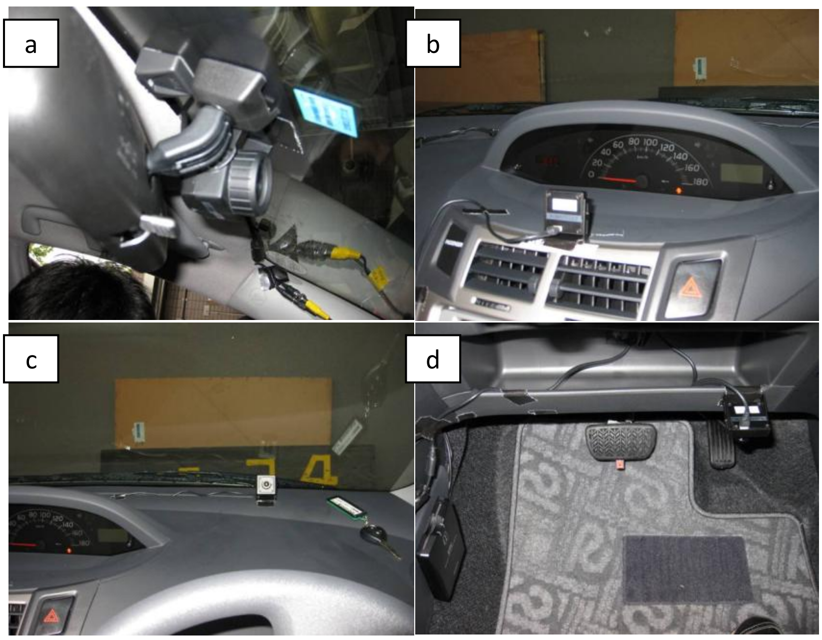


Figure 2.2.5 The cameras to record experimental scene in the car
(a: forward scene, b: speedometer scene, c: driver scene, d: brake pedal scene)

The optoelectronic switch detected braking operations, and four cameras recorded a forward driving scene, a speed meter scene, a driver's facial scene and a brake pedal behavior scene as shown in Figure 2.2.5. All these data was stored into a personal computer on the car.

(3) Design of intersections and the experimental conditions

The experimental driving was conducted at a driver's license training ground with 230 m X 130 m in Kagawa prefecture of Japan as shown in Figure 2.2.6.

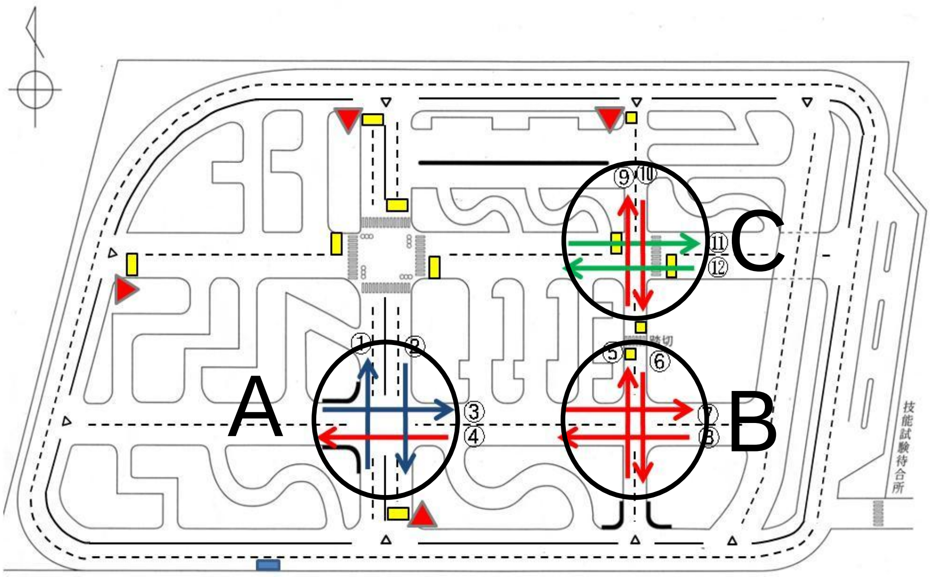


Figure 2.2.6 A car used in the experiment

Three intersections without traffic lights were selected, and separately designated as the intersection A, B and C. In order to set various intersection environments, stop signs, blind corners, rubber stop lines were set. Cameras and graduated rulers to measure stop were used as shown in Figure 2.2.7.

(a) Graduated ruler to measure stopping position (b) Video camera to record stopping behaviors

Figure 2.2.7 Experiment devices to investgate stopping behaviors

Moreover, for evaluating the effect of environment of intersections on braking behaviors, six conditions using various features of stop signs and blind fences were designed as shown in Figure 2.2.8. An ordinary stop sign and enhanced stop sign which has flashing red LED lamp were selected.

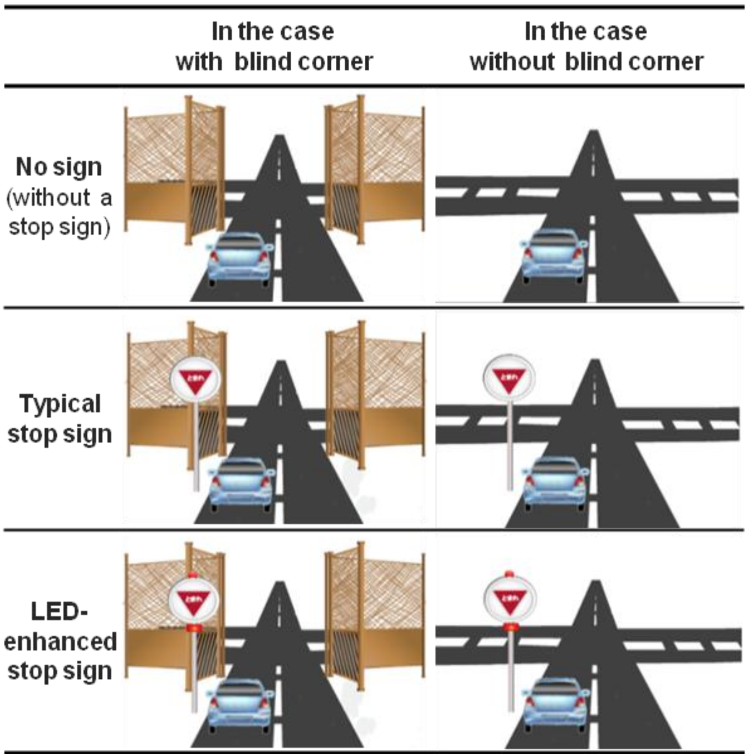


Figure 2.2.8 Six conditions regarding the environment of intersections

(4) Experimental scenario

After participants rode on the experimental vehicle, the operator in the back seat briefly explained a role of the whole experiment. Then, they had a short driving to learn a sense on the road for five minutes, and returned to the starting point to begin this experiment. The experiments were made of the primary and secondary experiment, and each experiment passed all intersection A, B and C, each trial was carried out twice in twenty minutes. Numbers of passes of the intersection with the respective conditions are shown as follows in Table 1.

Table 2.2.1 Number of passes the intersection with the respective conditions

Intersection Combination	Intersection	No Sign		Typical Sign		LED-enhanced Sign	
		with blind corner	without blind corner	with blind corner	without blind corner	with blind corner	without blind corner
I	A		2		2		
	B	2		1			1
	C			1		2	1
II	A	1	1		1		
	B			1		2	2
	C	1	1	1	1		
Total		4	4	4	4	4	4

(5) Evaluation methods of deceleration behaviors

Regarding the process of deceleration at intersections, parameters to evaluate driving behaviors were selected. Figure 2.2.9 shows a sequential echogram in terms of deceleration and stopping behaviors near the intersection. The parameters are as follows:

The velocity at braking initiation: Vo [Km/h]

The time from braking initiation to stop: Tp [s]

The distance from stop position to a stop line: Lo[m]

The rate of deceleration change from braking operation: Jerk [m/s^3]

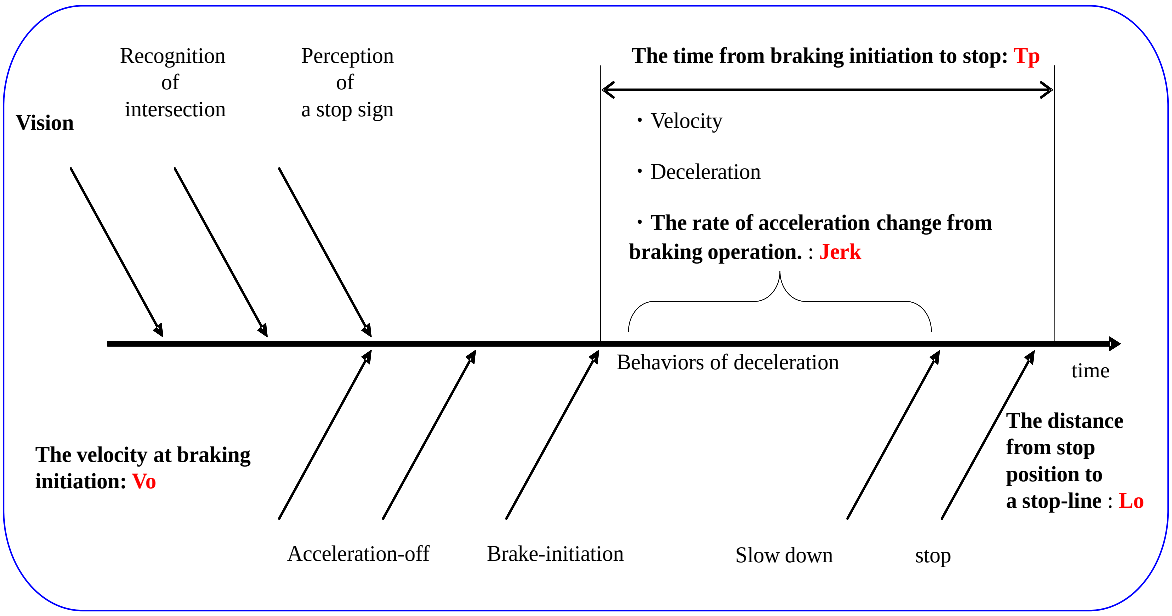


Figure 2.2.9 Sequential ethogram for decelerating and stopping behaviors near the intersection

2.2.3 The results of deceleration behaviors

Statistical methods were used and the statistical terminology was used in this study. There are defined here. (1) MS: the mean squares, (2) SEM: the standard deviation, (3) df: the degrees of freedom, (4) F: the F-ratio which cuts off various proportions of the distributions. This may be computed for different values of df1 and df2., (5) T: the T-ratio which cuts off various proportions of the distributions. This may be computed for values of df.,(6) p: prob, probability, sig., or sig. of F/T, (7) VIF: the Variance Inflation Factor by David, 1998.

Table 2.2.2 Statistical abbreviations and definitions in the chapter

	Statistical abbreviation	Definition
(1)	MS	Mean Squares
(2)	SEM	Standard deviation
(3)	df	Degrees of freedom
(4)	F	F-ratio which cuts off various proportions of the distributions. This may be computed for different values of df1 and df2
(5)	T	T-ratio which cuts off various proportions of the distributions. This may be computed for values of df
(6)	p	Prob, probability, sig., or sig. of F/T
(7)	VIF	Variance Inflation Factor

(1) Driving behavior

Because the driving behavioral data, Vo, Tp, Lo and Jerk have the correlation with a series of these braking operations, the results of deceleration behaviors in detail were attached in an appendix. I set up the dependent variable with age and the intersection by Multivariate Tests.

Velocity at braking initiation: Vo

The Vo at braking initiation were investigated for each intersection, Vo of young drivers at intersection A was M = 31.1 ± 2.558 km/h (average ± standard deviation). And Vo of elderly drivers at intersection A was M = 32.27 ± 3.051 km/h. Next, Vo of young drivers at intersection B was Vo M = 26.865 ± 3.437 km/h, and that of elderly drivers was M = 31.158 ± 4.454 km/h. At intersection C, Vo of young was M = 26.865 ± 3.438 km/h, and Vo of elderly drivers was the M = 31.158 ±

4.454 km/h as shown Table 2.2.3.

According to Multivariate Tests in terms of age and intersection, a result of age factor had very significant differences with [MS= 163.614, F (1, 87) = 11.293, p = .001]. Next, according to the results of Paired-Samples T Test (two levels: young and elderly driver), at intersection A, there was no significant difference with [MS = -1.17000, SEM = 1.45450, df = 9, t =-. 804 p =. 442], at intersection B, there was very significant difference with [MS =- 4.58947, SEM = 1.38401, df = 18 , t =- 3.316 p =. 004], and at intersection C, there was a significant difference with C [MS =- 3.726, SEM = 1.4375, df = 9, t =- 2.592 p =. 018], as shown in Figure 2.2.10.

Also, regarding intersection as a main factor, there was very significant difference as [MS = 276.247, F (2, 87) = 19.067, p =. 000]. According to a results from Scheffé test (three levels: intersection A, B, and C), Vo intersection A was higher than that of intersection C as [MD = 2.8077, SEM = 1.07431, p = .037], Vo of the intersection of B was higher than that that of intersection C as [MD = 5.473, SEM = .8850, p = .000]. However, at an interaction between age and the intersection, there was no significant difference with [MS = 17.174, F (2, 87) = 1.185, p = .311].

Table 2.2.3 The velocity at braking initiation: Vo comparing elderly drivers to young drivers

Age group		Intersection		
		A	B	C
Young drivers	Ave.	31.1	26.865	32.6
	Std.	2.558211	3.437299	3.902091
Elderly drivers	Ave.	32.27	31.15789	36.2
	Std.	3.050701	4.453627	3.99291

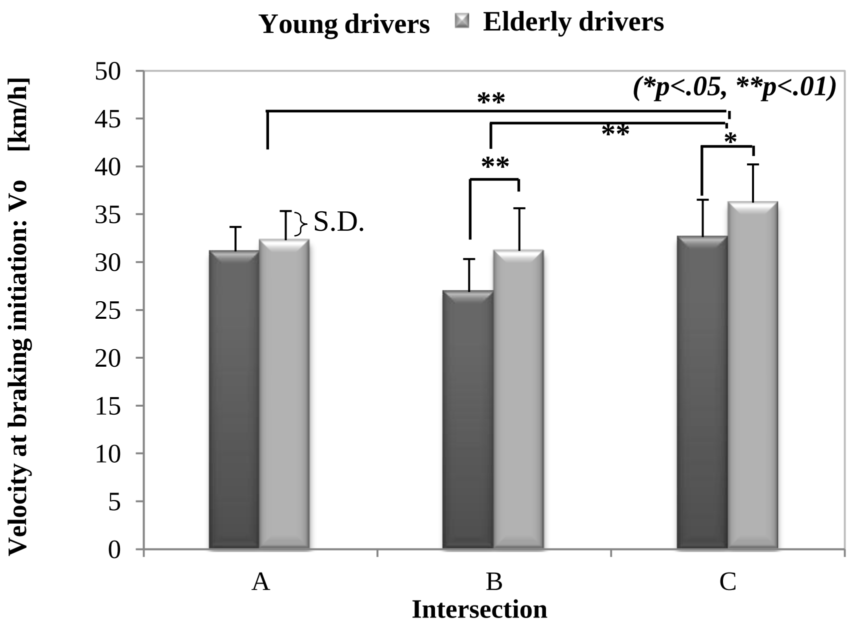
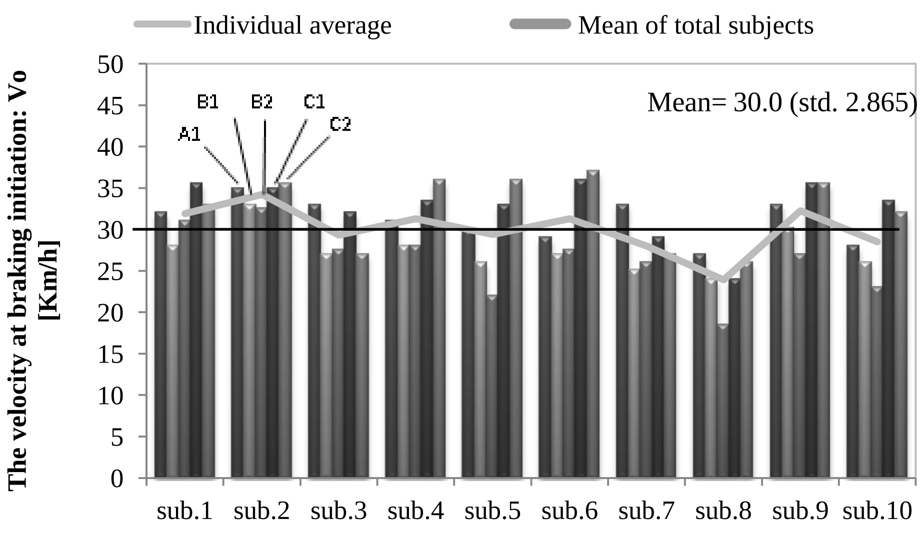
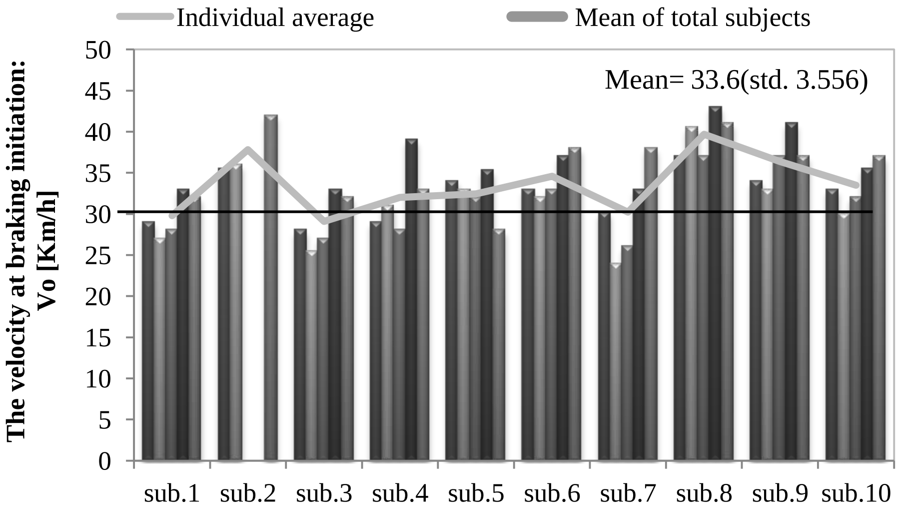


Figure 2.2.10 The average of the velocity at braking initiation: Vo

Figure 2.2.11 shows the individual Vo. As the results, both young and elderly driver show difference in the individuals. The elderly divers have higher individual difference.



(a) Vo of young driver



(b) Vo of elderly drivers

Figure 2.2.11 Individual results of Vo at braking initiation. (a) young drivers, (b) elderly drivers

The time from braking initiation to stop: Tp

The time deceleration from onset of deceleration to the lowest speed or stop, Tp was investigated. Tp of young driver at the intersection A was M = 6.555 ± 0.943s (average ± standard deviation), and Tp of elderly drivers at the intersection A was M = 6.2 ± 1.2401s. At intersection B, Tp of young rivers was M = 6.314 ±1.090s, and that of elderly drivers was M = 5.9 ± 1.2867s. And Tp of young drivers at the intersection C was M=6.835±1.0414s, that of elderly drivers was M=6.305±1.1891s as shown Table 2.2.4

As the result of Multivariate Tests, "age" as a main factor was shown significantly no difference as [MS = 2.753, $F(1, 87) = 2.127$, $p = .148$], "intersection" as a main factor was also shown significantly no difference as [MS = 1.299, $F(2, 87) = 1.003$, p =. 371]. Interaction between "age" and “intersection” also was also shown significantly no difference as [MS = .238, $F(2, 87) = .184$, $p = .832$], as shown in Figure 2.2.12.

Table 2.2.4 The time from braking initiation to stop for age and intersection

Age group		Intersection A	Intersection B	Intersection C
Young drivers	Ave.	6.555	6.314	6.835
	Std.	0.943531	1.08984	1.041393
Elderly drivers	Ave.	6.2	5.9	6.305263
	Std.	1.240072	1.286684	1.189058

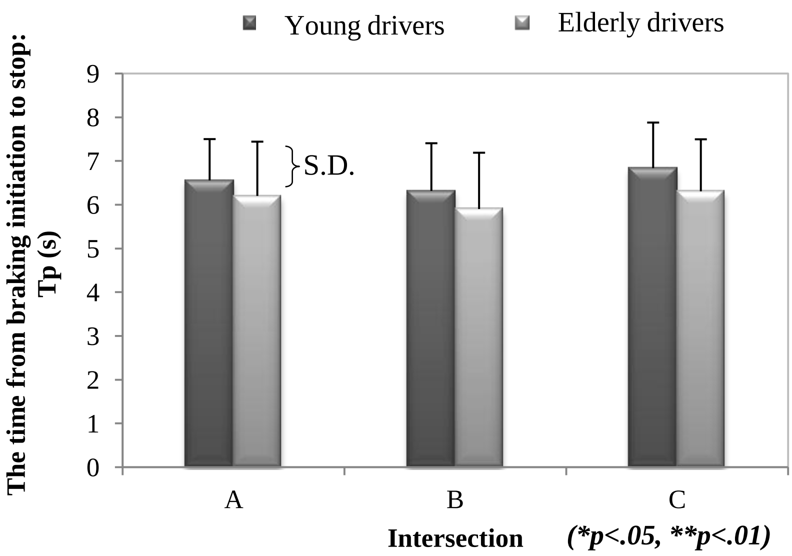


Figure 2.2.12 The average of time from braking initiation to stop: Tp

The distance from stop position to a stop line: Lo

Figure 2.2.13 shows the result of Lo. Lo of young drivers at the intersection of A was M =- 0.29 ± 0.9218m (average ± standard deviation), and that of elderly drivers was M =- 0.656 ± 1.240 m. At intersection B, Lo of young drivers was M =- 0.401 ± 0.8629 s, and Lo of elderly drivers was M =-

0.648421053 ± 0.7854 m. And, Lo of young drivers at the intersection C was M =- 0.223 ± 1.0861 m, that of elderly drivers was M =- 0.681 ± 0.6560 m as shown Table 2.2.5.

Table 2.2.5 The distance from stop position to a stop line in terms of age and intersection

Age group		Intersection		
		A	B	C
Young drivers	Ave.	-0.29	-0.40105	-0.22316
	Std.	0.921894	0.862889	1.086104
Elderly drivers	Ave.	-0.65556	-0.64842	-0.68056
	Std.	0.913935	0.785453	0.655999

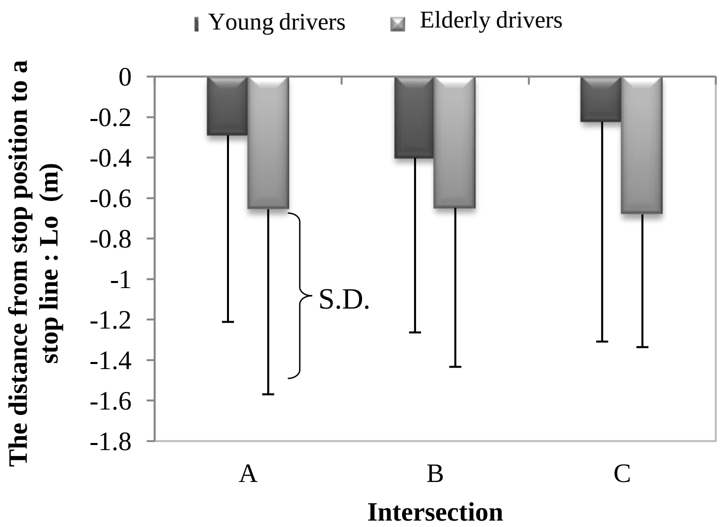
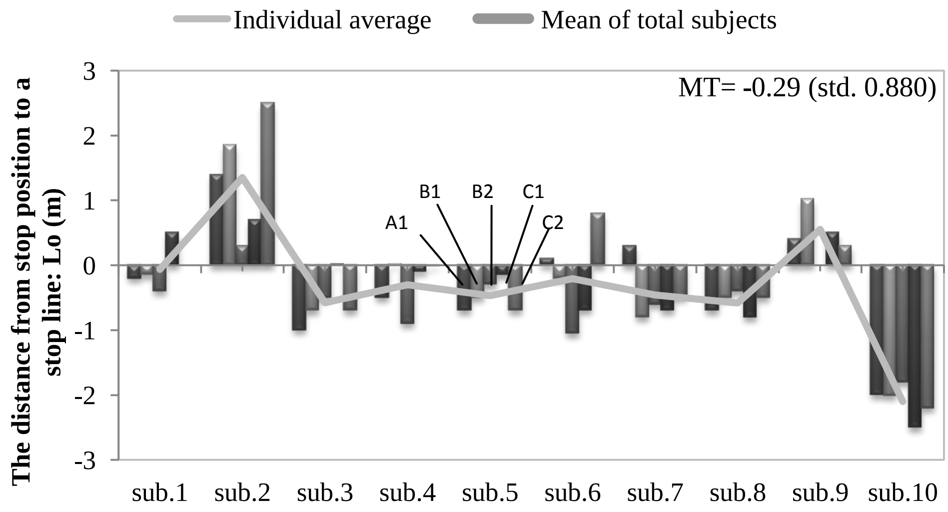


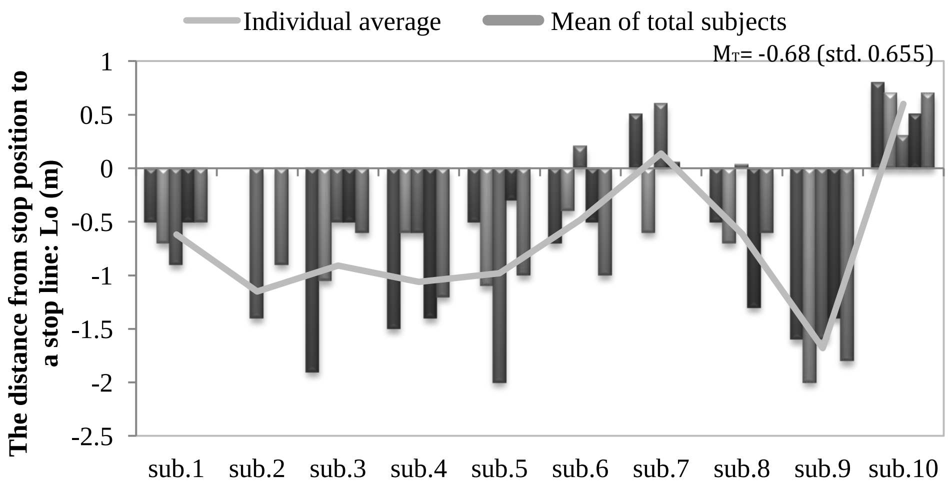
Figure 2.2.13 The average of the distance from stop position to a stop line: Lo

Next, as the result of Multivariate Tests, "age" as the main factor shown significantly no difference as [MS = 2.475, F (1, 87) = 3.224, p = .076], "intersection", a main factor, and interaction between "age" and the "intersection" were also shown significantly no difference as [MS = .025, F (2, 87) = .033, p = .968] and [MS = .149, F (2, 87) = .194, p = .824].

Figure 2.2.14 shows individual Lo of young and elderly drives. As a result, Lo of young shows that they stopped at intersections in the range of ± 1m except for two drivers, but Lo of elderly drivers shows they exceeded over the range of ± 1m.



(a) Lo of young drivers



(b) Lo of elderly drivers

Figure 2.2.14 Individual results of *Lo*. (a) young drivers, (b) elderly drivers

The rate of acceleration change from brake operation: Jerk

Jerk_min and Jerk_max as the driver's variation of deceleration were investigated. As shown in

Figure 2.2.15, Jerk_min of young drivers at the intersection A was M = -2.37 ± 0.0904 m/s^3 (average ± standard deviation), and Jerk_max of young drivers was M = 2.385 ± 1.7651 m/s^3. Jerk_min of elderly drivers at intersection A was M = -3.09 ± 0.7125 m/s^3, and Jerk_max was M = 3.40 ± 2.6680 m/s^3. At intersection B, Jerk_min of young drivers was M = -2.4655 ± 1.2170 m/s^3, Jerk_max of young drivers was M = 2.17 ± 1.0539 m/s^3, Jerk_min of elderly drivers was M = -3.4158 ± 1.0652 m/s^3, and Jerk_max of elderly drivers was M = 3.7312 ± 2.6312 m/s^3. At intersection C, Jerk_min of young drivers was M = -2.3855 ± 0.9775 m/s^3, Jerk_max was M = 2.835 ± 1.6122 m/s^3, Jerk_min of elderly drivers was M = -2.847 ± 1.1192 m/s^3, and Jerk_max M = 2.758 ± 2.4502 m/s^3, as shown in Table 2.2.6.

Table 2.2.6 The rate of acceleration change from brake operation: Jerk

Age group			Intersection		
			A	B	C
Young drivers	Jerk_min	Ave.	- 2.37	-2.4655	-2.39
		Std.	0.090	1.217	0.978
	Jerk_max	Ave.	2.39	2.17	2.84
		Std.	1.765	1.054	1.612
Elderly drivers	Jerk_min	Ave.	-3.09	-3.46	-2.85
		Std.	0.713	1.065	1.119
	Jerk_max	Ave.	3.40	3.73	2.79
		Std.	2.668	2.631	2.450

Figure 2.2.16 shows the individual results of Jerk_min and Jerk_max. As a results of young drivers, three subjects operated brake pedal relatively suddenly, and in case of elderly drivers, two subjects operated extremely sudden braking even one subject operated violent sudden braking. it

was noted that elderly drivers operated braking more dangerous than young drivers did.

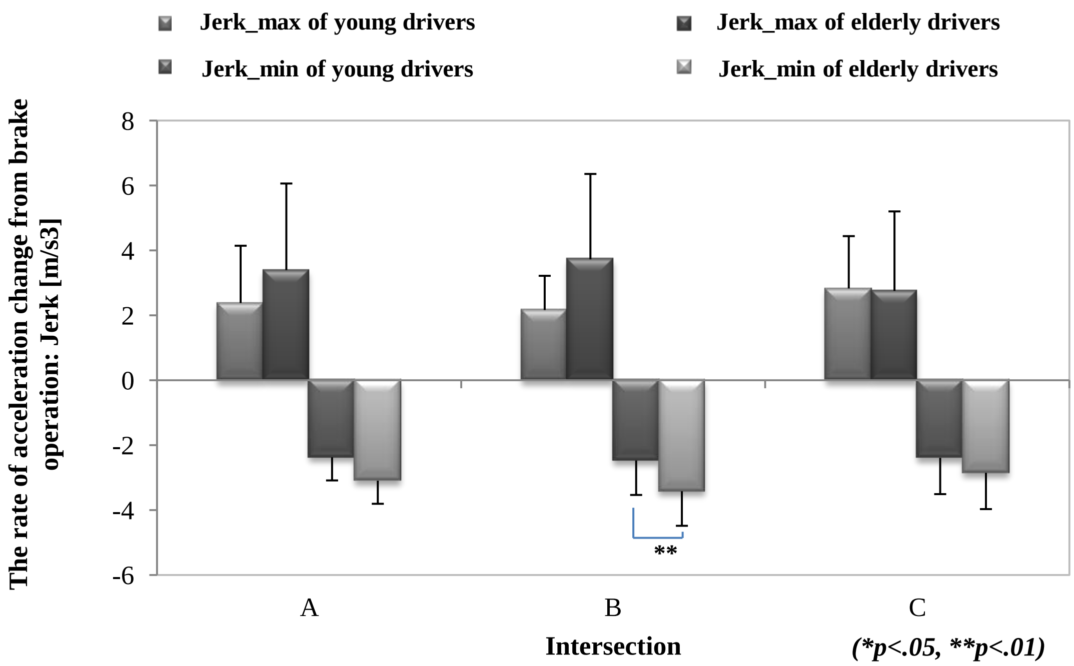
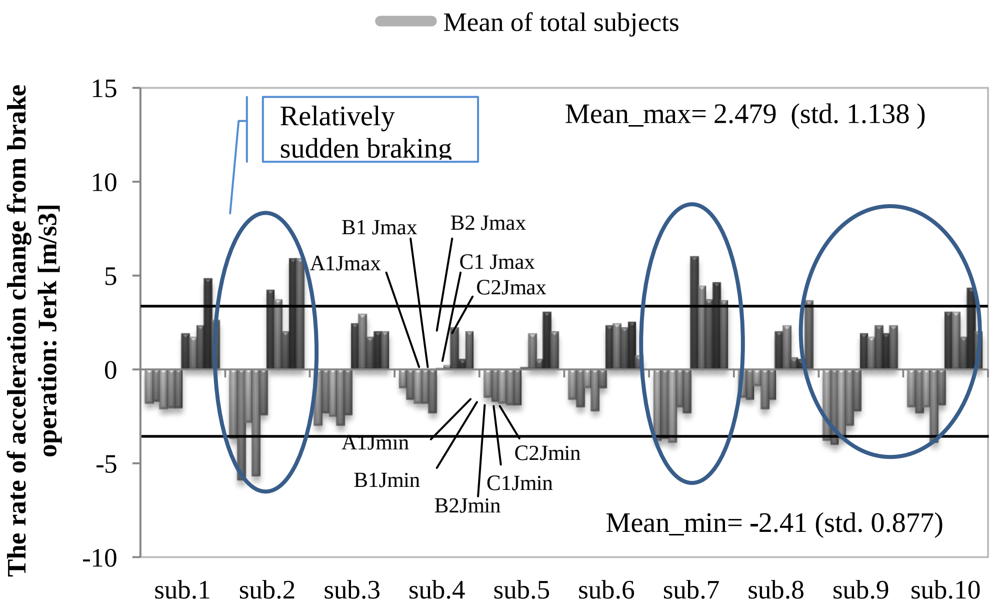
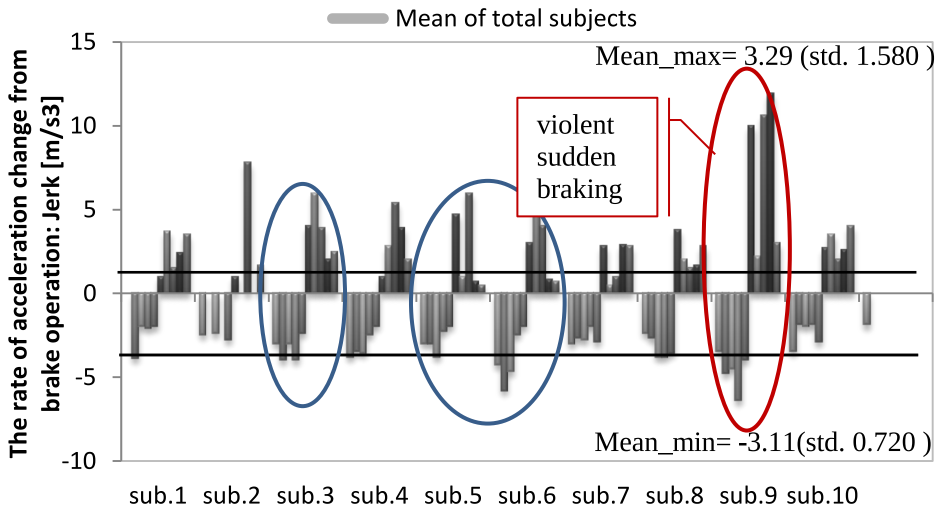


Figure 2.2.15 The rate of acceleration change from brake operation: Jerk



(a) Jerk of young drivers



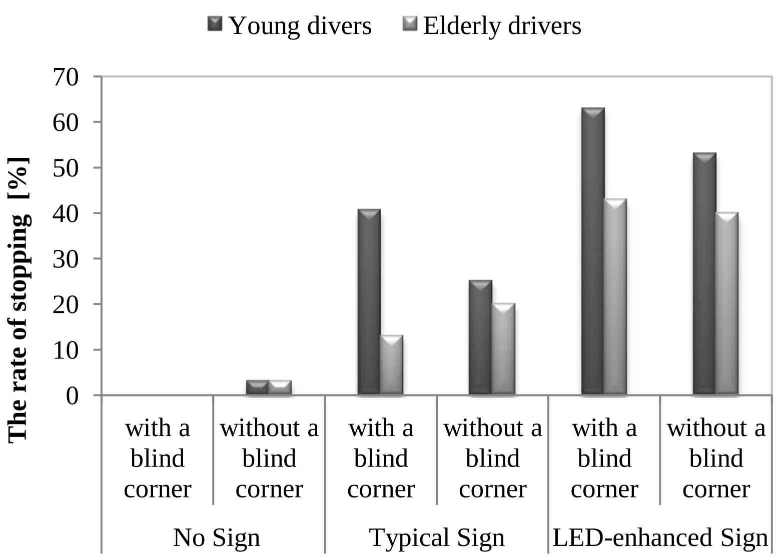
(b) Jerk of elderly drivers

Figure 2.2.16 Individual results of Jerk. (a) young drivers, (b) elderly drivers

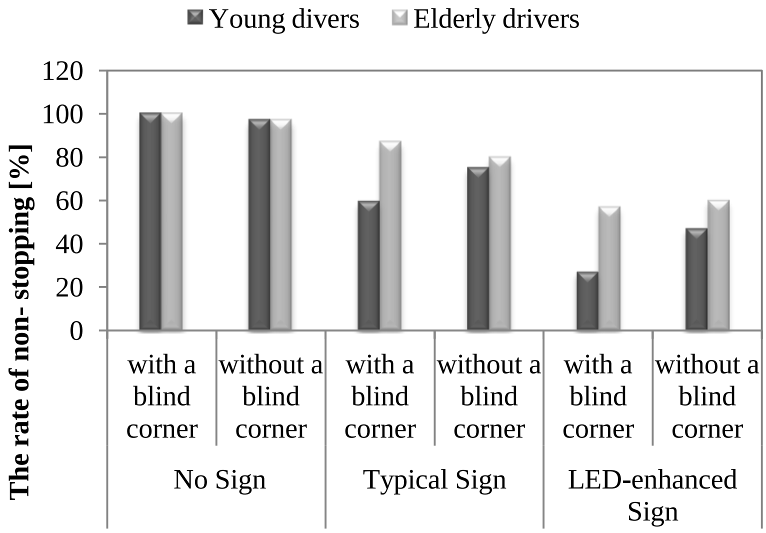
(5) The results of stopping behaviors

The rates of stop and non-stop

Figure 2.2.17 shows a result regarding the rates of stopping and non-stopping. It was shown that elderly drivers have low rates of stopping than that of young drivers.



(a) The rate of non-stop



(b) The rate of non-stopping

Figure 2.2.17 The rates of stop and non-stop in terms of environments of intersections

In this figure, the rates of stopping of young and elderly drivers at the condition of the No Sign and "with a blind corner" is 0 percentages. However, at the condition of LED-enhanced Sign and "with a blind coiner", 64 percentages of young drivers and 43 percentages of elderly drivers stopped at blind corners.

The result of multiple regression analysis regarding the factors of age and intersection

Factors that affect stopping behaviors were investigated by using the multiple regression analysis. The dependent variables are age group, signs and blind corners as an integer. The values are follows. Regarding driving experience and physical characteristics, the Age factor are entered; over the age of 75 aged =1, the former part of aged from age 65 to 74 =2, the untrained driver at age from 20 to 29=3, and the trained driver at the age from 20 to 45=4, respectively. The sign factors are No Sign= 1, Typical Sign= 2, LED-enhanced Sign= 3, respectively. The blind factors are from 0 to 4 with regarding to the number of corners.

In order to identify influence of age, signs and blind corners on stopping, the multiple regression analysis was performed, and the results are shown in Table 2.2.7. The values of relationship between rates of stop and factors in the regression model was significantly correlated as [F=36.322, and p =.000]. An output of Adjusted R Square is 0.932, and an output of Predicted R-squared appears 0.965. Therefore the regression model shows significant explanatory power. Because each tolerance limit is more than 0.1, and VIF is less than 10, thus, there are no problems at multicollinearity of variable factors.

Table 2.2.7 The results of multiple regression analysis

dent variable	lent variable	Unstandardized Coefficients		ıdardized Coefficients Beta	alue	value	ɔllinearity Statistics	
		B	. Error				Tolerance	VIF
	nstant)	ł4.833	5.373		ł.371	.045		
topping	age	0.917	1.962	.257	.782	.024	1.000	1.000
	sign	4.125	2.403	.928	).040	.000	1.000	1.000
	lind	1.292	1.962	-.061	658	.529	1.000	1.000
Predicted R-squared=.965, Adjusted R Square=.932, df=6.797 F=36.322, Sig=.000								

As shown Table 2.2.7, the influence of age factor that measured t= 2.782, p= .024 was statistically significant difference within the 5% significance level, which have a positive (+) affects on the age and driving classifications as Standardized Coefficients Beta= .275. In addition, the sign factor that measured t = 10.040, p = .000 was statistically significant within 1% significance level, which had a positive (+) affects on the age and driving classifications as Standardized Coefficients Beta= .928. As the results, an age factor despite of the discovery of signs should be easier to stop at the intersection with awareness faster, and increase commitment to stop could increase the probability of stopping.

2.2.4 Discussion

This study investigated the deceleration behaviors and the rates of stop comparing the elderly drivers with young drivers. Hence, the factors were affected on stopping behaviors from the points of view as age and environment of intersection. The sequential deceleration behaviors were influenced by the velocity which was before the velocity at braking initiation Vo, the time from braking initiation to stop, Tp, the distance from the distance from stop position to a stop line, Lo, and the rate of acceleration change from brake operation Jerk.

It was found that elderly drivers showed the different deceleration behaviors from young drivers; 1) The velocity before the deceleration Vo, was very fast, 2) The time during deceleration Tp, was short, 3) The distance from stop position to a stop line Lo, was long, 4) The rate of acceleration change from brake operation Jerk, was large. These findings are same with the previous studies that driving skills deteriorate gradually with age. Numerous factors can effect on the deterioration, including loss of visual processing ability on the periphery, also decline of the dynamic vision and a death of vision, deficits due to medical conditions, cognitive decrements and sensory impairment. However, according to the studies of Hong, et al. (2009), elderly drivers approached the intersection slower than young drivers, and the passing time of elderly drivers was longer than that of young drivers in left-turning driving tasks at intersection.

Table 2.2.8 shows the rate of stop and non- stop in the various intersection conditions from elderly drivers braking behaviors features. Black blocks show the most occupied rates of stop or non-stop in lateral conditions, and gray blocks show second occupied rates. It is shown that in both elderly and young driver group the rates of stop and non-stop are associated with the sign condition considerably. For example, 43% of elderly driver's stop rates had stop behavior in LED-enhanced Sign and "with a blind corner" considering 0% in the condition with No Sign and "with a blind corner", also, 63% of young drivers stop in the same condition. However in "with a blind corner" did not show stopping at intersections. These results were associated with the results of Multiple Regression analysis that found significant difference in the factors of age and stop sign considerably.

Table 2.2.8 The rate of stop and non-stop in the various condition for elderly drivers' braking behaviors

			No Sign (percentages)		Typical Sign (percentages)		LED-enhanced Sign (percentages)	
			with a blind corner	without a blind corner	with a blind corner	without a blind corner	with a blind corner	without a blind corner
young drivers	Stop		0	3	40.5	25	63	53
	non-stop	Willingness to Stop	48	59	59.5	75	27	47
		Unknown Willingness to Stop	16	0	0	0	0	0
		Unwillingness to Stop	36	38	0	0	0	0
elderly drivers	Stop		0	3	13	20	43	40
	non-stop	Willingness to Stop	57	39	78	70	45	56
		Unknown Willingness to Stop	19	8	6	0	0	2
		Unwillingness to Stop	24	50	3	10	12	2

Block Occupied the most rates.
Block Occupied second many rates.

2.2.5 Summary

In this experiment, the features in terms of braking behaviors of elderly drivers were shown obviously. That's the braking behaviors were inapposite as above mentioned, and the enhanced level of stop signs was considerably important. At the sequential deceleration behaviors, individual differences of elderly driver were observed statistically, and several suggestive support methods were expected as shown in Table 2.2.9.

Table 2.2.9 Comprehensive countermeasures and individual countermeasure of safe driving regarding the features of elderly drivers

The feature of braking behaviors for elderly drivers	Comprehensive countermeasures	Individual countermeasures
High speed near intersections	Improvement the consciousness of road safety - Notice information of intersections in advance	Notify approaching a intersection in advance - Call attention to intersection with voice and images
Sudden braking and stopping	Suggestion of a prevention regarding sudden braking - Practice of correct control of brake pedal	Training of braking control - Brake pedal replace with fly-by-wire
Inaccuracy stopping position	Improve of awareness of operation safety - Education about vehicle principle with a easy book	Inducement of braking timing and stopping position - Control of brake pedal by operation profile
Incorrect operation of brake pedal	Visibility improvement of stopping position - Stop-line or sign, etc. make it easy for drivers perceive	Assistance of visual function - Stop-line or sign, etc. make it easy for drivers perceive

In the table, considering each feature of deceleration behavior of elderly drivers, available support system was suggested by noticing the individual differences of elderly drivers. As the results, examples of the designing of support and assistant systems were proposed. And support systems to prevent nonstop collisions at intersections was proposed.

CHAPTER 3

STUDY ON THE COMPOSITION OF ADVANCED DRIVING ASISSTNACE SYSTEM AND IT'S EFFECTS BASED ON PHSICAL RESPONSES

3.1 The design of advanced driving assistance system for elderly drivers

3.1.1 Introduction

The design of advanced driving assistance system for elderly drivers should regard the features of elderly drivers such as vision, cognition function, driving characteristics and etc..

I investigated deceleration behaviors at non-signal intersections in Chapter 2. It was clarified that, elderly drivers have difficulties on recognizing intersections, deciding braking timing and adjusting stop position. Based on this results, it is necessary to propose an effective driving support system to assist braking behaviors for elderly drivers.

In this chapter, I will a method to show design a driving assistance system for elderly drivers to prevent the face to face accidents, and clarify the methodology to support for elderly drivers based on braking behaviors and cognitive function at a stopping situation.

3.1.2 Concept of a driving assistance system

Based on the characteristics of elderly drivers, I will suggest an optimal driving assistance system for elderly drivers. The system has to be designed to eliminate a multitasking situation for reducing the work load. In other words, elderly drivers can concentrate the task of each step using driving assistance systems.

On the other hands, to design the effective alerting methods for elderly drivers, it is important to support each step like the supporting awareness of stop signs, inducing braking behavior and stopping considered other vehicles and checking left and right.

(1) Stage 1: Assistance for awareness of intersection

In order to prevent missing to detect intersections from stop sign or stop line, it will be effective to inform intersections for elderly drivers. The assistance systems which present voice information were developed, and it was already commercialized. This system informs intersections to driver ahead 100m of a stop positions (stop lines). As the results, it is confirmed that non-checking rate of stop signs in elderly drivers decreased by presenting the voice information.

(2) Stage 2: Assistance for inducement of deceleration and stopping

Because the elderly drivers maintain high speed near intersections and were late for braking timing, the support to enhance the braking is needed. In other words, the inducement of braking operation by audiovisual alert will be more effective.

(3) Stage 3: Assistance of confirming safety by check right and left

Guidance of spatial direction cautions is need, as well as, stages 1 and 2 inducing proper braking behavior of drivers. For example, the caution-guidance using visual images with pointing finger is designed.

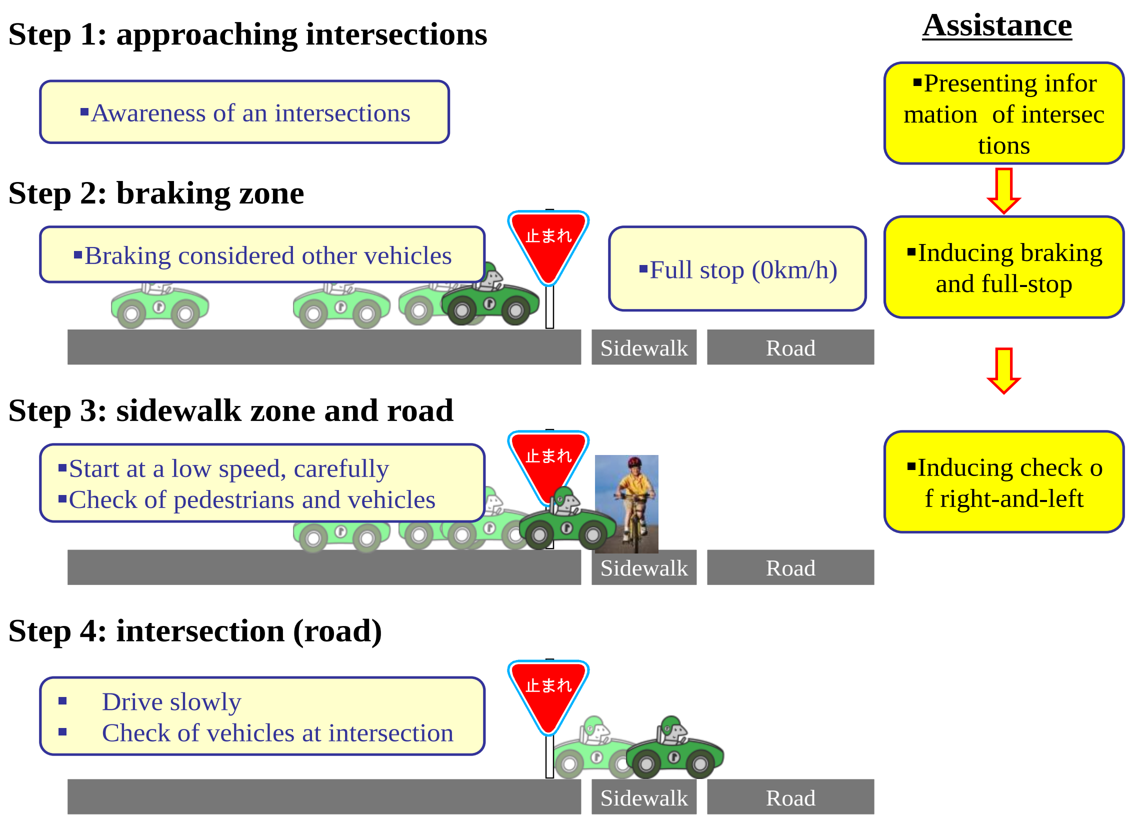


Figure 3.1.1 Concept of a driving assistance system

3.2 Investigation of the effectiveness using physiological signals of auditory-visual alert for elderly drivers

3.2.1 Introduction

Driving performance is influenced by very complex factors among environments and drivers. The driver's factors include the individual differences with regard to age, gender, driving experience and skill. In particular, there has been an increase in the traffic accidents caused by the elderly driver, which have occurred as a result of non-pause stops at intersections. Therefore, a driving assistance system has been developed to support actively such elderly drivers. Then, an appropriate driving support system for elderly drivers must be designed in order to adapt to the individual difference in their characteristics [78]. Moreover, it is even more important to evaluate the effectiveness of such support systems using objective methods like physiological signals as well as subjective evaluations.

In recent years, there have been attempts to acquire physiological signals noninvasively as an evaluation index because these are not influenced by subjectivity. There have been many studies in which human inner states were estimated and analyzed by measuring physiological signals such as electrocardiograms (ECGs) [79]. Recently, the increases in oxy-hemoglobin (oxy-Hb) and decreases in deoxy-hemoglobin (deoxy-Hb) have been introduced to determine cortical activations in the brain. The multichannel near-infrared spectroscopy (MNIRS) has been developed in this field of study and it can be used successfully to monitor human brain functions[81]. As another index based on human physiological signals, the aortic pulse wave (APW) can be estimated from the pulse wave measured using finger.

A driving assistance system was constructed in this study, which consisted of various combinations of information presentation methods to encourage pausing and stopping at intersections. Five alarms were designed using various combinations of audio–visual signals. Six participants from a group of 45 elderly drivers were chosen based on preliminary tests. In addition, nine young drivers were selected from a group of ten as a comparison group. In the experiment, while the drivers performed a driving task on a city road using a driving simulator, the physiological signals were measured, including the ECG, the cerebral blood flow using near-infrared spectroscopy (NIRS) and the APW. The effects of a warning on an elderly driver's psychosomatic state were analyzed, and the physiological signal activations after alarms were observed.

3.2.2 Experimental Procedure

(1) Subjects

In this study, the participants included 45 elderly drivers (67–79 years old; female: 15, male: 30) and ten young drivers (21–24 years old). In order to determine the suitability of the driving task, preliminary tests were conducted to select the participants prior to the experiment. The goal of these tests was to quantify the individual cognitive and judgment ability. A useful field of view test (UFOV), mini-mental state examination (MMSE), visual acuity test and color vision test were used for the evaluation. Moreover, in order to compare their results with those of the elderly drivers, all of the young participants were also asked to perform the tasks.

The resulting UFOV and MMSE percentages for all 45 elderly drivers are plotted in Figure 3.2.1. In the figure, higher percentiles indicate higher scores, and circled numbers show subjects who participated in a pre-test. The circled numbers close to the black spots in the figure indicate the individual elderly drivers. The cognition and judgment abilities of the elderly drivers varied considerably, as seen from the figure. Four groups, O_A, O_B, O_C and O_D, were classified by descending order of ability.

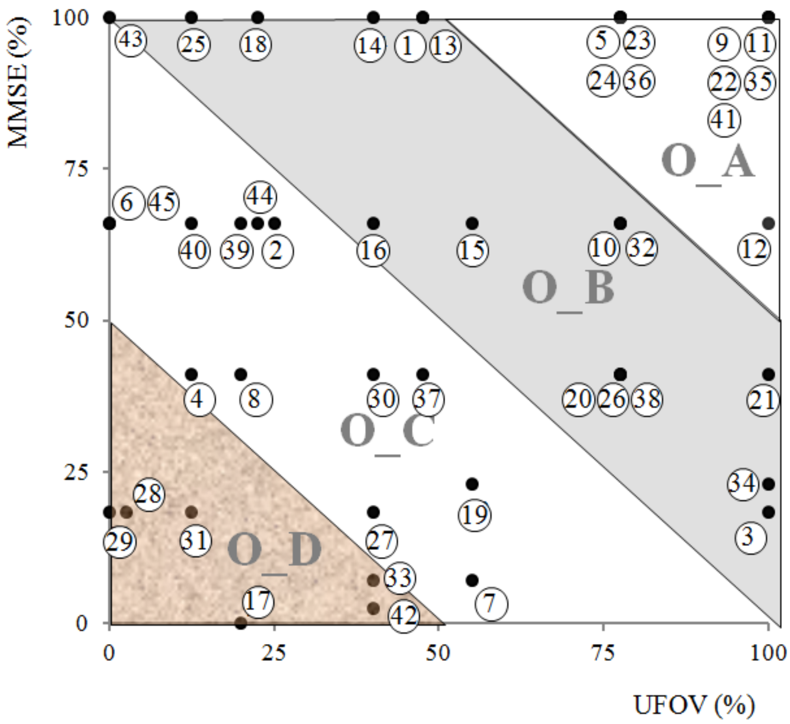


Figure 3.2.1 Group classifications of forty-five elderly drivers based on the results of UFOV and MMSE

In the driving support experiment with a driving simulator, the elderly participants were selected by considering the reliability of the experimental results. Two drivers (㉒,㉟) from group O_A, three (⑩, ⑬, ㉜) from group O_B, none from group O_C, and one (㉛) from group O_D were selected to participate in the driving experiment. Driver's performances showing the response to an alarm were obtained by measuring physiological signals. In addition, the nine young drivers participated in the same experiment for comparison. Prior to the driving experiment, all of the participants were taking part in the informed consent.

(2) Alarm Conditions and Procedure

The detection and recognition of the intersection, the brake pedal control, and the five alarms were constructed based on the time series for driving behavior prior to stopping. As shown in the time chart of Table 3.2.1, all of the conditions, excluding the none condition, consisted of an alarm sound or images, as well as the voice warning, in accordance with approaching the intersection. Each condition utilized a variety of metrics consisting with visual and auditory warnings (sound and voice). The contents of the alarm combinations are explained as follows.

No alarm condition (None)

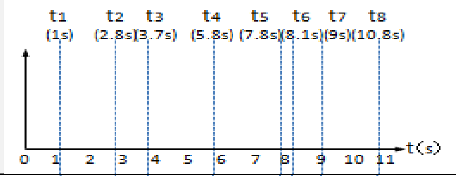
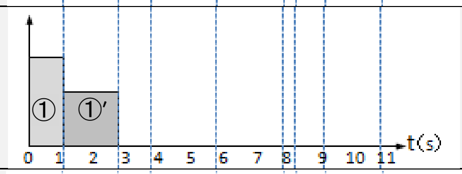
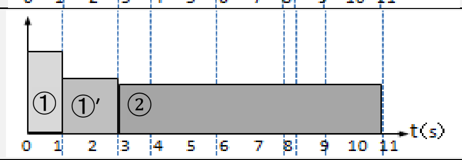
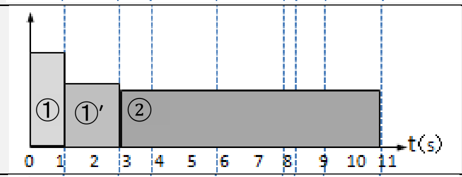
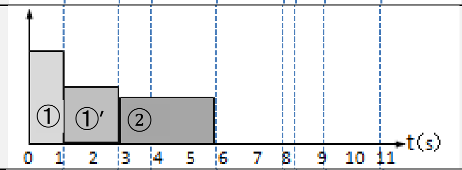
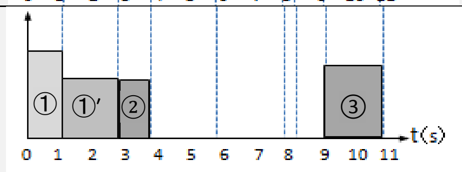
① Information condition (Info): After presenting a pong (sound) + (display) in order to support the perception (discovery) of the intersection, a woman's voice informed the driver that there was an intersection.

② Low-frequency beep condition (Low-f. beep) and ③ High-frequency beep condition (High-f. beep): After informing the approaching intersection for the driving under these two conditions, a beep sound was presented in order to induce the braking operation. The elderly drivers had narrower audible frequency ranges than the young drivers and could not hear the treble frequency very well. Therefore, in order to clarify the most appropriate beep frequency in the bass and treble ranges to induce braking action, this condition was divided into low. frequency and high. frequency ranges. The low-frequency beep was at 1.0 kHz, with the 0.38-s intervals, for the Low-f. beep condition, whereas the beep had a frequency of 3.7 kHz (emergency pulse sound) and intervals of 0.2 s for the High-f. beep condition.

④ Display condition (Display): The driver was informed about approaching the intersection at first. Then, visual information was presented to induce the braking operation to investigate whether this had an effect or not. That is, after the presentation of the Info condition, images showing the operation of the brake were shown on a navigation display, which was placed at the center of the instrument panel.

⑤ Voice alarm condition (Voice): In relation to the auditory stimulus, in order to clarify the difference between the simple beep sound without meaning and a voice providing a detailed explanation, the Voice condition was set up. Under this condition, after the Info condition, a female voice told the driver to "brake smoothly" for inducing the braking operation and "stop completely" to promote compulsory stopping.

Table 3.2.1 Sequential content and timing chart for alarm conditions

Condition	Contents	Timing chart
None	Vertical axis represents stimulus strength	
① Info.	① Pong (sound) + (image) ①' There is a stop intersection (voice)	
② Low-f. beep	① Pong (sound) + (image) ①' There is a stop intersection (voice) ②Beep–beep (1.0 kHz, 0.38s continuous sound)	
③ High-f. beep	① Pong (sound) + (image) ①' There is a stop intersection (voice) ②Beep–beep-(3.7 kHz, 0.2s continuous sound)	
④ Display	① Pong (sound) + (image) ①' There is a stop intersection (voice) ② Showing an image operating a brake pedal	
⑤ Voice	① Pong (sound) + (image) ①' There is a stop intersection (voice) ② Brake smoothly (voice) ③ Stop completely (voice)	

(3) Physiological Indices

In this study, Electrocardiogram (ECG) was measured by using Power Lab (AD Instruments co. Ltd.). The indices of LF as low-frequency component and HF as high-frequency component were investigated at the interval of heart beat (RRI), since RRI is influenced by autonomic nerve system. The index LF (low-frequency component) is influenced by sympathetic and parasympathetic nerve system. The index HF (high-frequency component) is influenced by parasympathetic nerve system.

When a human feels mental stress, the value of LF/HF becomes larger. LF/HF and HF were used as indices of sympathetic nerve system and parasympathetic nerve system, respectively.

Changes of oxy-Hb concentration and deoxy-Hb concentration on a frontal cortex taking charge of human's cognition and decision were measured by using a near infrared spectroscopy measurement equipment (NIRS; OEG-16 Instrument by Spectratec. Ltd.). It consists of 16 optical fibers and uses the near-infrared light (wavelength of 700 ~ 900 nm) shown in Figure 3.2.2. In this study, wave form of channel 2 was selected for representing indices for the brain activation of right frontal cortex.

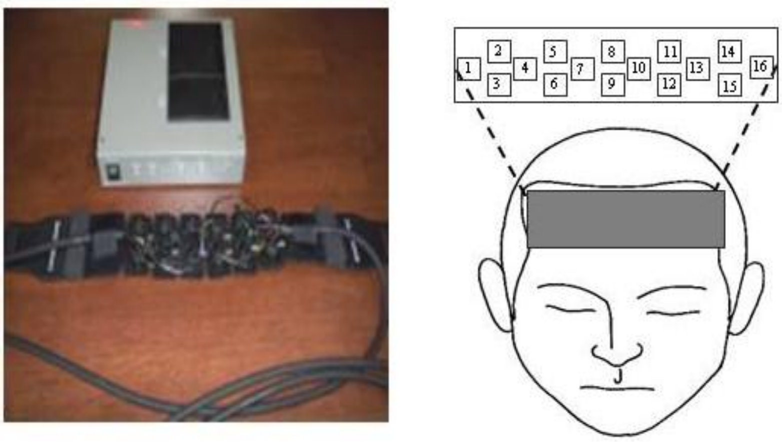


Figure 3.2.2 NIRS measuring equipment (left) and 16 channels on frontal cortex (right)

As the other indices using human physiological signals, the aortic pulse wave (APW) can be estimated from blood flow pulse measured by finger plethysmogram. The plethysmogram was also recorded using a fingertip lobe pulse wave measuring equipment (BACS, CCI Inc.). It consists of an infrared light emitting diode and a phototransistor. The fingertip blood volume pulse waves provide chaotic physiological information and time-series data on the largest Lyapunov exponents(LLE) obtained by chaos analysis offer an index of adaptability to changes in the external environment. When a human feels mental relaxation, the values of HF and LLE become larger. This change is derived from the activation of parasympathetic nerve system and indicates the amount of observer's relaxation.

(4) Experimental Tasks and Scenario

This experiment was executed for thirty-minutes driving by using a driving simulator (DS-2000, Mitsubishi Precision co. Ltd.), as shown in Figure 3.2.3. Before the experiments, each participant experienced a practice driving for five minutes. The order of the alarm condition was counter-balanced for the subjects. The driving course was a two-lane straight road. The performances of operating on a steering wheel, accelerator and brake pedals were recorded. They were asked to keep a constant speed at 60 km/h, and to stop shortly as usual in front of any intersection. They passed through the 12 intersections in the experiment. The audio warning and female voice alerts were given via a speaker placed behind the driver's seat and alarm images were presented on the LCD monitor of 7 inches, which is placed at the center of the dashboard.

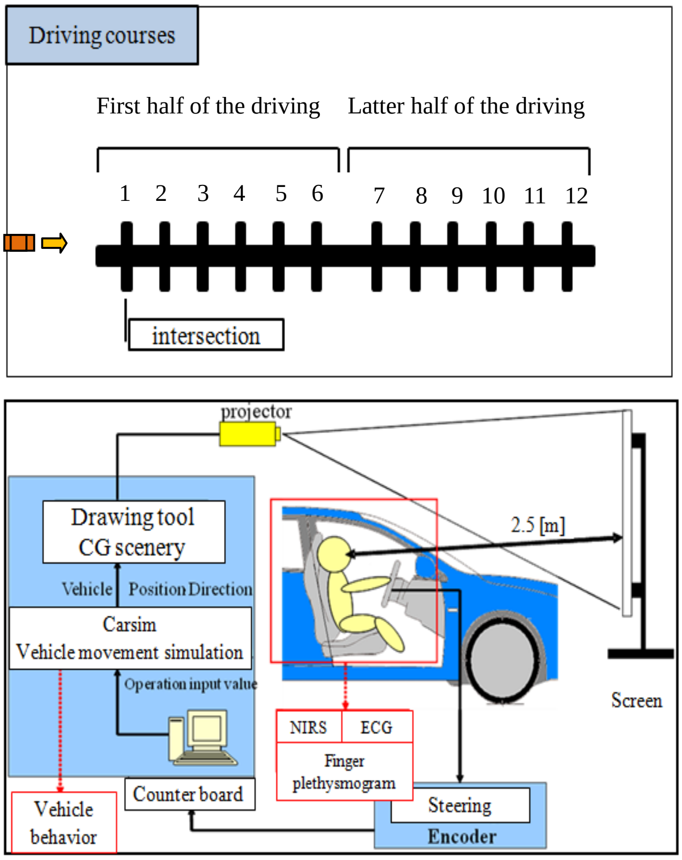


Figure 3.2.3 Driving course and driving simulator

(5) Statistical Methods in the Signal Analysis

As a method of statistical processing, the multivariate analysis was performed and the Scheffé verification method as the post-hoc analysis was also used. In this analysis, the level of statistical significance was set at 0.05 percent.

3.2.3 Experimental Results

(1) Time History Curve of Physiological Signals

The LF/HF and oxy-Hb responses to the alarms during driving are shown in the top graphs of

Figures 3.2.4 (a) to (g), with the time histories of the HF and LLE responses shown in the bottom graphs. In each graph, the horizontal axis indicates the time during the entire experimental period from the start to the end of the driving. The vertical line shows the timing of each initial alarm, including the no alarm condition, with a random order used for the alarm conditions, as shown in the figure; the vertical lines shows the positions of 12 intersections. Moreover, the round number above every vertical line shows the alarm conditions from NONE and ① to ⑤ on the Table 1. The experimental results for six elderly drivers and one representative from among the nine young drivers are shown.

For subject ㉒ of the O_A group (O_A-㉒), without the alarms, increases were observed in LF/HF when approaching intersections 1, 2, 3, 4, 6, 7, 8, 11 and 12. In the first half of driving, the arousal levels increased at Info, Low-f. beep, Display and Voice, whereas in the latter part of the driving, the arousal levels increased after presenting Low-f. beep and High-f. beep. Meanwhile, increases in the cerebral blood flow, as represented by the oxy-Hb concentration, were observed at Low-f. beep, High-f. beep, Display and Voice during the first half of the driving. Then, in the latter part of the driving, increases in the concentration of oxy-Hb were observed at Info, Low-f. beep, High-f. beep, Display and Voice. LLE showed decreases at Low-f. beep, High-f. beep and Voice in the first half of the driving and at Low-f. beep in the latter part of the driving.

Without the alarms, subject ㉟ of the O_B group (O_B-㉟) showed increases in LF/HF when approaching intersections 1, 3, 5, 7, 8 and 9. In the first half of the driving, the arousal levels increased at Low-f. beep, High-f. beep and Display, whereas in the latter part of the driving, the arousal levels increased after presenting Info and High-f. beep. Meanwhile, increases in the cerebral blood flow, as represented by the oxy-Hb concentration, were observed at Info, Low-f. beep, Display and Voice in the first half of the driving. Then, in the latter part of the driving, increases in the concentration of oxy-Hb were observed at Info, Low-f. beep, Display and Voice. LLE showed decreases at Info and Low-f. beep in the first half of the driving and at Low-f. beep, High-f. beep and Voice in the latter part of the driving

Next, without the alarms, subject ㉜ of the O_B group (O_B-㉜) showed increases in LF/HF when approaching intersections 2, 5, 7, 8 and 12. In the first half of the driving, the arousal levels increased at Info, Low-f. beep, High-f. beep and Voice, whereas in the latter part of the driving, the arousal levels increased after presenting Info and Display. Meanwhile, increases in the cerebral blood flow, as represented by the oxy-Hb concentration, were observed at Low-f. beep, High-f. beep, Display and Voice in the first half of the driving. Then, in the latter part of the driving, increases in the concentration of oxy-Hb were observed at Info, Low-f. beep, High-f. beep, Display and Voice. LLE showed decreases at Info, Low-f. beep, High-f. beep and Display in the first half of the driving.

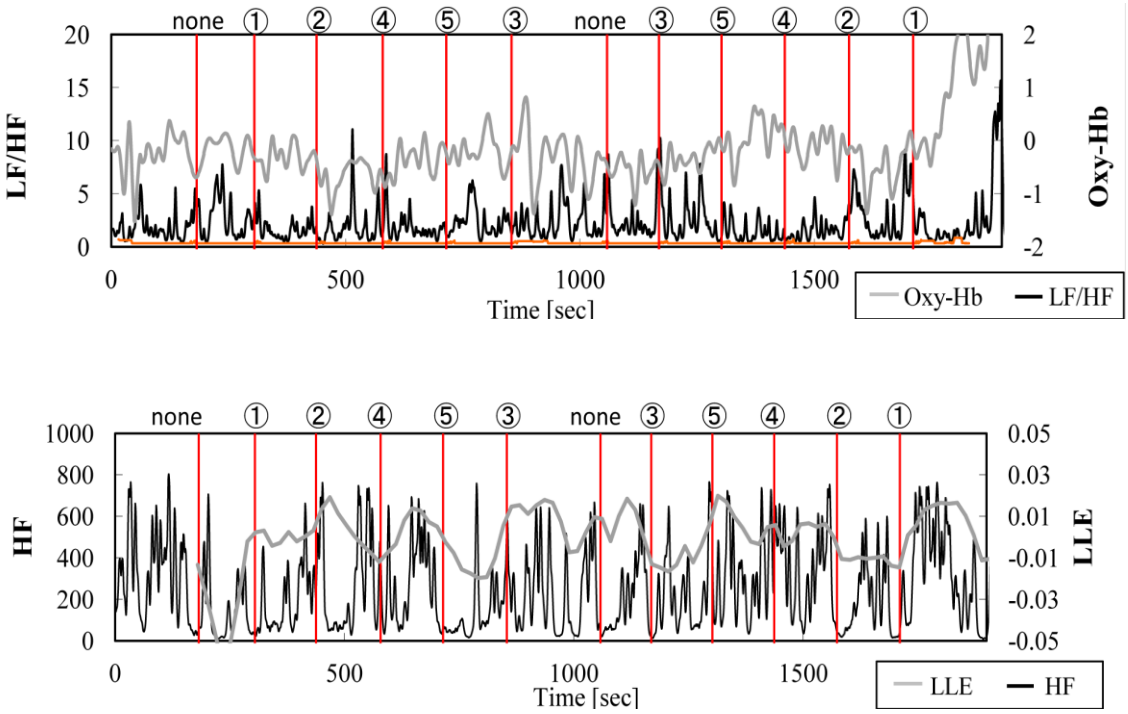
subject ⑩ of the O_B group (O_B-⑩) showed increases in LF/HF when approaching intersections 1, 3, 4, 5, 6, 7, 9, 10, 11 and 12 with None condition. In the first half of the driving, the arousal levels increased at Low-f. beep, High-f. beep and Voice, whereas in the latter part of the driving, the arousal levels increased after presenting Info, Low-f. beep, High-f. beep and Voice. Meanwhile, increases in the cerebral blood flow, as represented by the oxy-Hb concentration, were observed at Info, Low-f. beep, High-f. beep and Voice in the first half of driving. Then, in the latter part of the driving, increases in the concentration of oxy-Hb were observed at Info, High-f. beep and Voice. LLE showed decreases at Info and Display in the first half of the driving.

Without the alarms, subject ⑬ of the O_B group (O_B-⑬) showed increases in LF/HF when approaching intersections 2, 4, 5, 10 and 11. In the first half of the driving, the arousal levels increased at High-f. beep, Display and Voice, whereas in the latter part of the driving, the arousal levels increased after presenting Info and High-f. beep. Meanwhile, increases in the cerebral blood flow, as represented by the oxy-Hb concentration, were observed at Low-f. beep, High-f. beep, Display and Voice in the first half of the driving. Then, in the latter part of the driving, increases in the concentration of oxy-Hb were observed at Info, Display and Voice. LLE showed decreases at Info and Display in the first half of the driving and at Display in the latter part of the driving.

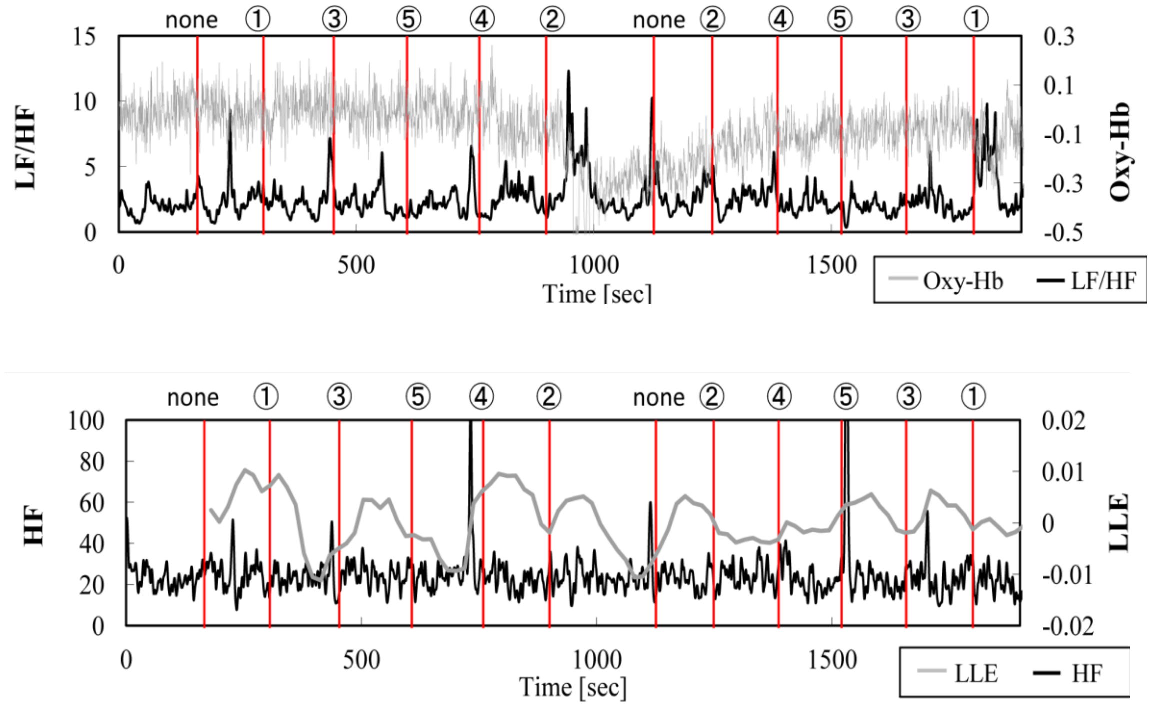
Next, for subject ㉛ of the O_D group (O_D-㉛), before the alarms were presented, increases were observed in LF/HF when approaching intersections 5 and 8. In the first half of the driving, the arousal levels increased at Info, Low-f. beep, High-f. beep, Display and Voice, whereas in the latter part of the driving, the arousal levels increased after presenting Info, Low-f. beep, High-f. beep and

Display. Meanwhile, increases in the cerebral blood flow, as represented by the oxy-Hb concentration, were observed at Low-f. beep, High-f. beep, Display and Voice during the first half of the driving and at the Info, Low-f. beep, High-f. beep and Voice conditions during the latter part of the driving. LLE showed decreases at Info and Low-f. beep during the first half of the driving and at Low-f. beep and High-f. beep during the latter part of the driving.

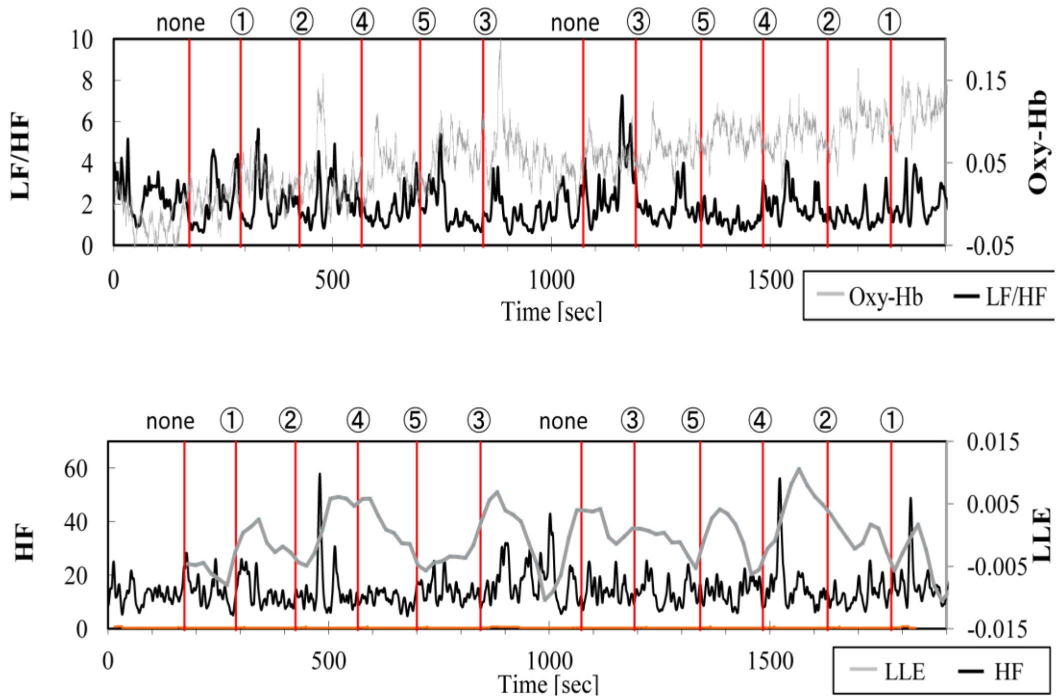
Finally, without the alarms, the representative of the young drivers showed increases in LF/HF when approaching intersections 5, 9, 11 and 12. In the first half of the driving, the arousal levels increased at High-f. beep, Display and Voice, whereas in the latter part of the driving, the arousal levels increased after presenting High-f. beep and Display. Meanwhile, increases in the cerebral blood flow, as represented by the oxy-Hb concentration, were observed at Info, High-f. beep and Display in the first half of the driving. Then, in the latter part of the driving, increases in the concentration of oxy-Hb were observed at Info, Low-f. beep, High-f. beep and Voice. LLE showed decreases at Display in the first half of the driving and at Low-f. beep and High-f. beep in the latter part of the driving.



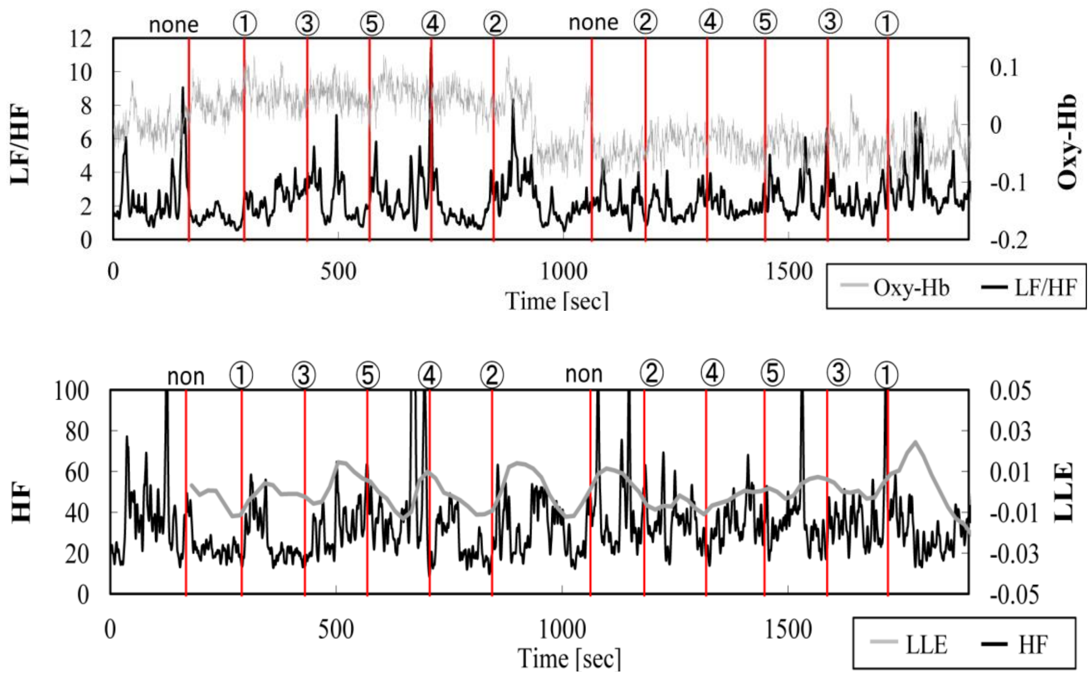
(a) In a case of O_A-㉒



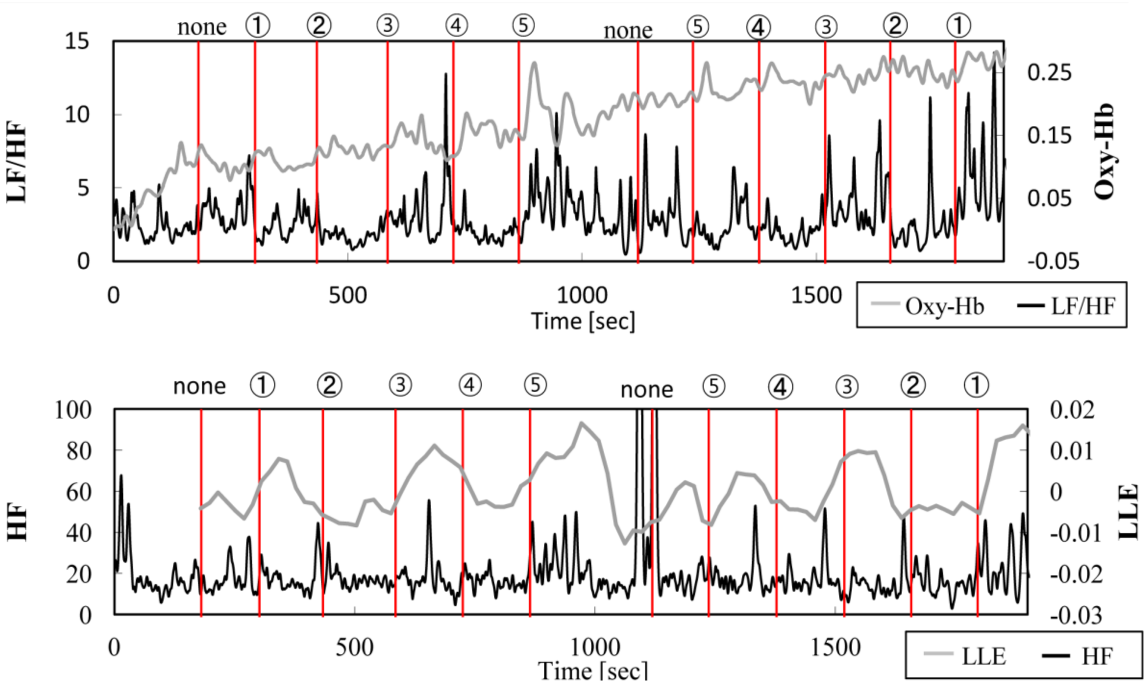
(b) In a case of O_A-㉟)



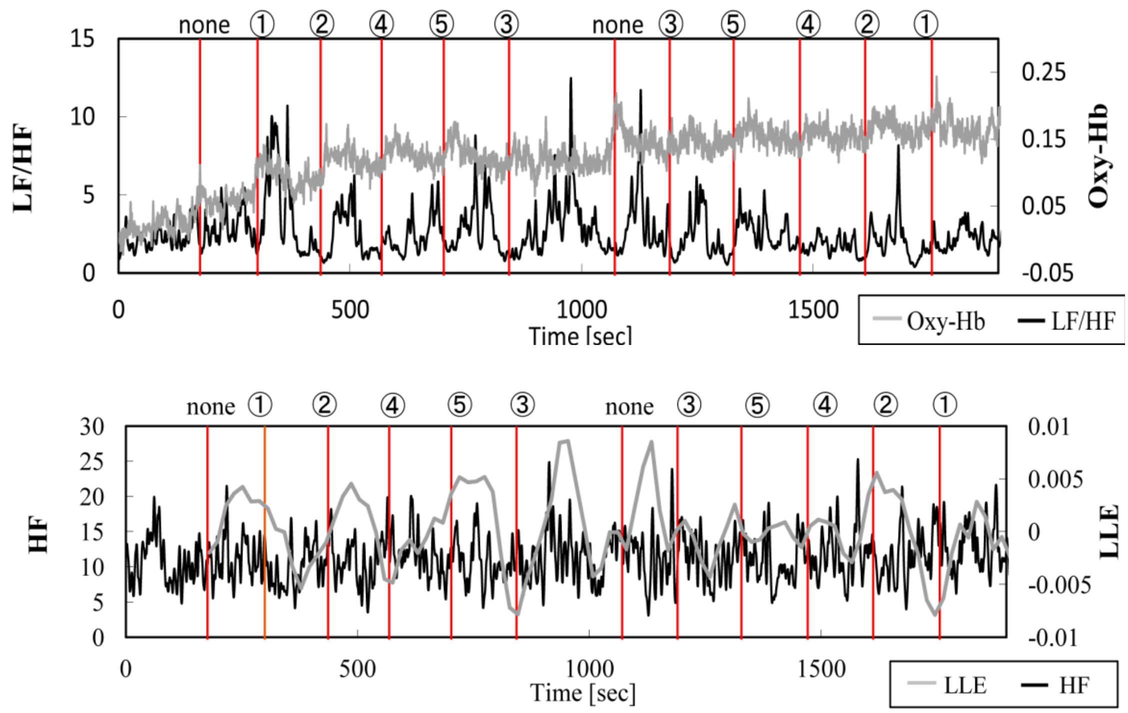
(c) In a case of O_B-㉜



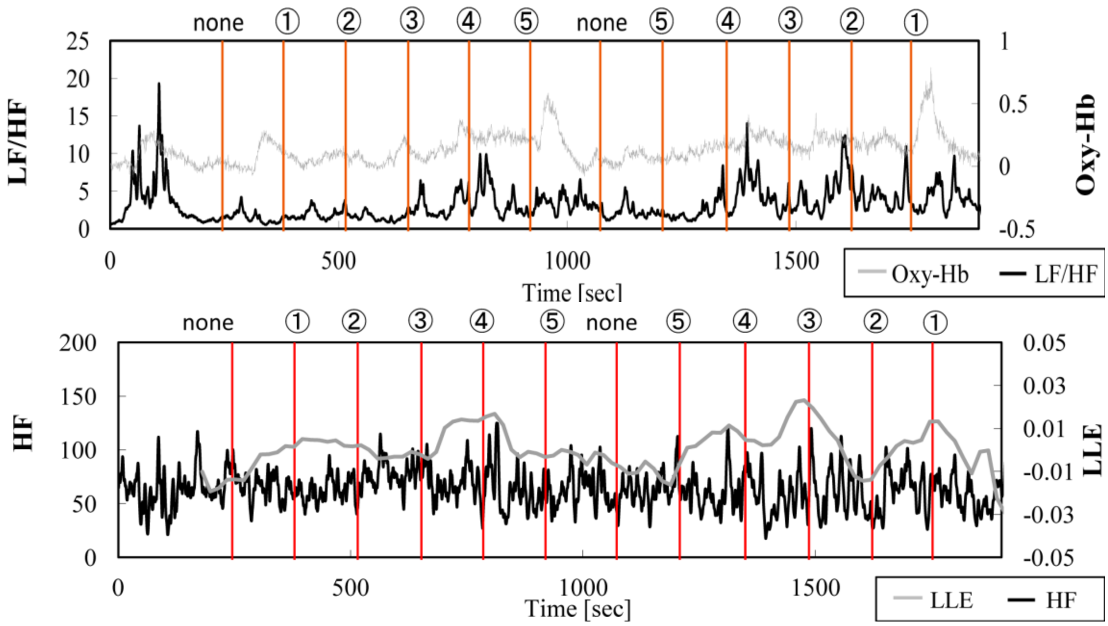
(d) In a case of O_B-⑩



(e) In a case of O_B-⑬



(f) In a case of O_D-㉛



(g) In the a of one representative from young drivers

Figure 3.2.4 Time histories of phiscal responses for every subject

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As shown in Table 3.2.2, a comparison of the responses after presenting the alarm shows that every participant was moderately influenced by Info alarm as the preliminary alarm, but the effects

Table 3.2.2 Summary of the responses at physiological

Subjects		Driving Course	Increase of LF/HF by intersections						Increases of LF/HF					Increases of Oxy-Hb					Decreases of LLE				
			1	2	3	4	5	6	①	②	③	④	⑤	①	②	③	④	⑤	①	②	③	④	⑤
			7	8	9	10	11	12															
O_A	㉒	First half																					
		Latter half																					
	㉟	First half																					
		Latter half																					
O_B	㉜	First half																					
		Latter half																					
	⑩	First half																					
		Latter half																					
	⑬	First half																					
		Latter half																					
O_D	㉛	First half																					
		Latter half			`																		
young driver		First half																					
		Latter half																					

of the secondary beep alarm were wide individual difference. Every group of participants was also significantly influenced by the Voice alert.

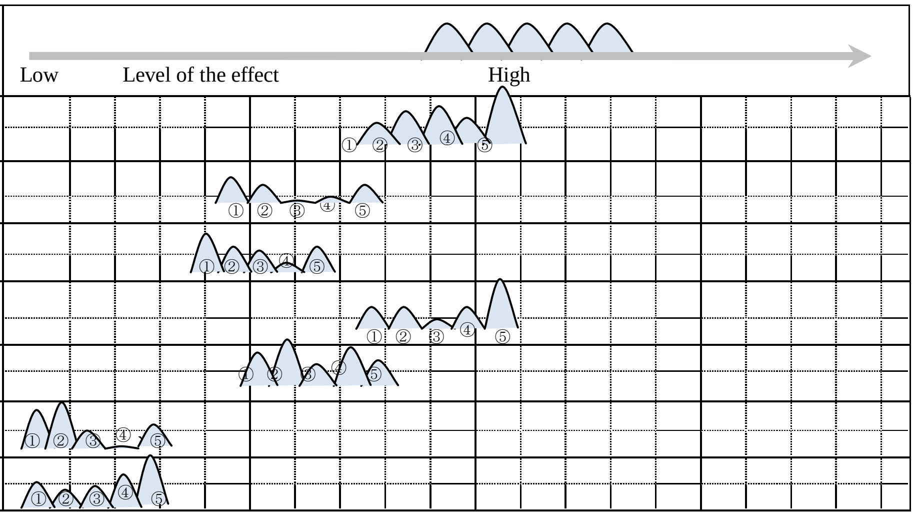
Next, Table 3.2.3 shows Level of tension by increases of LF/HF based on Table 3.2.2 during total experiment time. As shown in the table, O_B ⑩ and O_A㉒ of high level of tension were observed at the Voice alert. By the Info alert, although the tension was lower, but the effect was higher than the other alert conditions. However, in young driver' group, in spite of low tension' level, effect by Voice alert was high.

(2) Estimation of Alarm Effects

Sympathetic activation of LH / HF

As shown in the Figure 3.2.5, the difference in 40 seconds between the before and after the initial alarm was observed by results of ANOVA analysis. The changing difference in terms of LF/HF was shown compared with None condition. Significant difference with 1 percentage is

Table 3.2.3 Level of tension by increases of LF/HF based on Table 2

Subjects		Level of tension Increase LF/HF (point)	
O_A	㉒	16	
	㉟	12	
O_B	㉜	6	
	⑩	17	
	⑬	14	
O_D	㉛	4	
young driver		4	

shown by ‘**’, and that with 5percentages is shown by ‘*’. As a result, significant increase for Info and Voice conditions was shown in O_A group. The fairly increase in Info, the High-f. beep and Voice conditions was shown in O_B group. There was a significant increase in Info, the Low-f. beep and Voice conditions for O_D group. In addition, for the Young group, the activation of sympathetic nerves was very low and there was a significant increase in the High-f. beep and Voice conditions.

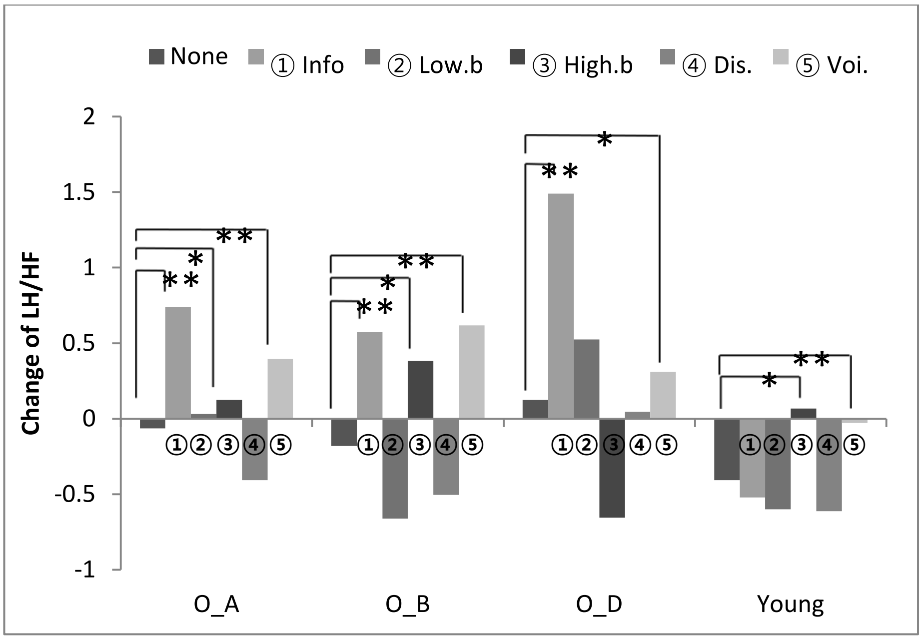


Figure 3.2.5 Difference in LF/HF compared with None condition (*p < 0.05, **p < 0.01))

Sympathetic activation of oxy-Hb

After the concentration of oxy-Hb was normalized by Z score (Z score means standard scores and it is quantified by “Z= (x-μ)/σ; μ is the mean and σ is the standard deviation)”, the amount of oxy-Hb was compared with that of the none condition as shown Figure 3.2.6. As a result, although very small increases were shown in O_A group, there was a significant increase in the High-f. beep and Voice conditions. O_B group has significantly increased for the all conditions, compared with the none condition. As well as the group O_B, in group O_D and Young, there was a significant increase in all conditions.

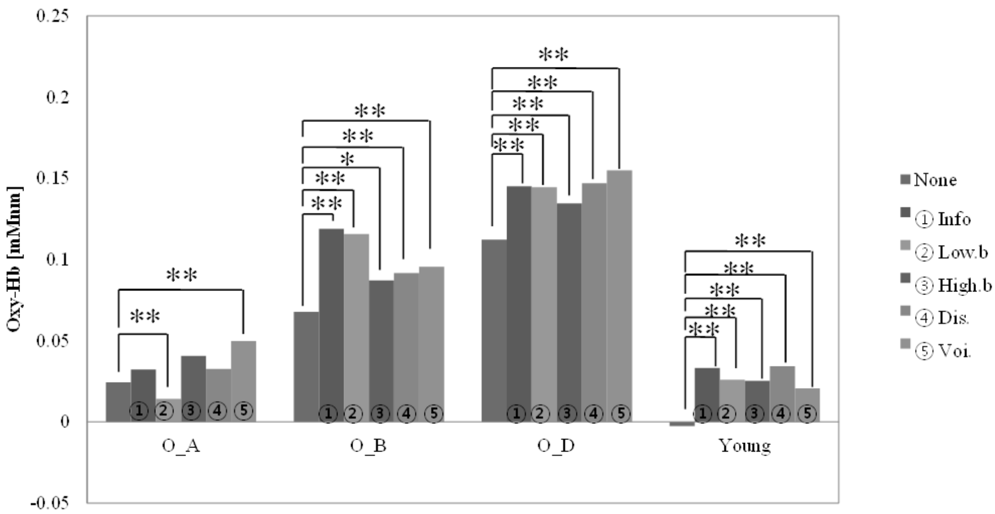


Figure 3.2.6 Difference in oxy-Hb compared with None condition (*p < 0.05, **p < 0.01)

Parasympathetic activation of LLE

Figure 3.2.7 shows LLE results obtained by the chaos analysis from a finger plethysmogram. The smaller fluctuation of blood vessel means the relaxation and ease to prepare the facing risky problem for driver. The figures were separated for significant differences in elderly drivers and young drivers. In addition, significant differences were not shown to increase in the value. The results show that, in O_A group, conditions of Low-f.beep and Voice was greatly reduced as compared with none conditions. In O_B group, significant decrease was observed in the conditions of High-f. beep and Voice. In O_D group, there was a significant decrease in the every condition of Info, Voice and High-f. beep. In the Young group, significant decrease was shown only in Voice condition.

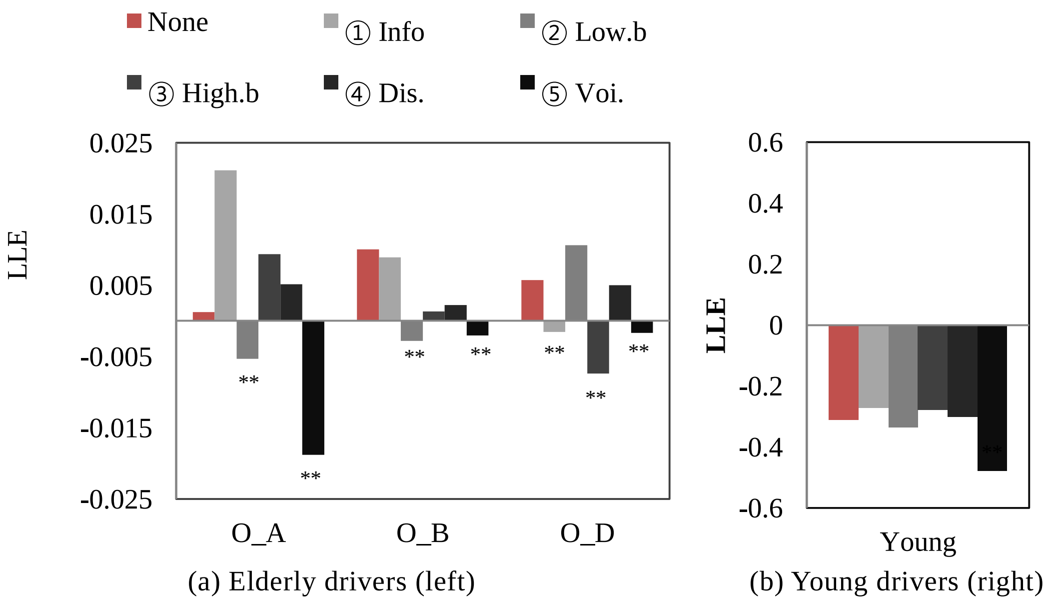


Figure 3.2.7 Difference in average LLE compared with None condition (*p < 0.05, **p < 0.01)

3.2.4 Discussion

In this study, the results showed the significant effects for elderly drivers from the obtained physiological reactions. As shown in the change in LF / HF, the sympathetic nerve was activated significantly in Info conditions of the whole elderly group. In Voice condition, significant effect on elderly group as well as the young was observed. Then, the change in oxy-Hb and related effects were observed more, compared with the LF / HF. The oxy-Hb in group O_A was increased in High-f.beep and Voice conditions compared with None condition. In O_B, O_D and Young group, significant increases of oxy-Hb were clarified for all kind of alarm. Next, from LLE results showing a decrease in parasympathetic activity, a significant decrease in Voice condition were observed in all groups, which was clearly observed as the effect of Voice conditions.

In consideration of the reaction tendency in each group of elderly drivers, it became clear that the effect of the alarm system was rather large in the poor ability group. Further, taking the individual cognitive and judging ability into account, there would be a suitable driving support to induce optimal driving behavior. For that reason, it was considered to be possible to design alarms or warnings in accordance with the suitability of the individual system instead of uniform single driving assistant and supporting alarm.

3.2.5 Summary

The driving assistant system was designed to adapt for elderly drivers as sequential support alarms while approaching the intersections. The significant changes in the physiological reactions were recognized as well as behavioral change after assisting alert for elderly drivers. From the opinions of participants at the experiment, such a driving support system was acceptable for elderly drivers and they understood the effect for their driving behavioral changes to safer operation by such a driving support at a city intersection, When considering the reaction trend for each group of elderly drivers, it became clear that the effect of the alarm system was rather large in the poor-ability group. Further, taking the individual cognitive and judgment abilities into account can design suitable driving support to induce an optimal driving operation. It can be suggested that the effect of driving support at intersections was beneficial for elderly drivers with more advanced aging. The warning sound system was effective to help for early braking, and it became clear that the support through voice warning was effective for the risky moment when the brakes must be applied.

For that reason, it was considered to be possible to design an alarm or warning for suitable stopping at intersections in accordance with the individual characteristics of the driver, instead of a uniform driving assistant and supporting alarm.

In this study, a driving support system to present a warning sound, a visual alarm on a display and voice alarm when approaching an intersection was constructed. By analyzing the physiological responses of the driver after the audient and supporting alarm, following results were obtained.

(1) The activation effects by the Info and Voice warnings can be confirmed based on the results showing the increase in the LF/HF value of the heart rate, which indicates the dominance of sympatric nerve system. On the other hand, increases in the oxy-Hb concentration and activated brain activity were observed when passing the intersections. These trends were clearly shown in the O_D group as significant features of the elderly drivers.

(2) When comparing the results of five kinds of audio–visual alarms informing the driver approaching intersections, the activation of physiological responses to the Info and Voice conditions was clearly observed. In addition, the individual differences in the responses to alarms were extremely large among the elderly drivers. Based on these individual differences among the elderly

drivers, it was clarified that the elderly O_A group shows reactions which was close to those of a young driver. In contrast, the effects of an alarm were very large and drastic for the O_D group, which had relatively poor driving abilities.

(3) From these considerations, the effect of driving assistant system at intersections was adaptive for elderly drivers with more advanced aging. The warning sound was effective to enhance early braking and the voice warning was also effective for inducing the braking operation.

CHAPTER 4

ADAPTIVE DRIVING ASSISTANT SYSTEM FOR ELDERLY DRIVERS CONSIDERING INDIVIDUAL CHARACTERISTICS

4.1 Introduction

According to the latest traffic accident reports[1,2],accidents are frequently occured at city road intersections by elderly drivers. For the prevention of non-stopping accidents caused by elderly drivers (i.e., accidents caused by a failure stopping at intersections by elderly drivers), an anti-stopping alert is required to guide the appropriate braking operation when approaching an intersection. In a previous section, an audio-visual alarm was constructed[3~7] that consists of a nudge and approaching alarm, a display, a warning sound and voice. As shown in Figure 4.1.1, if the driving behavior is assumed to be a series of recognition, judgment and operation within the driving environment, we can assumed that the driving operation is performed according to an internal model based on the experience and custom of every individual. in this flow, the driving assistance system equipped with a primary alert provides environmental information and provides a secondary alert when approaching an intersection.

In this chapter, changes of the driving behavior are investigated when the supporting system provides audiovisual stimulus; such changes were investigated using the driving simulator in a city road. Moreover, it was noted that the individual differences in the capability of cognitive judgment and driving ability were remarkable; therefore, a questionnaire survey of driving attitudes and interest was conducted in addition to the visual and judgment function test for each elderly individual in advance of the experiment.

The results of our study revealed that changes in the driving behavior caused by the assistance system were different among elderly drivers and that the changes were related to cognition and judgment capabilities, experience and attitude. Therefore, it can be concluded that warning alarms should be adapted to every individual.

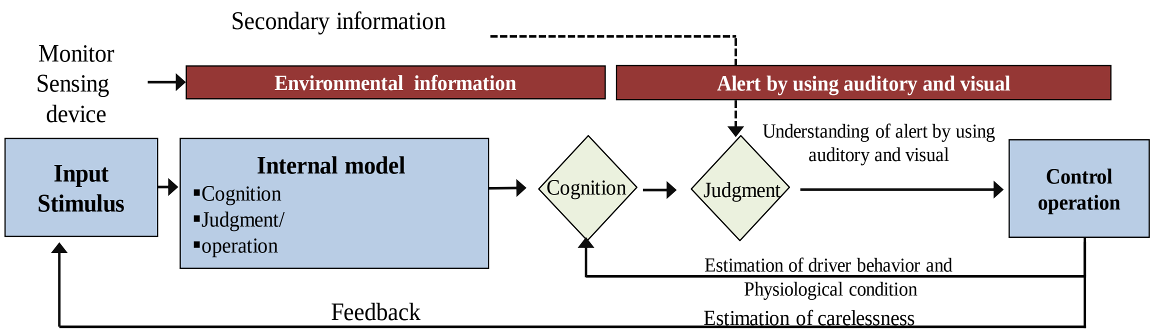


Figure 4.1.1 Driver behavior model with preliminary information and secondary alert system

4.2 Experimental Methods

4.2.1 Experiment participants

In this study, in order to evaluate a subject's driving style and to judge conformity as a subject of the driving task, we analyzed the driving of 45 elderly people. The subjects were initially examined with a usual field of view test (UFOV). To clarify the cognition ability and the ability to make judgments, a mini mental state examination (MMSE) was performed. In addition we used driver's driving style questionnaires (DSQ)[2] and a test using a listening survey related to personal information. From these tests, we can classify the elderly participants' ability to recognize target objects and to make judgments.

From 45 participants, eight elderly drivers were selected for further observation of their driving behavior, and this behavior was then compared to that of ten young college students. Informed consent was obtained from each subject before the study.

4.2.2 Outline of driving assistant system

A driving assistance system is a system that detects an external intersection environment and induces appropriate driving behavior in the flow of a human's cognition, judgment and control (operation). Here, the level of driving assistance is classified into four steps, in consideration of a series of driving behavior processes: cognition, judgment, braking operation and stopping at an intersections. Step 1 assists the recognition of an intersection, Step 2 induces braking, Step 3 insists on speeding up the braking operation and results in a stop and Step 4 guides the right-and-left check after a stop at each an intersection. In this study, we established five methods of presenting information using a combination of alarms and audiovisual methods. Estimated TTC (TTC_est; Kurahashi et al., 2006) is the presenting timing which was used for alarm presentation as shown in equation (1). In the equation, we set the velocity of the leading vehicle to 0 km/h, and the distance between the two cars (a lead vehicle and a subject vehicle) to 0 m. As the result, we obtained equation (2):

$$TTC_{est} = \frac{1}{V_r}\left\{-\frac{(V_{bon}-V_{boff})^2}{2a_s} + \frac{(V_1-V_{boff})^2}{2a_l} + D_{boff}\right\} \quad (1)$$

(Vbon: velocity when brakes on, Vboff: velocity when brakes off, Dbon: distance at braking on, Dbon: distance at braking off, a_s: acceleration of subject vehicle, a_l: acceleration of lead vehicle)

$$TTC_{est} = -\frac{V_{bon}}{2a_s} \quad \left[a_s = \frac{C_0 \cdot X_a}{C_1 + X_a} \cdot (1 + C_2 \cdot Y_{a)}\right] \quad (2)$$

(C0 = -0.670, C1 = -0.914, C2 = -0.076, Xa = Ya = Vbon)

In addition, the Time-to-Collision cross line (TTCr) was calculated based on the velocity and the distance to the stop line at each intersection, and shows the expected arrival time to the stop line. Five different alarms are presented: information presentation (Info.), low-frequency beep presentation (Low-f.beep), high-frequency beep presentation (High-f.beep), display presentation (Display) and voice presentation (Voice) as shown Table 4.2.1.

① Information presentation (Info.): after presenting “(sound) + (display)” in order to support the perception (discovery) of the intersection, a woman’s voice informs the driver of an intersection.

② Low-frequency beep sound presentation (Low-f. beep): after Info. presentation, a beep sound at a low frequency of 1.0 kHz sounds at intervals of 0.38 s (low stable pulse beep sound) is presented in order to induce the braking operation.

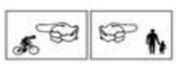
③ High-frequency beep sound presentation (High-f. beep): after presenting the Info., the beep sound at a high frequency of 3.7 kHz are presented at intervals of 0.38 s (highly urgent pulse beep sound),for the same reason as above with the Low-f.beep .

④ Display presentation (Display): after presenting the Info., visual images of the braking operation are displayed on a 7” LCD display installed in the center of the dashboard.

⑤ Voice: after presenting the Info., a female voice tells the driver to "brake smoothly" to induce the braking operation and to "stop completely" to promote compulsory stopping.

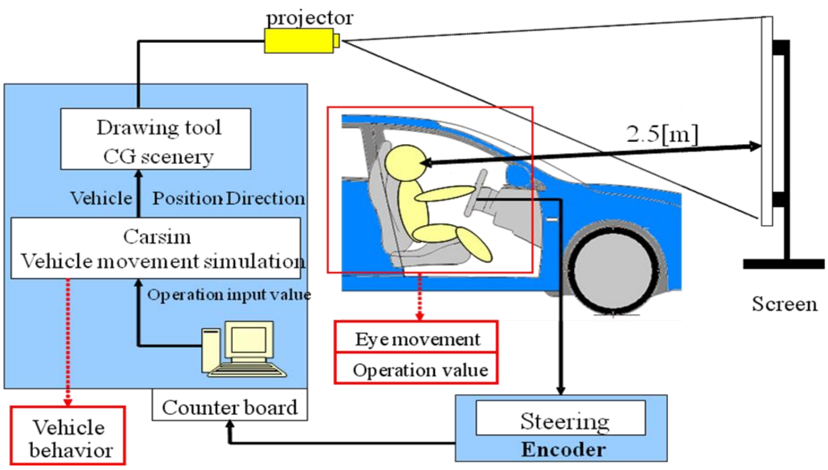
Table 4.1.1 Alert conditions and sequence

<table>
<tr><th rowspan="2">Condition
Name
Timing</th><th>Step 1</th><th>Step 2</th><th>Step 3</th><th>Step 4</th></tr>
<tr><th>TTCr ≤ TTC_est + 3</th><th>TTC r ≤ TTC_est</th><th>TTCr ≤ 2 s or
Ahead of 5 m of stop line</th><th>After stopping at intersection</th></tr>
<tr><td>① Info</td><td rowspan="5">pong
(sound)
&
There is a stop intersection.
(voice)
&

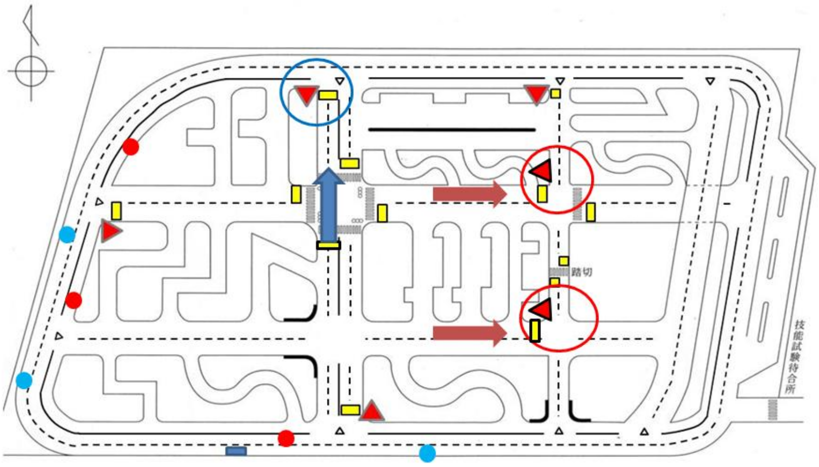
(Display)</td><td>-</td><td>-</td><td></td></tr>
<tr><td>② Low-f. beep</td><td>beep beep
(1.0 kHz, 0.38 s continuous sound)</td><td>-</td><td></td></tr>
<tr><td>③ High-f. beep</td><td>beep beep
(3.7k Hz, 0.2 s continuous sound)</td><td>-</td><td></td></tr>
<tr><td>④ Display</td><td></td><td></td><td></td></tr>
<tr><td>⑤ Voice</td><td>“brake smoothly”</td><td>“stop completely”</td><td>“left, right”</td></tr>
</table>

4.2.3 Experimental device and scenario

In order to verify the validity of the driving assistance system clearly we designed, a sequential alarm system that fitted the features of elderly driving behavior. In addition, individual differences in cognitive abilities and driving style were considered, as well as the influence of the alarm system on braking behavior. The effect of the alarm was then investigated in relation to how it altered the driving behavior and braking behavior. A driving simulator (DS-2000, Mitsubishi Precision Co. Ltd.) was used as shown in Figure 4.2.1 (a). A 7′ LCD monitor was installed at the center of a dashboard for presenting information, and speakers for the warning beep sounds and the voice information were placed behind the driver's seat. The scene of the driving course was projected on a screen, and as shown in Figure 4.3 (b) is a straight road with intersections. After practicing driving for five minutes, the real driving task was initiated using different alarms, and questionnaires were presented subsequently.



(a) Configuration of diving simulator



(b) Course of the driving scenario

Figure 4.2.1 Driving simulator and the test course

4.3 Results and Discussions

4.3.1 Behavioral changes in operation after assistance in term of recognition and judgment ability

(1) Classification of elderly individuals in term of differences in cognition and judgment abilities

The K-Means Cluster Analysis was carried out the drivers were and it was classified into four groups according to the results of the MMSE questionnaire and the UFOV experiment of the preliminary survey of 45 elderly drivers. The results were based on the correct answer rates of UFOV (central dual task) and the percentages of MMSE (score). The performance distribution of 45 elderly drivers is shown in Figure. 4.3.1. The borders were defined by K-mean cluster analysis. The higher percentile is the high score, and the circle numbers were given in the order that the subjects took the pre-test. UFOV is the visual area which can be detected at a brief glance without eye or head movements. MMSE test is a brief 30-point questionnaire test that is used to screen for cognitive impairment. It is commonly used in medicine to screen for dementia. As a result, each group was classified more clearly by MMSE rather than UFOV. The elderly drivers are represented by the numbers ① to ㊸ . The participants for the driving experiment were selected after an interview and for the convenience of the participant's intention to drive in the simulator; the selected participants are shown with a red number in the figure 4.3.1. The driving data of eight elderly drivers, participants ⑩, ⑬, ㉒, ㉓, ㉜ and ㉟ from group O_A, and participants ㉘ and ㉛ from group O_C, were obtained for the further analysis.

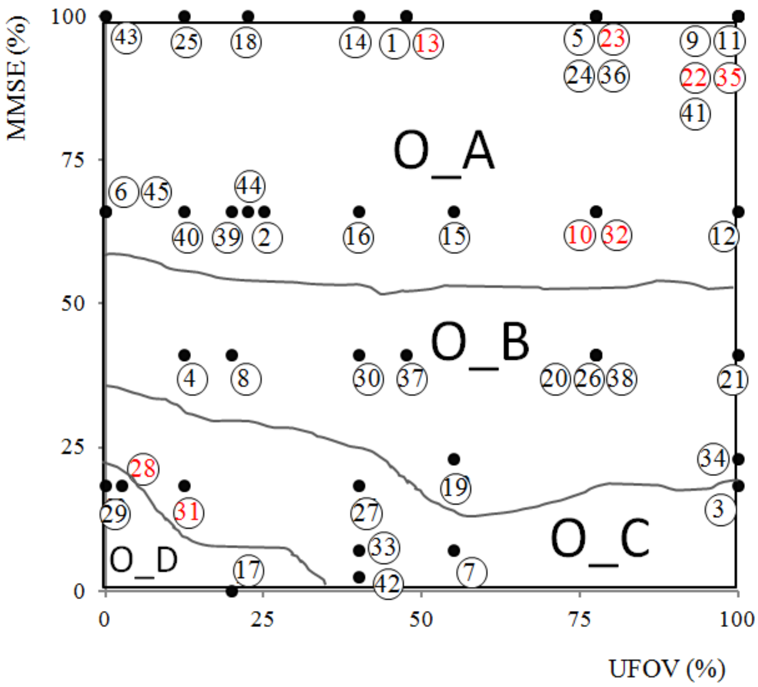


Figure 4.3.1 Classification into for groups regarding the driving behavior of 45 elderly drivers by plotting the percentiles of both UFOV and MMSE results

(2) Difference of deceleration behavior caused by difference of cognition and judgment abilities

Figure 4.3.2 shows average (two times x six conditions) of velocity Vo at the initial deceleration time for every participant and a Time-to-Collision (TTCo). Six participants from the O_A group are shown on the left of the figure, and two participants from the O_C groups are shown on the right. As shown in Figure 4.3.2, Vo varies among individuals. But the group difference is not clear. However, it is clear that the TTCo of group O_C is shorter than that of group O_A.

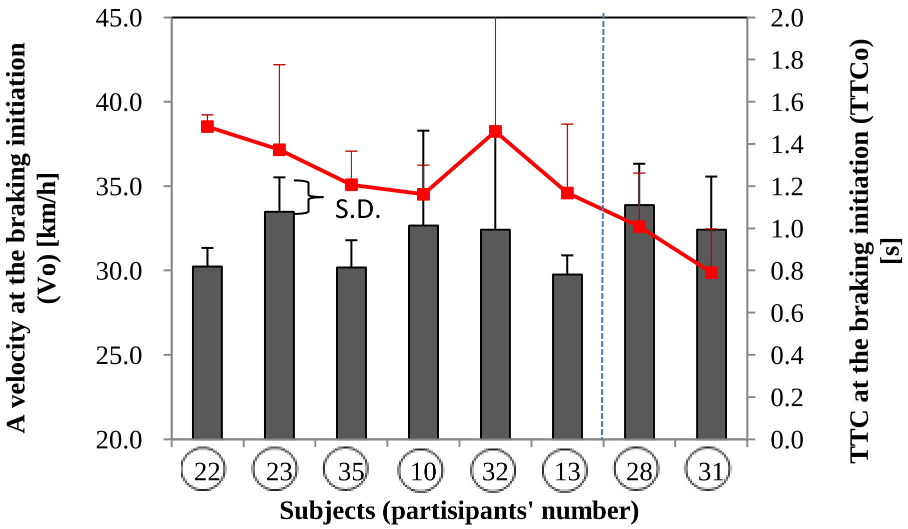
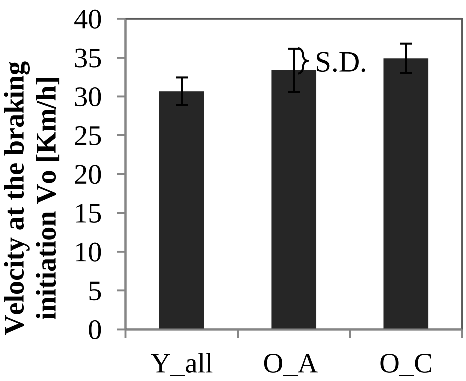
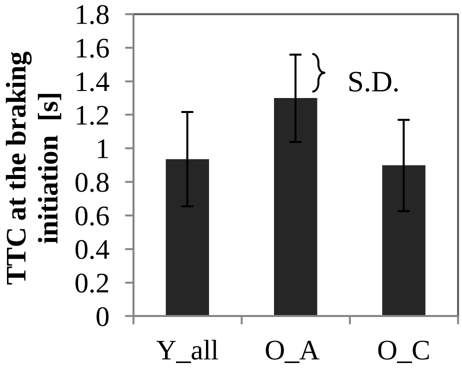


Figure 4.3.2 Individual Vo and TTCo

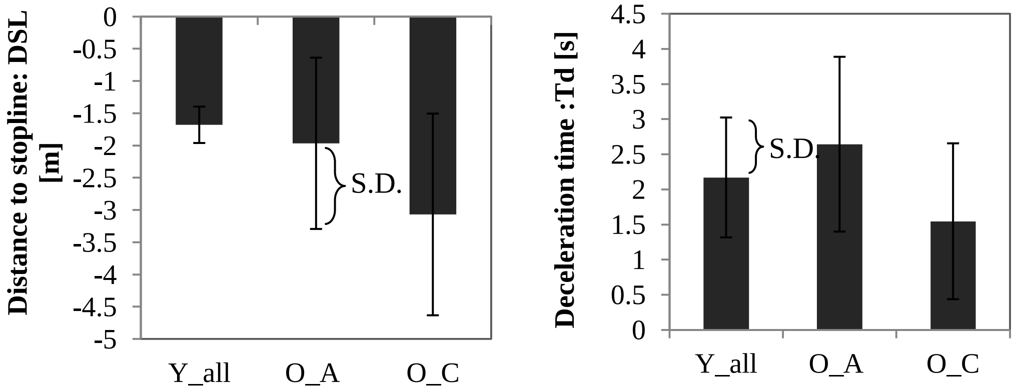
Next, we compare the decelerating and stopping behaviors near the intersection as shown in Figures 4.3.3(a) to (f) for young drivers (Y-all) and elderly drivers (O-A and O_C). Figures 4.3.3 (a) and (b) show **v**elocity at braking initiation (Vo) and TTC at braking initiation (TTCo**)** at the initiation of deceleration. These figures show that Vo is higher for the O_C group than for the Y_all group. Next, the TTCo of the O_A group is higher than the O_C group and the Y_all group. With regard to the distance to stop line (DSL) shown in Figure 4.3.3 (c), distance to stopline (DSL) of the O_C group is longer than that of the O_A group and the Y_all group. With regard to the results of the deceleration time (Td) shown in Figure 4.3.3 (d), the Td of the O_A group is significantly longer than that of the O_C group. In addition, Figure 4.3.3 (e) shows that the maximum braking acceleration (Max_BS) of the O_C group is significantly higher than that of the Y_all and O_A groups. Then, when comparing the TTC at the maximum braking stroke (TTC_mbs) as shown in Figure 4.3.3 (f), the O_C group's TTC at maximum braking stroke (TTC_mbs) is longer than the O_A and Y_all groups. From these results, when comparing the deceleration behavior of young drivers with that of elderly drivers, the typical difference between elderly drivers and young drivers is obvious; furthermore, the results reveal that the deceleration initiation rate of the O_C group is lower, which represents the abrupt deceleration operations of elderly drivers cognition and judgment abilities are declined.



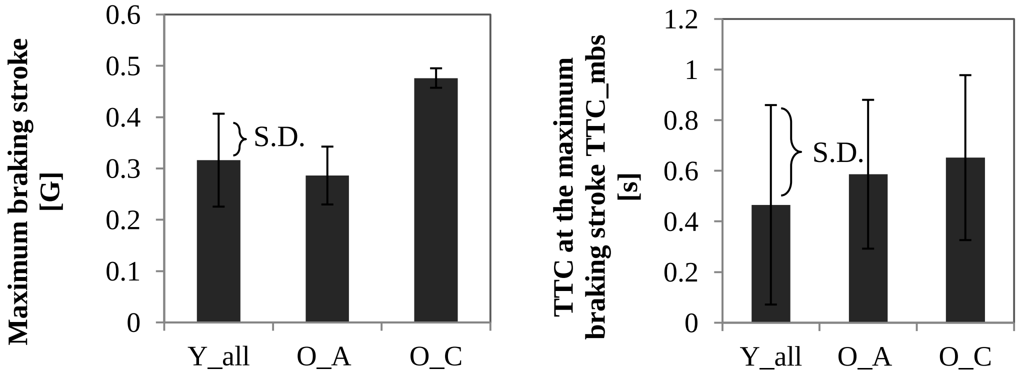
(a) Velocity at the braking initiation (Vo)



(b) TTC at the braking initiation (TTCo)



(c) Distance to a stopline (DSL) (d) Deceleration time (Td)



(e) Maximum braking stroke (Max_BS)
(f) TTC at the maximum braking stroke TTC_mbs

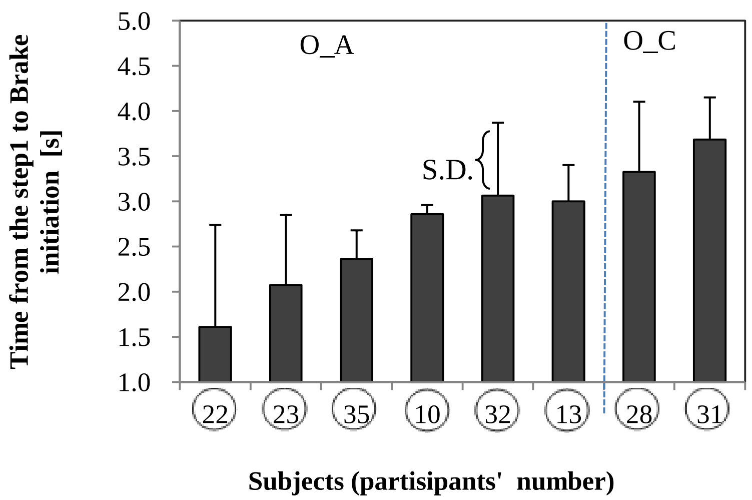
Figure 4.3.3 The individual Vo and the TTCo

(3) Behavioral changes corresponding to driving support

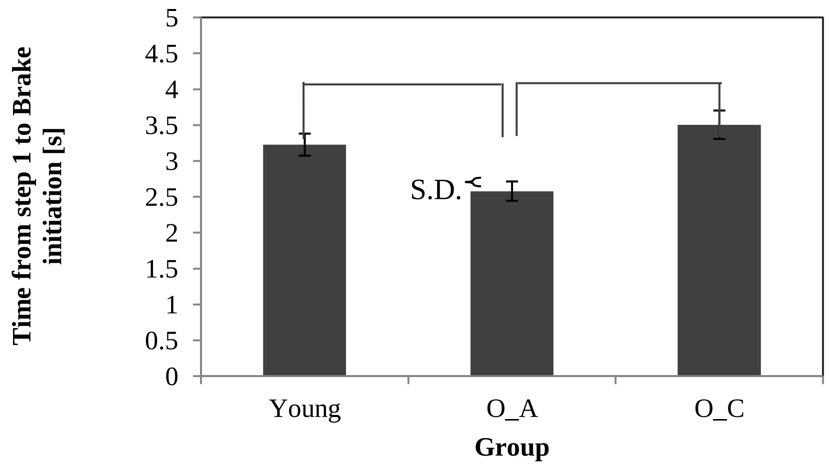
Table. 4.3.1 Databases of their performance indexes

ID no.	Age (Gender)	Velocity at braking initiation (Vo) [Km/h]					Deceleration time (Td) [s]					Distance to stopline (DSL) [m]					Stopping time (s)				
		Info.	Low-f. beep	High-f. beep	Disp.	Voice	Info.	Low-f. beep	High-f. beep	Disp.	Voice	Info.	Low-f. beep	High-f. beep	Disp.	Voice	Info.	Low-f. beep	High-f. beep	Disp.	Voice
10	69 (M)	33.4	36.3	33.8	33.6	34.4	7.0	9.4	10.1	9.9	9.9	-1.9	-2.8	-2.2	-3.5	-3.5	1.6	2.4	3.2	-	-
13	72 (M)	30.5	35.4	33.3	31.1	31.0	6.0	8.4	8.2	7.2	4.7	-0.6	0.3	0.1	2.2	-1.2	0.8	0.0	1.4	2.6	1.8
22	68 (M)	31.4	32.2	33.2	32.3	33.6	8.5	8.3	8.0	9.2	8.1	-2.4	-1.8	-1.6	-1.3	-4.0	1.4	2.7	2.5	2.5	3.6
23	69 (M)	31.9	32.5	37.4	32.2	39.3	7.6	9.4	11.6	9.0	11.3	-2.1	-2.5	-2.4	-2.4	-2.3	3.8	3.5	3.5	3.7	3.5
28	72 (M)	37.7	33.5	37.6	34.4	34.5	4.9	7.4	4.3	9.5	4.8	-3.0	-2.3	-2.6	-2.0	-2.2	1.9	4.8	3.5	2.3	4.4
31	70 (F)	34.8	33.5	32.8	33.2	37.2	15.2	10.1	3.4	3.8	3.4	-2.3	-2.6	-3.9	-3.3	-7.1	1.0	3.8	1.2	2.7	0.6
32	69 (M)	26.8	40.7	35.5	31.2	35.6	14.0	14.2	8.8	8.3	9.2	-3.6	-3.9	-3.8	-1.5	-1.3	5.1	0.7	1.6	3.1	2.5
35	65 (M)	34.8	33.5	32.8	33.2	37.2	9.0	6.8	6.7	7.5	6.9	-1.8	-2.8	-2.3	-2.5	-2.0	0.7	0.0	1.8	2.1	1.8

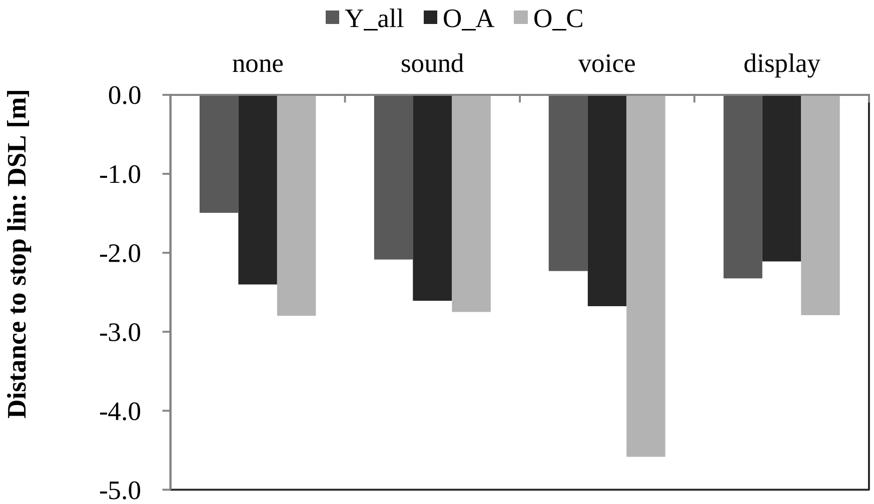
In order to observe changes of the driving behavior in terms of a driver's individual difference, the databases of their performance indexes are shown in Table 4.3.1. Figure 4.3.4 (a) to (d) show changes in the deceleration and stopping actions after the step-by-step instructions of the support system. In Figure 4.3.4 (a) and (b), the deceleration initiation time after the first alarm (Info) is compared between the participants as they approach intersections. Figure 4.3.4 (a) shows individual differences, and Figure 4.3.4 (b) shows differences between the groups. Figure 4.3.4 (c) is the comparison of changes in the DSL caused by step 2 and 3 at Table 4.3.1. For instance, "None" was assigned result for Info condition only, and "Sound" was assigned for "Low and High-f. beep". Next, Figure 4.3.4 (d) shows changes in the stopping time to the stop line caused by step 4 at Table 4.1.1. For instance, "None" was assigned result for "Info" condition only, and "Voice + Display" was assigned for both audio-visual alarm.



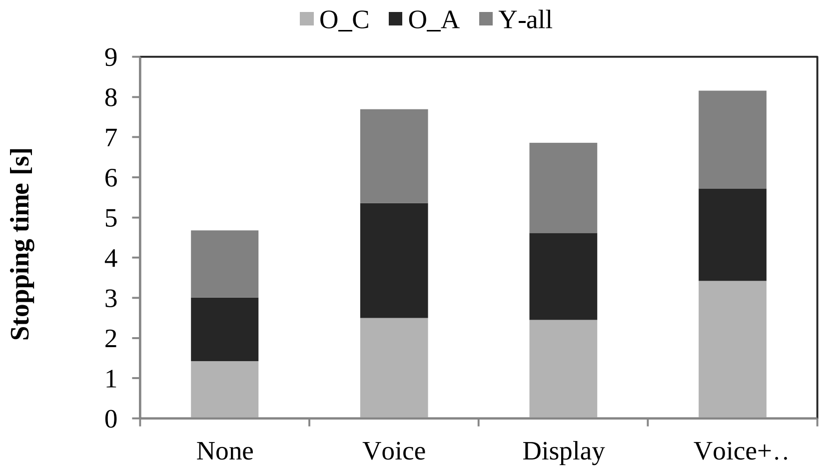
(a) Individual deceleration initiation time after step 1 (Info)



(b) Average deceleration initiation time after step 1 (Info)



(c) Change to DSL caused by step 2 and 3



(d) Changes in stopping time to stop line caused by step 4

Figure 4.3.4 Change of stopping behaviors according to each step

4.3.2 Behavioral change of operation after the assistance in term of driving style

(1) Classification of elderly drivers by driving style

To sort the driving propensity of each elderly driver, not only cognition and judgment abilities, but also the driving style was used. The following six items associated with the deceleration and stopping behavior items of the DSQ[5] questions related to driving style were selected: 1) negative (attitude toward) driving, 2) impatient driving, 3) meticulous driving, 4) preparation against (traffic) signals, 5) unstable driving and 6) worried (apprehensive) driving. Then, a classification of elderly drivers according to their driving style was performed through the K-Means Cluster Analysis, and expressed as O_a, O_b, O_c and O_d. Using the participant numbers that were classified through the distribution of cognition and judgment abilities shown in Figure 4.3.5.

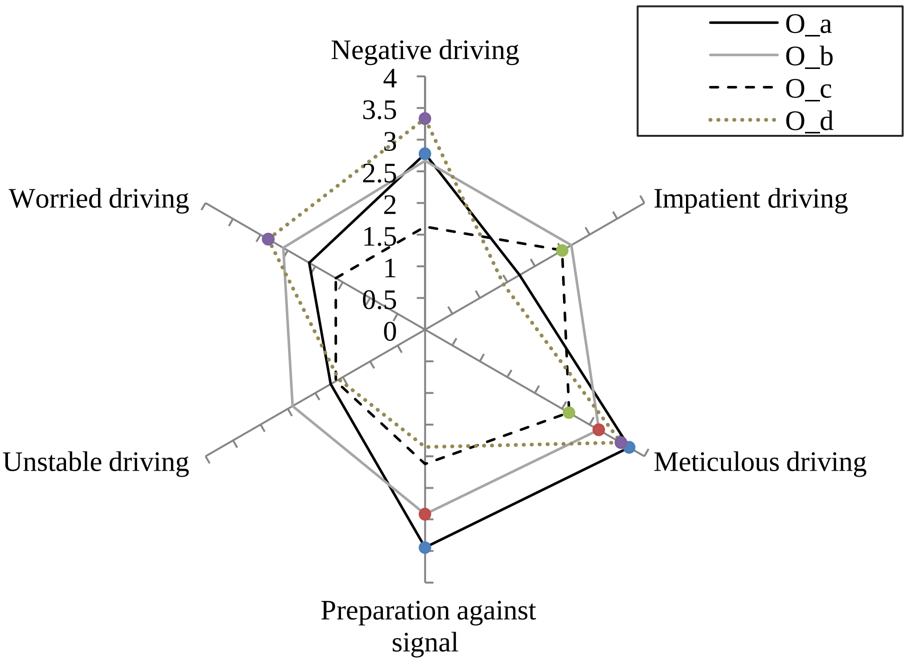


Figure 4.3.5 Driving styles of each group classified by DSQ results (the circle points show significant items in each group)

I can indicate that participant numbers ⑬, ㉓, ㉜ and ㉟ belong to the O_a group; participant numbers ㉒ and ㉘ belong to the O_b group; participant number ⑩ belongs to the O_c group; and finally, participant number ㉛ belongs to the O_d group.

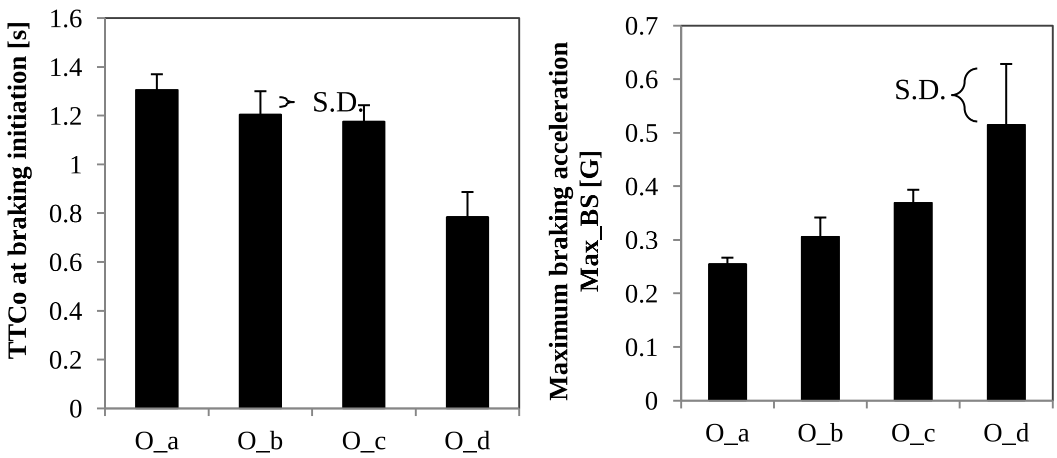
In order to investigate the driving styles evaluated significantly greater in a group based on the DSQ results, a multivariate analysis evaluation was conducted for each group. The results we obtained indicate that the three styles of negative, meticulous and preparation against signals in the O_a group scored higher than the other styles. In the O_b group, the two styles of meticulous and preparation against signals, similar to the O_a group, scored higher than the other styles. Next, in the O_c group, the styles of impatient and meticulous driving scored higher than the other styles. Finally, in the O_d group the styles of negative, meticulous and apprehensive driving scored higher than the other styles. The result listed in Table 4.3.2 indicates basic information of the experiment's participants, the groups classified according to the cognition and judgment abilities obtained by UFOV and MMSE and the groups classified according to the driving style. Further, Figure 4.8 shows average values of the driving style of each group.

Table 4.3.2 Participant results after preliminary tests

ID No.	Age (Gender)	UFOV % (Correct answer rate)				MMSE Percentrank function % (Score)	Group by Cognitive Ability	Group by Driving Style
		Central Task		Peripheral Task				
		Single	Dual	Single	Dual			
10	69 (M)	100.0	77.5	100.0	40.0	66.0 (29)	O_A	O_c
13	72 (M)	100.0	47.5	47.5	47.5	100.0 (30)	O_A	O_a
22	68 (M)	100.0	100.0	100.0	77.5	100.0 (30)	O_A	O_b
23	69 (M)	100.0	77.5	55.0	77.5	100.0 (30)	O_A	O_a
28	72 (M)	100.0	2.5	100.0	15.0	18.2 (26)	O_C	O_b
31	70 (F)	55.0	12.5	55.0	55.0	18.2 (26)	O_C	O_d
32	69 (M)	100.0	77.5	55.0	100.0	66.0 (29)	O_A	O_a
35	65 (M)	100.0	100.0	100.0	12.5	100 (30)	O_A	O_a

(2) Deceleration behaviors caused by differences of driving style

Driving style and propensity were divided into the four groups O_a, O_b, O_c and O_d. Deceleration behaviors caused by differences in driving style are shown in comparison with the Max_BS and TTCo results in Figures 4.3.6 (a) and (b). The figures confirm that the TTCo results from the O_a to O_d groups became low; in contrast, the Max_BS results to be high for the O_a to O_d groups. From these results, it can be stated that elderly drivers have a tendency for large deceleration and sharp braking in increasing order from the O_a to O_d groups (i.e., O_a, O_b, O_c and O_d, in this order); in other words, the emergent operation with high deceleration and sudden braking is depended on the driving style of "preparation against signal".



(a) TTC at braking initiation (TTCo) (b) Maximum braking (Max_BS)

Figure 4.3.6 Driving behaviors of O_a to O_d groups

(3) Behavioral changes corresponding to each driving support

In order to observe the changes in driving behavior in terms of the drivers' individual differences, a database of their performance indexes is shown in Table 4.3.1. The relation between time-to-Collision at braking initiation (TTCo) and the maximum braking acceleration (Max _BS) was investigated, as shown in the Figure 4.4.7. The reactions of elderly drivers and those of the young drivers are compared. From the rising and falling line in the figure, it can be seen that when there was a low TTCo at the time of initiating braking, a high brake behavior was operated to reduce the stopping distance. Although the braking initiation of elderly drivers was earlier compared with that of the young drivers, there was a higher level of maximum braking. An additional feature of the elderly drivers was that the timing of braking initiation was late, and deceleration was large in the O_C group with a low cognition and judgment ability compared to the O_A group that had a high ability.

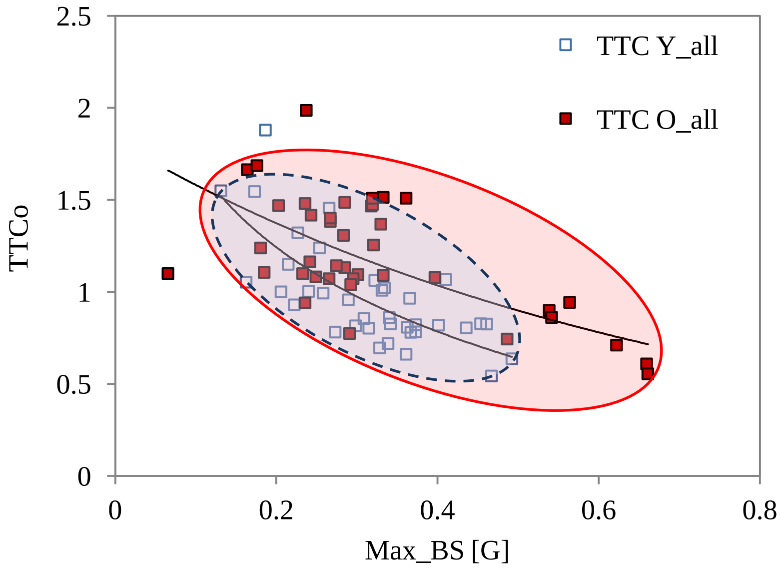


Figure 4.3.7 The difference of braking management between young drivers and elderly drivers

In Figure 4.3.8, the relation between Max_BS and TTCo in each group is shown, represented by a downward sloping curve, and the relationship between Max_BS and TTC_max in each group is represented by a straight line sloping upwards to the right. Symbols (e.g., O_Aa, O_Ab, etc.) in the diagram show the classification of the elderly drivers' cognitive abilities, judgment abilities, and driving styles. It is thus apparent that when TTCo is lower, Max_BS is higher. Moreover, in the O_A group, which has the highest cognition and judgment abilities of elderly drivers, regardless of the difference in driving propensity, there was no significant difference in the ability to perform the braking operation. In contrast, in the O_C Group the operation for braking is shown. It is considered that the driving support system for elderly drivers is most effective in the group where drivers had proficient cognition and judgment abilities, but had an unstable driving manner.

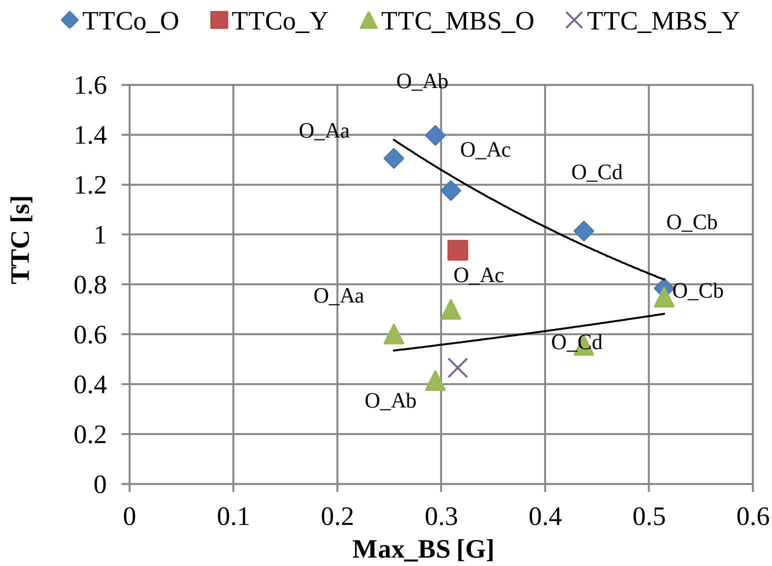


Figure 4.3.8 The braking management from the view point of classified group by cognitive judgment and driving style

Next, In Figure 4.3.9, the ratio of the O_A group to the Y_all group is plotted at around the level of 1.0. The plots indicate that the TTCo of the O_A group increases by approximately 1.5 times for the Low-f. beep conditions, as well as for the High-f. beep and Voice conditions. On the other hand, the TTCo of the O_C group increases approximately 2.7 times for the Low-f. beep conditions.

However, for the Voice conditions, the deceleration is large for this group, indicating that the Voice condition is effective.

From these results, we can conclude that the driving support at intersections is effective for elderly drivers whose driving performance has deteriorated with aging. In a warning sound system, the support of a low-pitched sound is effective for supporting of early braking. In addition, it is clear that driving support via a voice warning system is effective at the risky moment when brakes need to be applied.

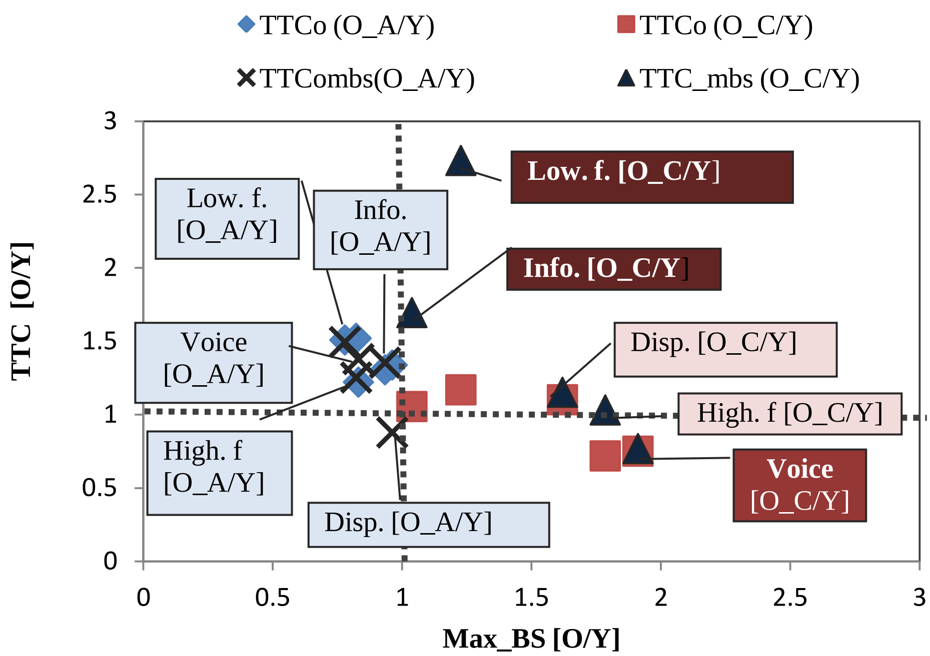


Figure 4.3.9 Driving styles of each group classified by DSQ results (the circle points show significant items in each group)

4.4 Summary

In this research, in order to understand clearly how driving behaviors change with the support of driving assistant systems, a sequential support alarm with the feature of elderly drivers' behavior was designed, and the influence of such a support was investigated in terms of behavioral change using the support. Here, driving behavior changes caused by driving support was examined for elderly drivers in a driving simulator that imitates city roads.

The following points became clear as a result of a series of experiments.

1) By observing changes of driving behavior after a nudge alarm at the time of approaching a city intersections, the decelerating action after the alarm revealed that warning with beeping sounds and voice instructions induce early braking, is effective as driving support to prevent accidents caused by not stopping.

2) When the effect of a driving support alarm, in addition to cognitive and judgment abilities, is compared between young drivers and elderly drivers, it was found that an elderly driver's ability is typically declined due to the age related health issues in comparison to a young driver. It became clear that driving support alarms is more effective for elderly drivers than for young drivers.

3) We think that the driving support to elderly drivers is effective for the group whose operation is declined in term of cognitive judgment capability and an operation disposition.

The above findings indicate recommendations for the designing of future driving support systems. That is, through a nudge alarm, it becomes possible to induce proper braking operation by use of beep sound or voice warning.

As a future work, more accurate identification method, which considers individual differences of different elderly drivers, is necessary for the process of classification and detailed stratification. In addition, the support with multi-modals method using olfactory or tactile stimulations, needs to be investigated.

CHAPTER 5

APPLICATION OF THE DRIVING ASSISTANCE SYSTEM FOR ELDERLY DRIVERS

5.1 Examination regarding the individual driving assistance system and the supporting timing to an elderly drivers

In Chapter 2 "Problems for advanced driving assistant system according to accidental analysis", we clarified that stopping behavior of elderly drivers at non-signal intersections is more dangerous comparing with the behavior of young drivers. Based on the results, we designed a driving assistance system to support stopping at intersections, and investigated the effect on physiological signals and driving behaviors. As the results, physiological signals in terms of concentration of oxy-Hb and LF/HF clarified that the information (alert) by Info, and Voice is effective, and information-presentation by Beep sound and Voice is more effective than the other alerts.

Based on the results, in the chapter 5, after we re-designed a driving assistance system with regard to the real driving environment as shown in Figure 5.1.1, the effect of the driving support on stopping behavior of elderly drivers in real driving was investigated. A real car with the experimental device was used, and the driving task was investigated at a driver's license course consisted of various intersections. Therefore, the result has sufficient validity and becomes a basis guideline for the development of this system.

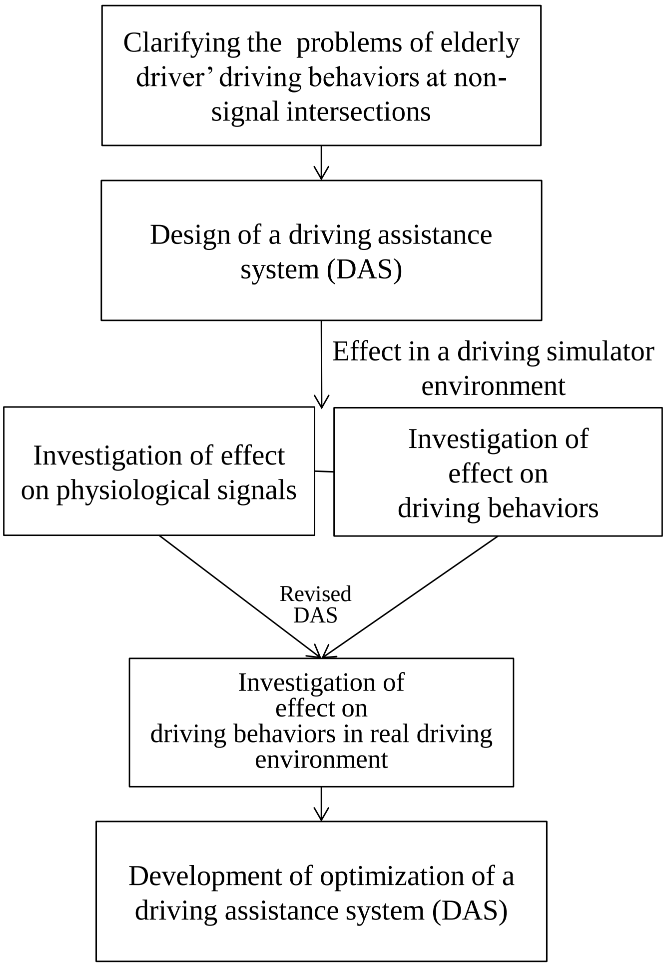


Figure 5.1.1 A relationship diagram on each study of chapter 5

5.2 Study of Safety Driving Assistant System using Audio-Visual Alert

5.2.1 Backgraound

It is important to improve the usability of automobiles and transportation systems for elderly drivers so they can drive more safely and easily **오류! 참조 원본을 찾을 수 없습니다.오류! 참조 원본을 찾을 수 없습니다.**. For this purpose, it is important to comprehend driving characteristics of elderly drivers and develop effective and acceptable driving assistance systems. According to traffic accident statistics, many accidents have occurred by elderly drivers. Especially, regarding to the face to the face collision, many elderly drivers were involved. Many accidents have occurred at intersections without traffic signals, and the influence of non-stopping or unsafe driving is important as a human factor. Then, for preventing non-stopping or unsafe driving at a stop intersection without a traffic signal, we designed a driving assistance system to induce safer driving performance. To verify the effect of system, we conducted a driving experiment with participants of elderly drivers at driver license center.

5.2.2 Experimental Methods

(1) Concept of assistance method

Considering the driving characteristics of elderly drivers, in the experiment, we investigated driving process, on braking and stopping behaviors and stop at intersections as shown in Fugure 5.2.1. The concept of the assistance method based on the investigation is shown in Figure 5.2.2. In other words, the assistance system affect on a whole stage from approaching to start again. A configuration of the system installed on a real car is shown in Figure 5.2.3.

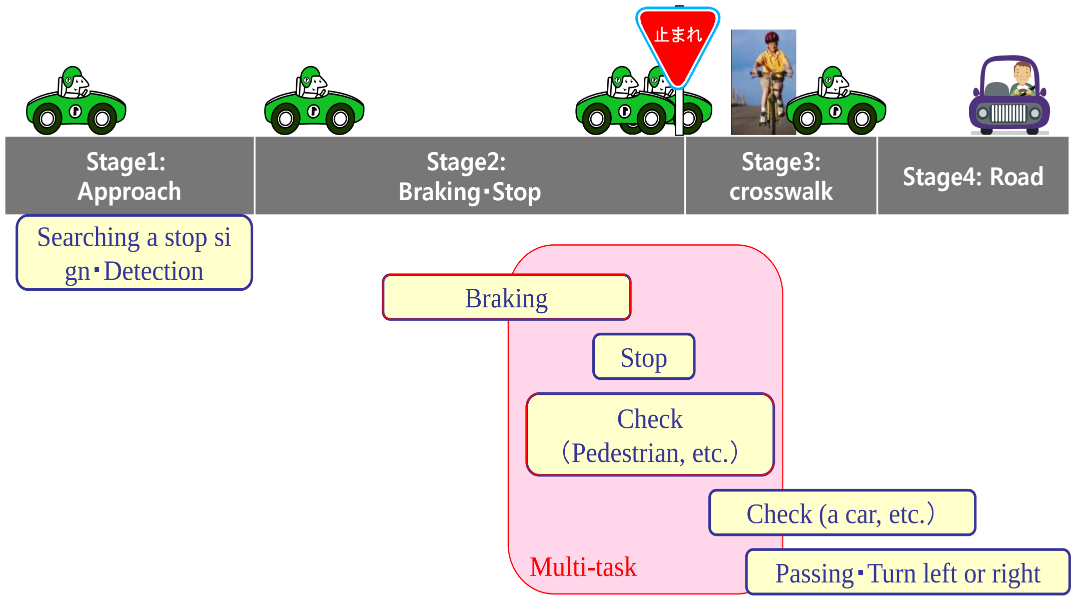


Figure 5.2.1 Stop task at an intersection

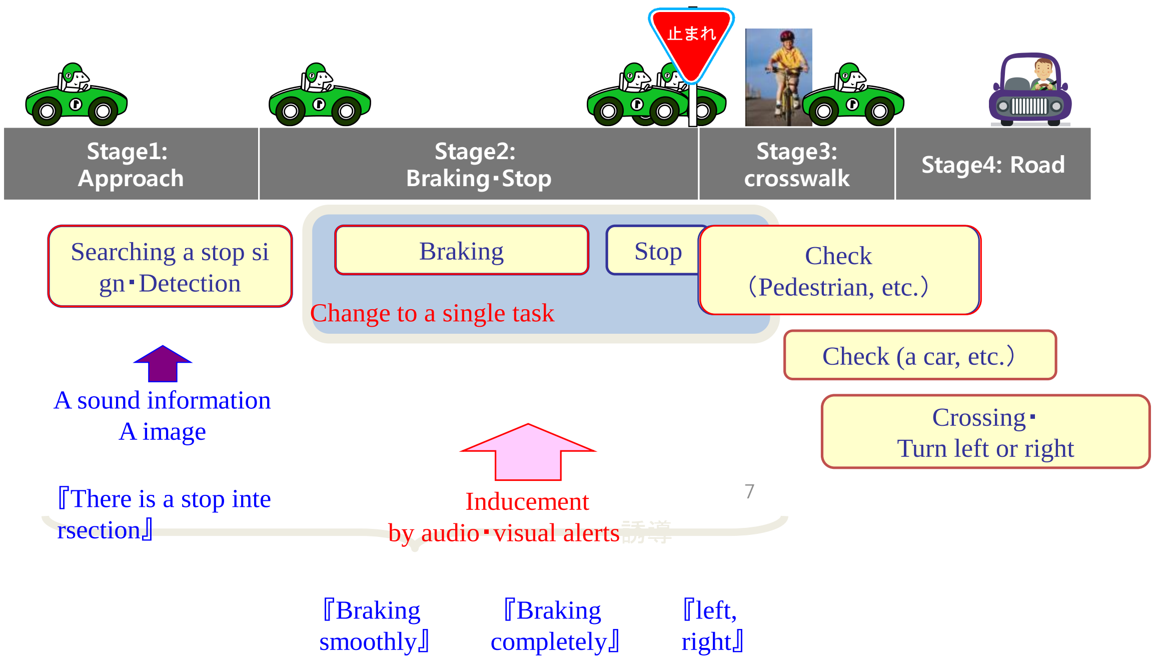


Figure 5.2.2 Concept of the assistance method

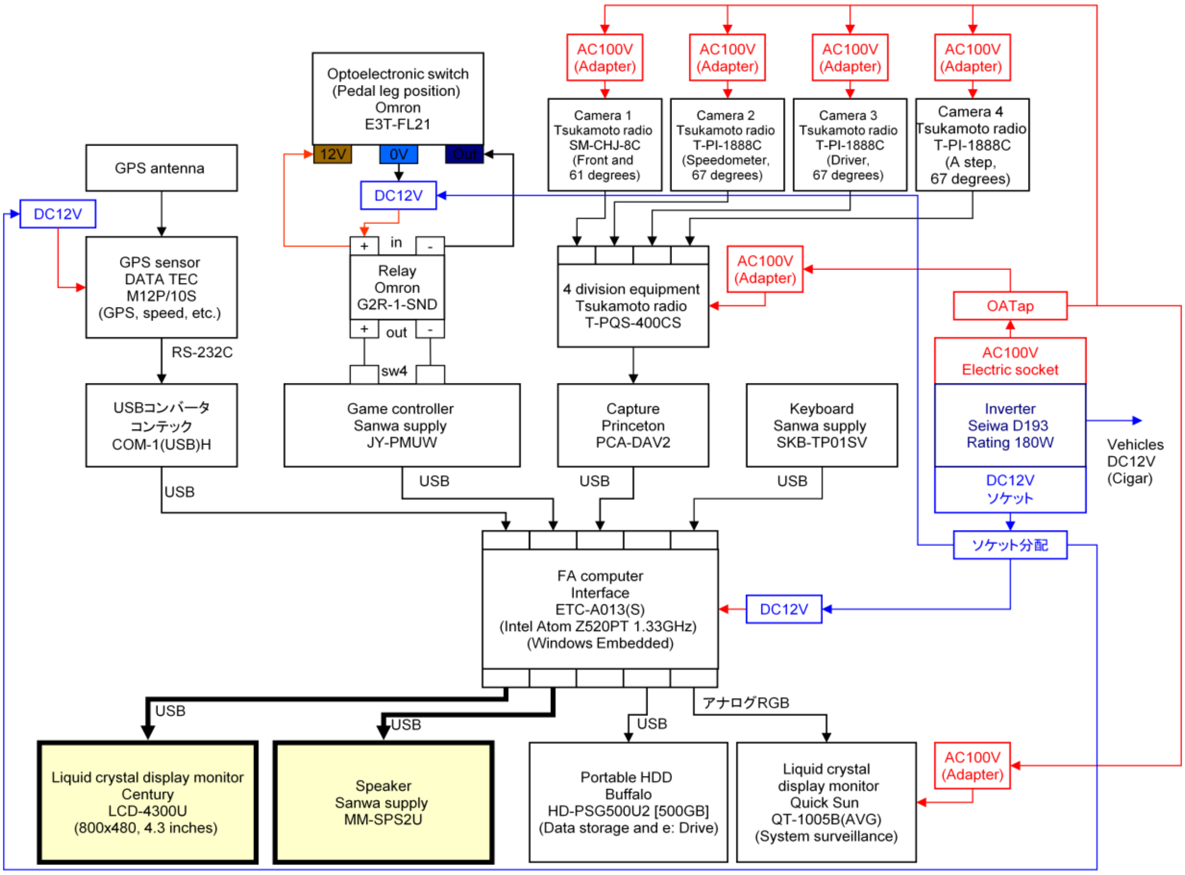


Figure 5.2.3 Configuration of assistece system

(2) Assistance system

The driving assistance system is a system which detects the external intersection environment and induces appropriate driving behavior in a flow of human's cognition, judgment, and control (operation). Therefore, the process of cognition, judgment and control with driving should be considered when designing appropriate driving assistance systems.

I classified the level of alarm system into four steps, considering a series of processes of driving behavior as the cognition, judgment, braking operation and stopping at intersection. There are Step 1 for helping the recognition of intersections, Step 2 for inducing the braking operation, Step 3 for inducing the braking operation and results in a stop, and Step 4 guides the right-and-left check after a stop at an intersection, respectively.

Moreover, Time-to-Collision cross line (TTCr) as an evaluation index was investigated based on velocity and the distance to stop lines ahead of intersections. This state variable means the expected arrival time to the stop line. Four alerts were consist of a information condition (info.), beep condition (beep), a display condition (Display) and a voice condition (Voice) as shown in figure 5.2.4.

① None: Non alert.

② Beep sound condition (Beep): after presenting a pong (sound) + (display) in order to support the perception (discovery) of the intersection, a woman’s voice informs the driver that there is an intersection ahead. And the beep sound is presented in order to induce the braking operation.

③ Display condition (Display): after presenting a pong (sound) + (display) in order to support the perception (discovery) of the intersection, a woman’s voice informs the driver that there is an intersection ahead. And visual images of the braking operation and the speed are displayed on a 7 inch LCD display installed at the center of dashboard.

④ Voice: after presenting a pong (sound) + (display) in order to support the perception (discovery) of the intersection, a woman’s voice informs the driver that there is an intersection ahead. And a female voice tells the driver to "brake smoothly" to induce the braking operation and "stop completely" to promote compulsory stopping.

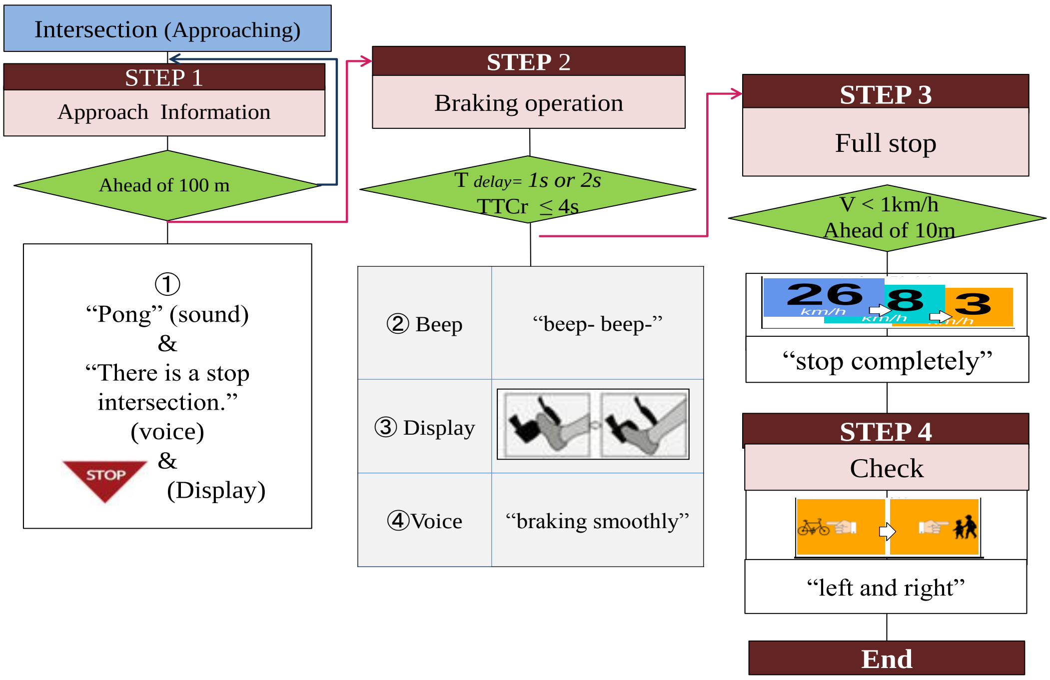


Figure 5.2.4 Control flow of driving assistant system

(3) Test course

The experiment was conducted at driver's license center in Kagawa prefecture, Japan. As shown in Figure 5.2.5, we selected three intersections with non traffic signal. Each width of the roads and driving views were different. In this driving course, there were no other moving cars and pedestrians that affect the driver's driving behavior.

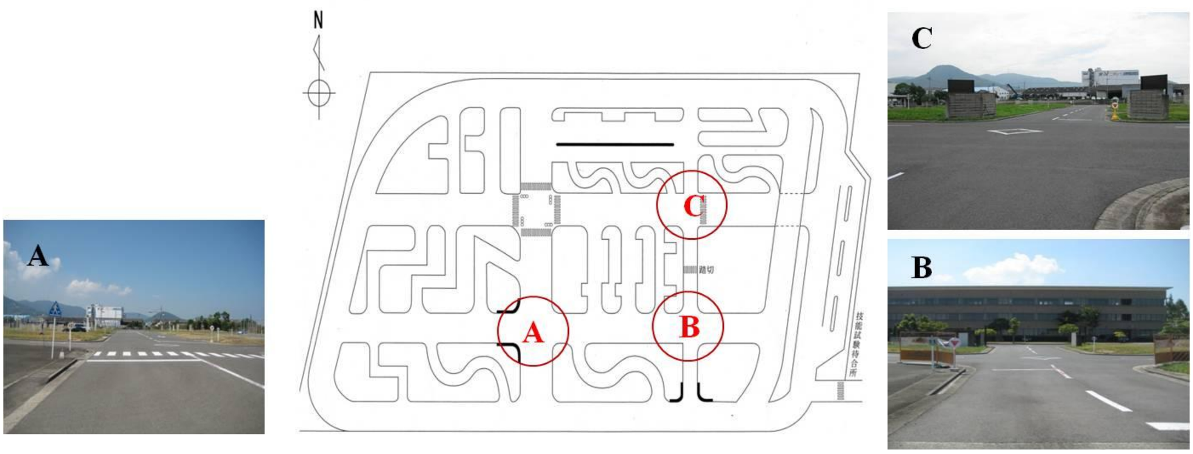
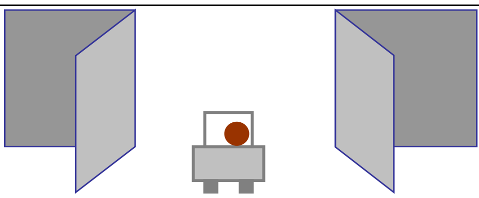
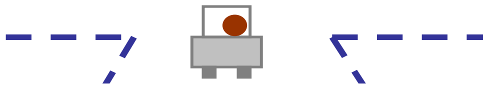
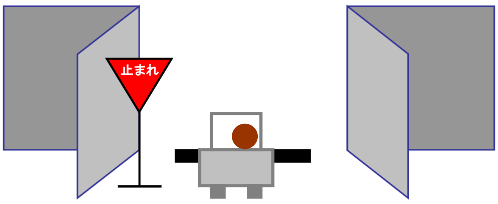
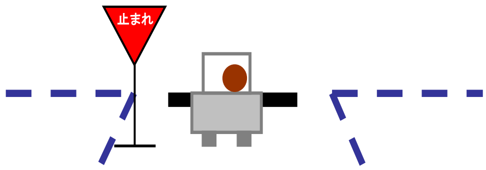
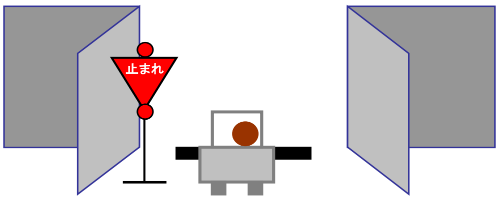
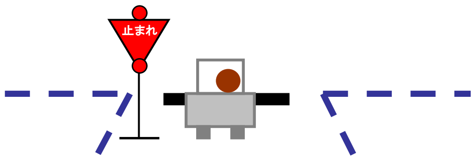


Figure 5.2.5 Driving course and intersection A, B, and C

Table 5.2.1 The features of stop signs and blind corners

The features of stop signs			The features Blind corner	
No sign	Typical stop sign	LED-enhanced stop sign	With blind corners	Without blind corners
X				X

Table 5.2.2 Conditions regarding signs and a blind corner

	Narrow view	Wide view
No sign		
Typical stop sign		
LED-enhanced stop sign		

When selecting participants, as priority, we chose both young and elderly drivers who did not show stopping intention which was described in the chapter 2.2. The young people (male; 7, female; 3, 22 -24 years old, mean age; 23 years old) and elderly people (male; 2, female; 3, 69-71 years old,

Table 5.2.3 Statistics and results of MMSE (each elderly subject)

No	Age (Gender)	Vision		Driving experience (years)	Driving frequency (per Week)	Experience of traffic accident	MMSE (score)
		Left	Right				
①	69 (M)	0.6	0.8	45	6	1	26
③	70 (F)	0.7	0.7	40	7	0	29
⑤	68 (F)	1.0	0.8	28	7	0	30
⑥	71 (F)	0.7	0.6	41	7	3(Auto-bicycle)	30
⑦	72 (M)	0.6	0.6	50	7	2	30

mean age; 70 years old) were taking part in the experiments as shown in Table 5.2.3. The participants were fully explained about the experiment and agreed on the contents

(4) Parameters of deceleration behaviors

For evaluating the effect on a braking initiation, the following state variables were investigated.

- Braking initiation TTCr [s]

- The degree of maximum deceleration [m/s^2]

As the effect on full stops, the following state variables were investigated.

- Rate of full stop [%]

- Minimum velocity [km/h]

As the effect on a right-and-left check, the following state variables were investigated.

- The frequency of a right-and-left check from braking initiation to stopping (The number of times at the phase 1)

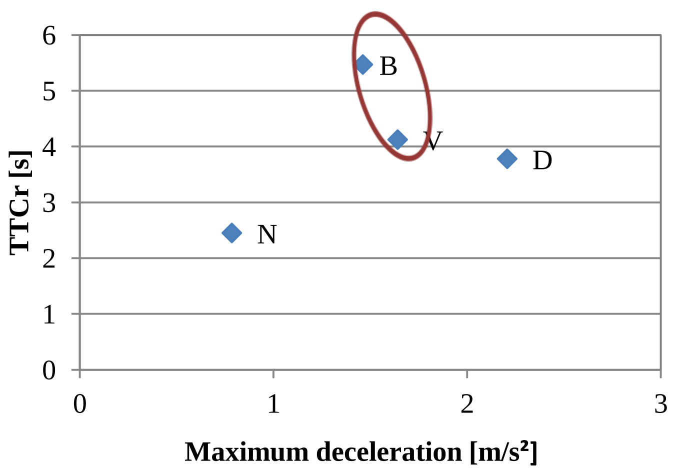
- The frequency of a right-and-left check from stop or minimum speed to acceleration on (The number of times at the phase 2)

5.2.3 Experimental Results

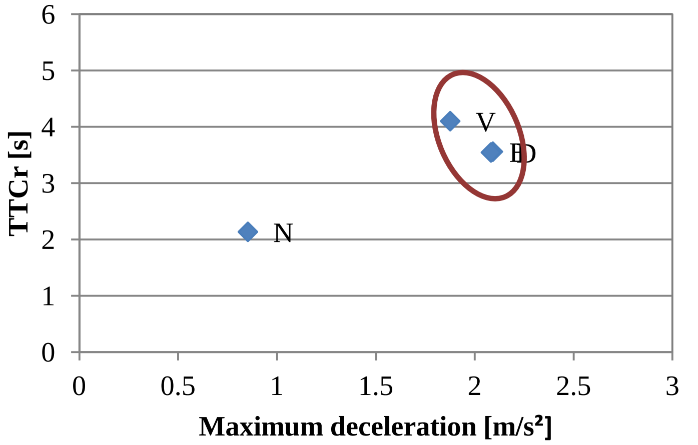
(1) The effect on TTCr

Figures 5.2.6 (a) ~ (e) show individual TTCr of elderly drivers with alerts when approaching intersections. In the figures, the N indicates None condition, the B is Beep condition, the D is Display condition and the V is Voice condition.

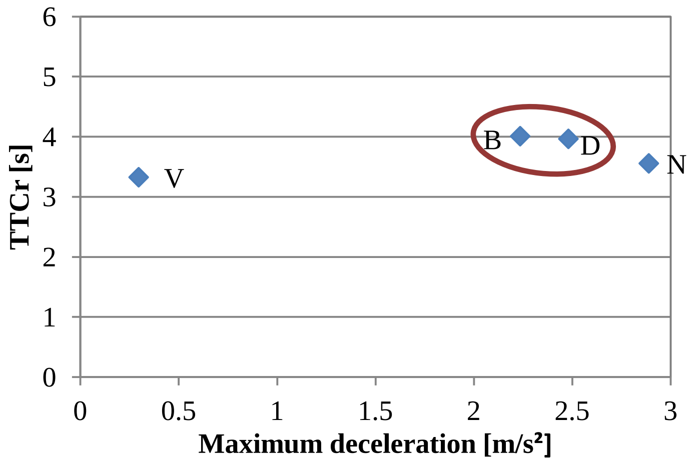
As the results, at the driving condition with Beep and the Voice were earlier than the driving at None in figure 5.2.6 (a). Especially, TTCr with the beep sound alert is earlier for 4 seconds. Beep condition was the most effective for subject ① who belongs to the group of O_D. Next, subject ③ belongs to the group of O_A initiated braking operations earlier under the condition of Voice and Beep. The other subject ③, ⑥, and ⑦ belongs to the group of O_A operated brake pedals earlier with Beep and Display, Voice and Beep and Beep and Voice.



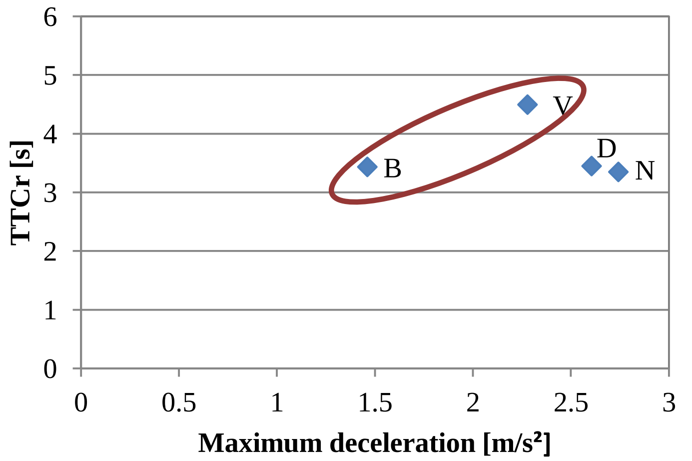
(a) Subject ① for O_D group



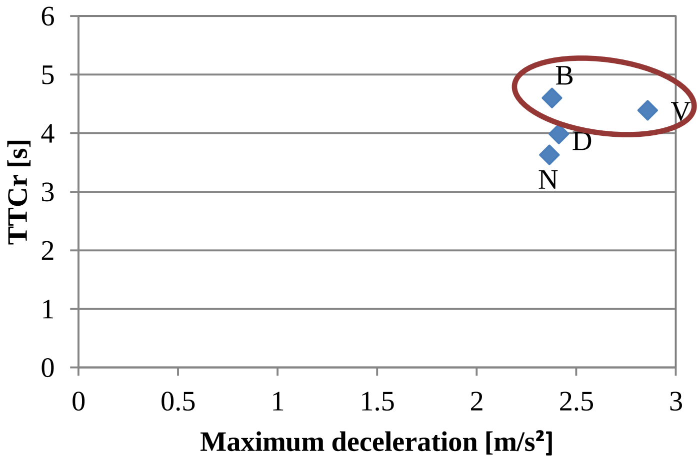
(b) Subject ③ for O_A group



(c) Subject ⑤ for O_A group



(d) Subject ⑥for O_A group



(e) Subject ⑦ for O_A group

Figure 5.2.6 TTCr and Maximum deceleration

Figure 5.2.7 shows the result of braking timing in terms of TTCr for all subject including young drivers. First, the braking initiations of drivers are late when compared with young drivers late, and the change of TTCr under assistance alert by beep, images and voice is large. In the other words, the driving assistance system is more effective than young drivers.

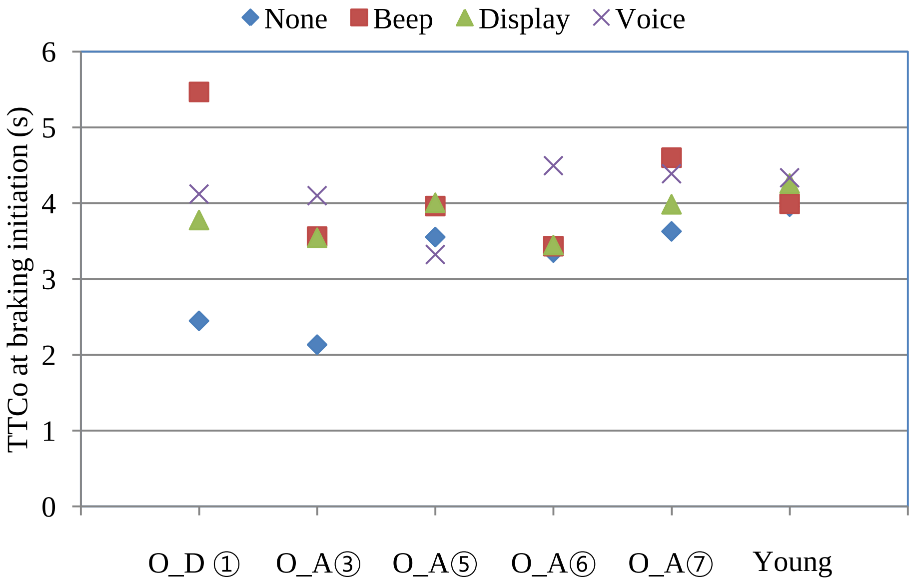
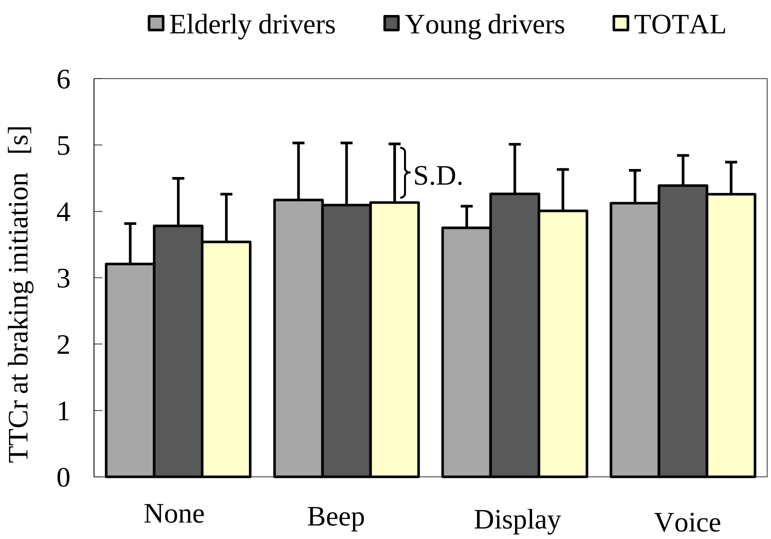


Figure 5.2.7 Braking timing in terms of TTCr and Maximum deceleration

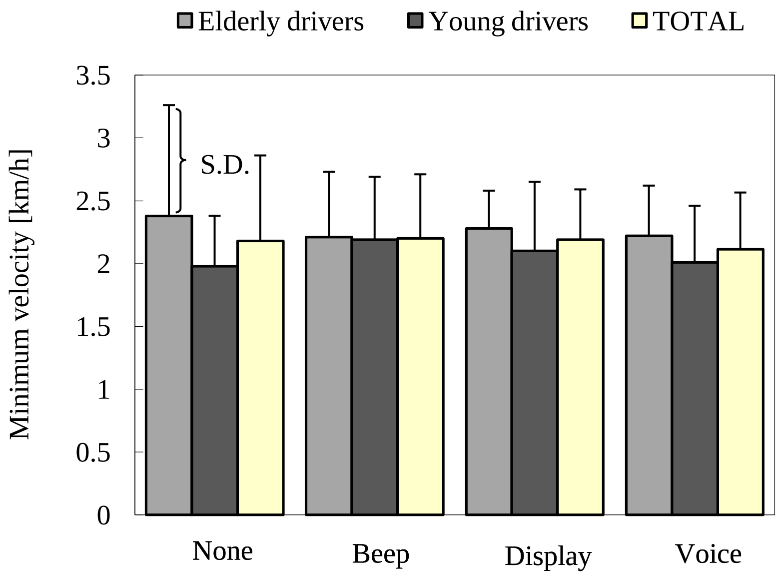
On the other hands, as shown the figure, it is obvious that the effects of alerts for O_A group are not enough. The change of braking timing in terns of TTCr of a subject O_A③ whose MMSE score is lower by one point, than the others, is larger than the change of the others of O_A group and is smaller than that of O_D group.

Regarding above the results, a correlation between the effect of driving assistances and the level of cognitive decline by aging is obvious.

Next, Figure 5.2.8 (a) shows the average of TTCr of each age group and alerts, and (b) shows average of Maximum deceleration. According to ANOVA analysis of TTCr; two factors: age group (two levels) and alert (four levels), there is significant difference in alert factor as [$F(3,72)=8.88$, $p<.01$]. As results of HSD, Voice alert is more effective than that None. However, there is no significant difference significant different for maximum braking acceleration.



(a) Average of TTCr at braking initiation



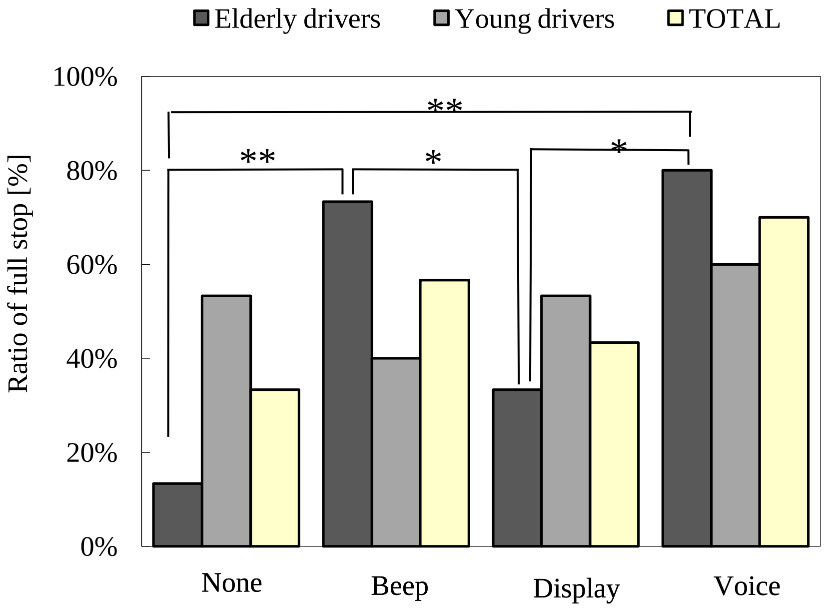
(b) Average of Maximum brake acceleration

Figure 5.2.8 TTCr and Maximum deceleration

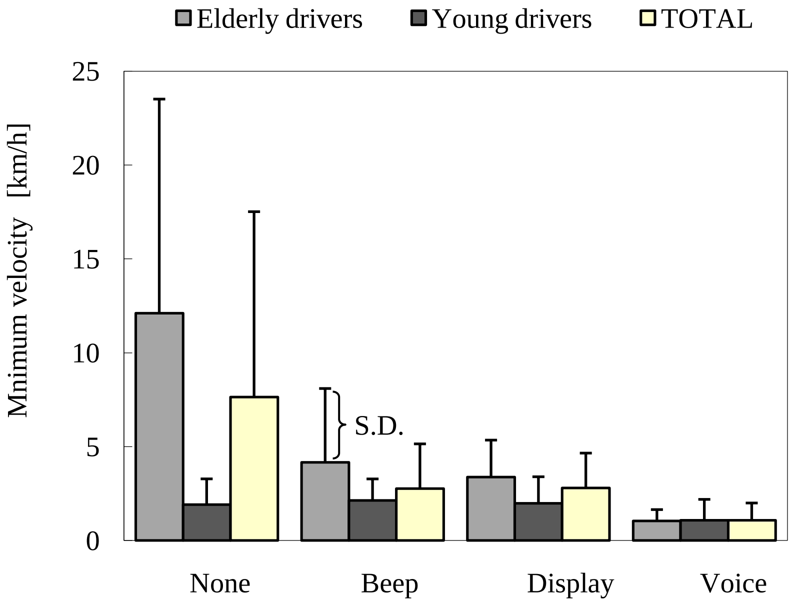
(2) Effect on full stop ratio

Regarding the age group and alert conditions, ratio of full stop at intersections is shown in Figure 5.2.9 (a), and the average of the minimum velocity is shown in (d). About the rate of full stop, based on a result of Cochran's Q test, a significant difference by support conditions was clarified in the elderly group [Q(3) =18.81 and $p<.01$]. By McNemar test, a significant difference was shown by Voice conditions compared with the None condition and the Display condition.

Interaction of driver groups and alert methods in terms of the minimum velocity is significant as [$F(3, 72) = 9.01$ and $p<.01$]. Regarding a result of simple main effect, between the age groups and alert conditions are significant as [$F(3, 72) = 38.26$ and $p<.01$] and [$F(1, 72) = 18.25$ and $p<.01$]. On the None conditions of an elderly group, average velocity was significantly higher than other alert conditions at the multiple comparison by HSD test.



(a) The ratio of full stop



(b) The minimum velocity

Figure 5.2.9 The ratio of full stop and the minimum velocity at intersecions

Figure 5.2.10 shows the rate of full-stop at intersections in terms of the cognitive groups of elderly drivers. As the result of O_A group, the rate of stopping increased in Beep, Display, and Voice, especially rates of stopping under a voice condition was highest. However, in the results of

O_D group, only under the voice condition the complete stopping with 100 percentages was observed, in spite of that the rate of full stop was 0 % only under the other conditions. From these the results, the voice assistance was most effective on stopping.

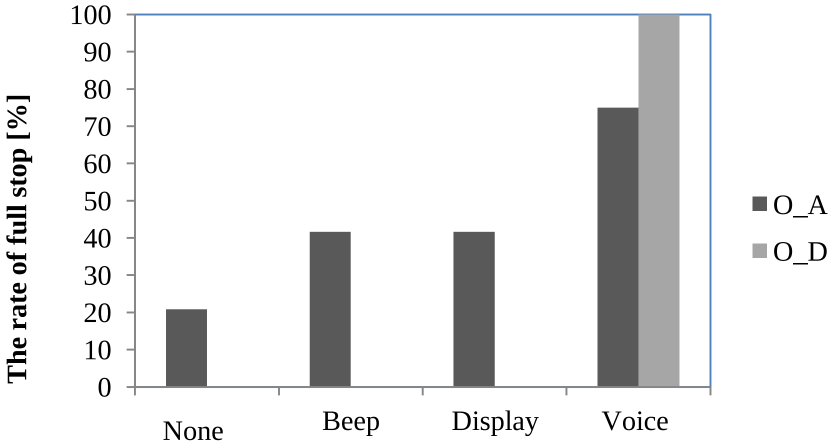
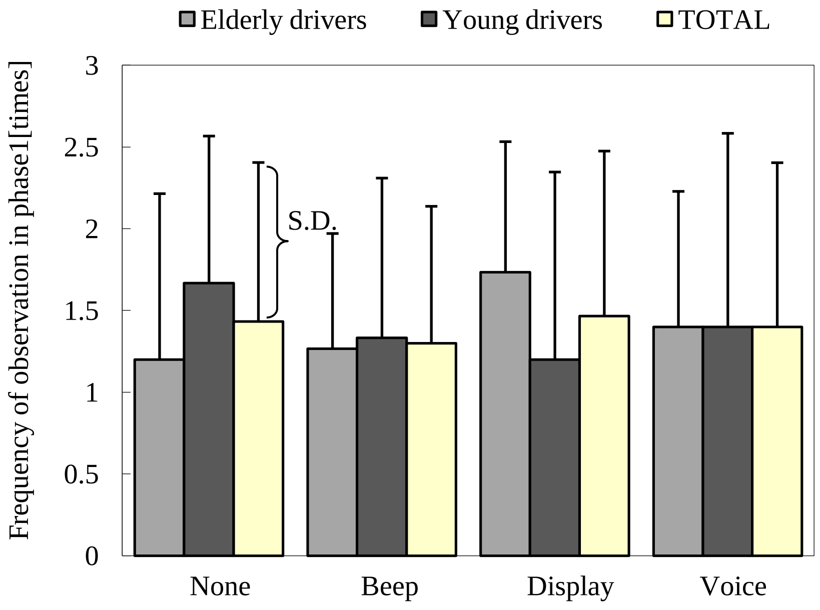


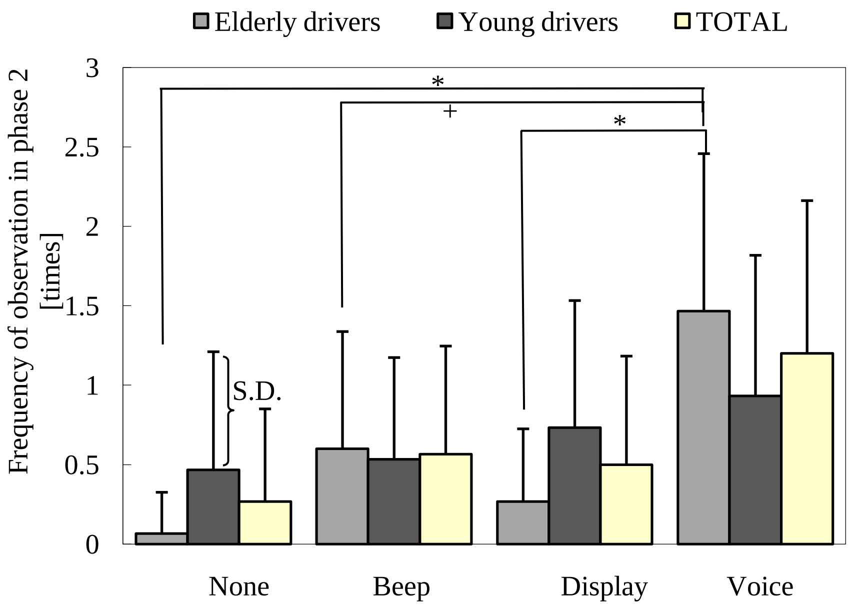
Figure 5.2.10 The rate of full-stop in terms of cognitive ability of elderly drivers

(3) Effect on Right-and-Left Check

Regarding the age and alerts groups, an average of the number of right-and-left checks in the phase 1 for each support condition is shown in Figure 5.2.11 (a). An average of the number of right-and-left checks in the phase 2 is shown in Figure 5.2.11 (b). In the phase 2, interaction of driver groups and alerts was significant [$F(3, 84) = 5.28$ and $p<.01$]. According to result of a simple main effect, a group effect in Voice condition was [$F(1, 84) = 4.08$ and $p<.05$], and alert conditions in an elderly group were significant as [$F(3, 84) = 18.67$ and $p<.01$]. The Voice condition of an elderly group was significant at the multiple comparisons by HSD.



(a) Frequency of right-and-left checks in the phase 1



(b) Frequency of right-and-left checks in the phase 2

Figure 5.2.11 Frequency of right-and-left checks at intersections

5.2.4 Discussion

In this the Chapter 5, based on the results at Chapters 3 and 4, I will verify the effect of driving assistance system on the change of braking and stopping behavior at intersections through real driving tasks.

As the results, when the compare elderly driver with young drivers, the timing of braking initiations (TTCr) was relatively late when approaching intersections. Moreover, regarding the result of O_A and O_D groups, braking timings of O_D groups was later than that of O_A, thus, the cognitive decline by aging affects on the braking behavior. In the other words, the driving assistance system is needed for elderly drivers declined cognitive ability.

Investigating the timing of braking initiation, while the voice condition for O_A group was the most effective, for O_D group, a beep alert was the most effective in that it induced early braking operation as shown in Figure 5.2.12.

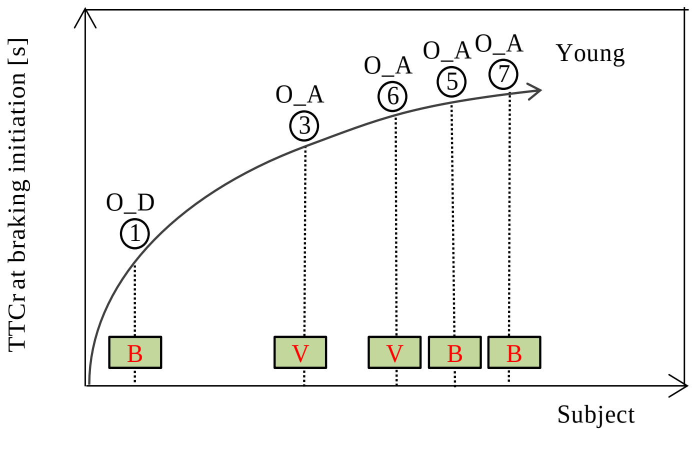
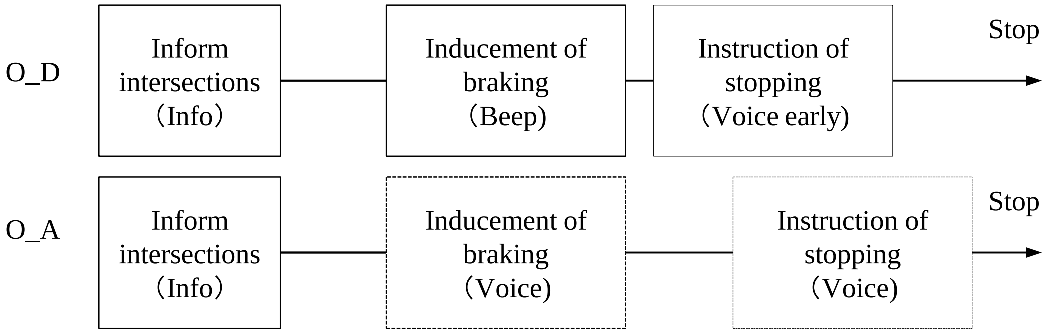


Figure 5.2.12 TTCr and the effect of alert conditions for each elderly driver group

In previous studies, it was presented that there was a close relation between hearing, visual ability and cognitive ability and it became clear that a decline of elderly drivers' hearing causes an accident. In other words, aging involves a decline of general physical function, not one function. In the study, a beep condition showed the effect on an elderly driver's group O_D with the inferior cognition ability. Because the beep condition was easy to understand, thus, the beep condition induced braking timing earlier than a voice alert condition with a lot of volume of information.

In contrast, elderly driver's group O_D showed high rates of stopping at a voice condition. Because a voice condition has the explanation in detail to induce stopping at intersections. In other words, it became clear that support by sound in detail has high effect. Therefore, when designing a driving assistance system for elderly drivers regarding cognitive ability, the alert timing to induce braking and stopping can be set as shown in Figure 5.2.13. On the other hand, in a display condition, the effect on improving the stop rate was not observed. I think that checking the alert-information with a display was a multitask and it was difficult to understand the meaning of information.



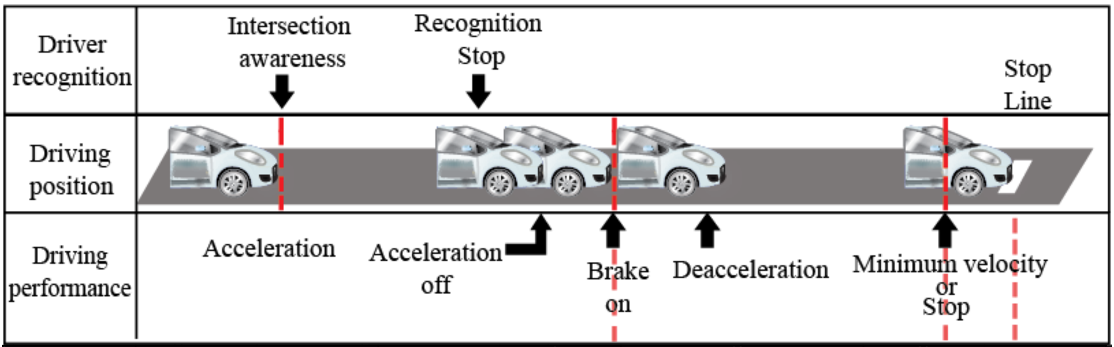
Figire 5.2.13 A example for supporting elderly driver regarding cognitive abaility

From the frequency of right-and-left checks, only the frequency of checks under the voice alert increased. It is obvious that a right-and-left check was very important for preventing the face to face collisions. And the effect to prevent collisions by the voice alert was higher than other alerts. On the other hand, the frequency of right-and-left checks with the display condition did not increase.

As a reason, since the visual stimulus was displayed on a LCD monitor on a dashboard, elderly drivers gazed at a monitor instead of checking the left and right.

Generally, assistance warning by a beep sound had the highest effect to enhance early brake behavior for an elderly group O_D who had the inferior cognition function. However, a voice condition as to induce stopping has high effect on increasing the rates of full stopping.

In contrast, a voice condition was very effective for elderly drivers O_A whose cognition function was not inferior. Regarding driving steps, the effect of driving assistances in terms of the level of cognitive function is shown in Figure 5.2.14.



Beep	o	o	Δ	o	Δ	x	x	x
Display	o	o	Δ	Δ	Δ	x	x	x
Voice	o	o	o	Δ	o	o	o	o
	O_A	O_D	O_A	O_D	O_A	O_D	O_A	O_D
	Awareness of intersections		Braking initiation		Full stopping		Safety check	

Figure 5.2.14 The effect of driving assistances in terms of process of stopping

5.2.5 Summary

In this research, as the first step on development about an individual driving assistance system for elderly drivers, an assistance system (navigation-system-coordinated stopping-situation assistance system) was designed.

As a result, it was confirmed that the system is effective to induce braking, the rate of stopping and the frequency of right-and-left check improve remarkable improve in elderly drivers especially.

Presenting information regarding stopping by each stage is effective that elderly drivers are able to make full stop. Moreover, it was confirmed that the receptiveness if the system by drivers is equivalent to the conventional support method.

In a future study, I will examine and verify an adaptive driving assistance system considered with individual characteristics of elderly drivers.

CHAPTER 6

CONCLUSIONS

6.1 Summary of this paper

This research showed a methoddogy for the establishment of designing approach for the driving support system preventing non-stopping and collision accidents on city roads, especially at intersections.

In Chapter 1, subjects of this study were selected regarding traffic situations including previous researches, and in Chapter 2, to develop a technology of driving assistance system for elderly drivers, results on fundamental investigation of driving was summarized. And next, in Chapter 3 to Chapter 5, a method for designing a driving assistance system and the validity were shown. In this study, I focused on a construction of a driving assistance system on coefficient of a view point of engineering. At the first step of the study, an optimal combination of the alarms between presenting information of traffic environment to call attention for driving (as a first-step alert) and warning to induce braking operations using audiovisual alerts (as a second alert) was investigated. Based on the investigation results, a driving assistance system was designed, and the effects were verified.

Next, driving style, which is influenced by environmental, physiological factors of each driver of elderly drivers was investigated. Moreover, individual difference of cognition-judgment ability was analyzed. The driving assistance systems as technology of accident prevention systems at the view point of the human-machine-interface are designed and the effects of these systems are verified. In this research, from a view point of engineering, these following two approaches are most important and experiments to follow these two approaches were conducted.

Design the assistance system for preventing non-stopping accident at intersections after evaluating the combined effect of alarm, warning and alert.

Construct and verify the driving assistance system to present anti-stopping alert at intersections based on the driving behavior of the elderly drivers.

The contents and results of the research were summarized as follows.

In Chapter 1 "Introduction", characteristics of elderly drivers are defined. Progress of traffic accident prevention safety technology and the present condition of developing of driving support technology are surveyed, and the composition of the background of research, the research purpose are shown.

In Chapter 2 "Investigation of elderly drivers' driving behaviors at intersections", driving behaviors in terms of braking of elderly drivers were investigated. Here, the characteristics of the elderly driver's driving behavior were observed. Therefore, it was clarified that requirements of a system to assist braking behavior was needed.

In Chapter 3 "Study on the composition of advanced driving assistance driving assistance system and it’s effects based on physical", the driving assistance systems, using combinations of audiovisual alarms, to prevent many traffic accidents by elderly drivers were designed. To verify the effect of suggested system, physiological index like a driver's cardiac beats, a cerebral blood flow, and a body surface pulse wave were measured. As a result, it was clarified that the individual difference of physiological reaction of elderly drivers was wide, and requirement of an optimal alarm system concerning this individual difference is confirmed.

In Chapter 4 "Adaptive driving assistance system for elderly drivers considering individual characteristics", change of braking behaviors of elderly drivers with a driving assistance system in a driving simulator environment was observed. Moreover, although individual difference brought by the ability of cognition and judgment, the positive effects on braking behaviors was clarified. Especially, the system is more effective to elderly drivers whose physical ability had fallen.

In Chapter 5 “Application of the driving assistance system for elderly drivers", I verified effect of the driving support system though field tasks. Generally, assistance warning by a beep sound had the highest effect to enhance early brake behavior for an elderly drivers’ group who had the inferior cognition function. However, a voice condition as to induce stopping has high effect on increasing the rates of full stopping. In contrast, a voice condition was very effective for elderly drivers’ group whose cognition function was not inferior.

In Chapter 6 "Conclusions", I summarized this research; and a future research task is described.

1) Design of the interfaces of driving system is very important for the prevention of traffic accidents and traffic safety. In the study, I verified the construction methodology of effective driving assistance system for elderly drivers. As the result, an optimal configuration of the driving assistance system for the elderly drivers was proposed. Importance of warning to attract attention to detect crossing vehicles and voice information to command timing of braking operation was observed. Moreover, optimal strategy of essential element technology as an in-vehicle driving assistance system was clarified.

2) To achieve traffic safety by many users, the receptiveness in a market is most important. Here, inducement of safety driving operation by presenting alerts according to individual different was observed. Furthermore, the stopping behavior was improved by presenting voice information at intersections.

In this study, through the experimental study using a driving simulator simulating the driving in urban area, the receptiveness of this system was clarified. The validity of an onboard equipment design (a driving assistance system) in man-machine was verified.

And a basic design of an accommodative driving assistance system in consideration of the individual characteristic was proposed.

6.2 Suggestion on adaptability for the individual drivers

From the above investigation, the functions regarding Human Machine Interface of driving assistance systems can be set up based on each elderly driver's cognitive judgment ability, or the individual difference of the driving style among elderly drivers. Based on this concept, it is evident that each elderly driver's braking-operation characteristics can be used to guide him/her to safety driving from the viewpoint of active safety. In other words, the braking management system that is adapted for the individual characteristic of a driver can be constructed based on Figure 6.2.1. In the figure, at first, the driving behavior of elderly drivers should be investigated and the behavior should be classified with regard to the ability of cognition and judgment (UFOV), driving attitude or driving style (DSQ), and a workload sensitivity questionnaire (WSQ). Next, braking timing and assistance methods can be set up based on the optimal driving assistance model according to the elderly groups which were classified through above investigations.

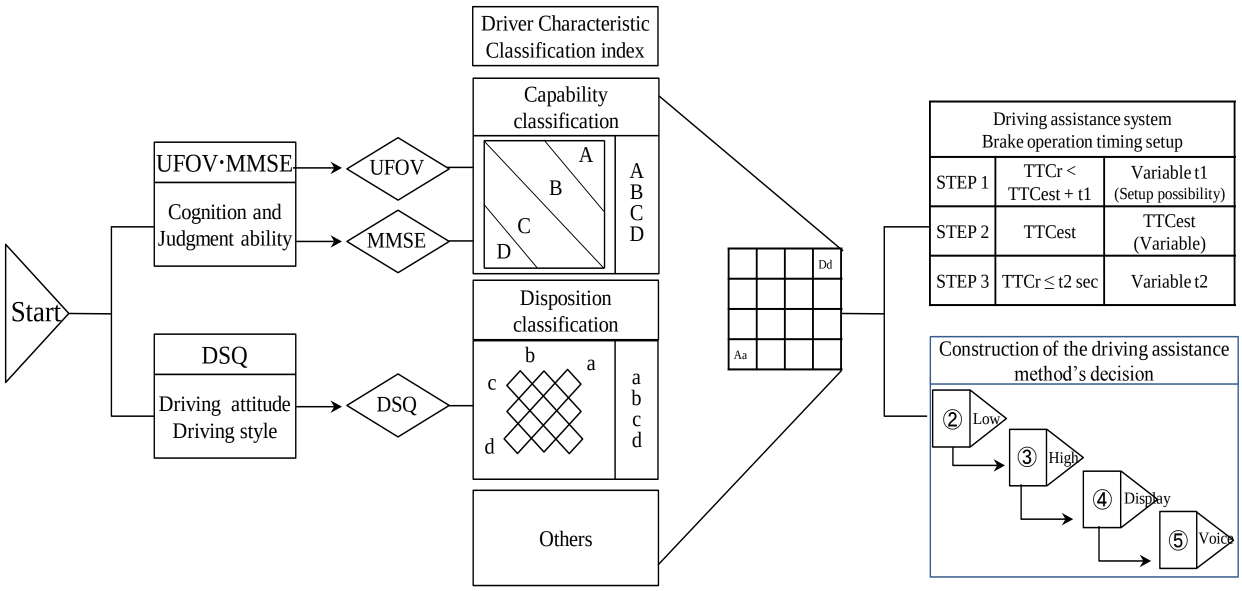


Figure 6.2.1 An example of adaptive driving assistance system for individual driving characteristics

By optimizing the driving support timing and a modal combination with various supporting methods, it can be possible to develop a driving assistance system that is most adapted for the individual characteristics of each driver. For example, if the support system warns elderly drivers whose cognitive judgment is deteriorating, hard braking can be prevented and an early braking operation can be induced.

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