A Study of Older Drivers' Travel Patterns, Driving Behaviors, and Driving Stress

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By

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Abstract

In the last decades, more researchers began to concern the aging problem in the car society. Many studies reported that physical and mental changes that often come with aging can affect older adult's travel patterns, driving behaviors, and driving stress. Meanwhile, the consequential increase of older driver-related accident has also been an inevitable problem. To improve older adult's driving and decrease their accident rate, there are four objectives in this research: 1) to evaluate the older adult's travel patterns; 2) to evaluate the older adult's driving behaviors; 3) to examine older adults' driving stress; 4) to establish the regression models to confirm the results above and identify the influence factors on older adults' travel patterns, driving behaviors, and driving stress.

First, we analyze older driver's travel patterns which include trip frequency, trip length, destination distribution and non-home-based (NHB) trips. A two-month experiment of 108 participants was carried out to collect GPS tracking data in Aichi Prefecture, Japan. Since apparently contradictory statements were often drawn in survey-based or simulators-based research, this study collects not only drivers' basic information but also GPS data. To identify the effect of living area, comparative analysis between older drivers and others was conducted in densely inhabited district (DID, i.e. urban) and other areas (non-DID, i.e. suburban, rural), separately. The present study found that there was no significant difference between the trip characteristics of older drivers and others who were living in DID. However, in non-DID, older drivers' trip frequency, trip length, destination and NHB trips rate were shorter and lower than others.

Second, this paper examines older adult's driving behaviors which includes road selection, left/right turn and driving speed. Analysis of road selection demonstrates that older drivers are reluctant to drive on expressway not only in short trips but also in long trips. The present study did not find significant difference between older drivers and others while turning at the intersections. Moreover, the results reflect that older drivers drove even faster than others at particular road types: national road and ordinary municipal road.

Third, older drivers' stress is investigated not only by self-reported data but also by physiological

indicators. The analyses were conducted on the conditions of intersections and straight roads, respectively. At first, the results suggest that older drivers reported much less stress than young drivers not only at intersections but also on the straight roads. It seems to support some previous studies which claimed that older drivers tended to overestimate their driving abilities. However, principal components (PCs) of the physiological data demonstrate that older drivers might underrate their driving stress in entire trips, except regarding turning at intersections. While examining whether the stress at intersections could affect their driving behaviors, no significant difference was found between two age groups' turning time. Meanwhile, no difference was found in the driving speed between the two age groups.

Last but not least, regression models of travel patterns, driving behaviors, and driving stress were established in the previous three chapters, respectively. The regression analyses confirmed that age had significant influence (or interaction influences with other variables) on these dependent factors.

Considering the relationships among travel patterns, driving behaviors, driving stress, and accidents, we suggest that 1) the education of safety driving and the recommendation of public transportation should be given to DID-living older drivers; 2) electric vehicles (EVs) may be suitable for promotion among older drivers in non-DID area; 3) relative organizations should provide more driver assistance systems, especially turning assistance system for older drivers; 4) intersection design should be improved for older drivers.

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Chapter 1. Introduction

1.1. Background

Over the last several decades, academia and the government have become increasingly concerned with global ageing and its influence on travel behavior, driver health and driving safety (Cabinet Office of Government of Japan, 2015; Crampton, 2009; UN, 2015a). According to United Nations World Population Prospects, Japan has entered the period of a super-aged society (United Nations, 2015b). With the highest proportion of older adults in the world, the number of older drivers in this country reached 16 million in 2015, and is expected to surpass 20 million by 2030 (National Police Agency, Japan, 2014).

Meanwhile, the consequential increase of older driver-related accident has also been an inevitable problem. For instance, although the number of traffic accident in Tokyo has reduced by more than 50% in the last decade, the ratio of older driver in all accidents nearly doubled from 10.9% to 20.4%. In the United States (NHTSA, 2015; Thomas et al., 2015; U.S. Census Bureau, 2014), the population of older drivers has grown faster than any other age group, and the population over 70 is projected to increase by more than 70% from 2014 to 2030. In 2013, the number of driving license holders over 70 years in the UK reached four million (4,018,900) for the first time. Similarly, the percentage of elderly drivers in the EU will exceed one-quarter by 2050 (Polders et al, 2015).

Many previous studies (Liu et al., 2016; Payyanadan et al., 2017; Shrestha et al., 2017; Wang et al., 2015) have reported older driver's driving behavior characteristics in accident analysis, transport planning, advanced driver assistance systems (ADAS) development, etc. Based on an online survey, Delhomme (2013) found that ageing influenced several driving behaviors, such as driving at a steady speed, conservative use of the accelerator, and gear shifting. Bunce (2012) noted that older drivers were more inconsistent than younger drivers in driving performance. According to Liu and Donmez (2011), older driver's behavior was most sensitive to in-vehicle distractions such as cell phone, passengers, in-vehicle controls, eating, drinking, and smoking.

Most of these studies were mainly based on the questionnaire survey or driving simulator. Questionnaire survey study evaluates older adults' driving performance by self-report data which is collected through paper-based survey or telephone interview (Baker, 2014; Baldock, 2006; Owsley, 1999). During driving simulator, age-related driving behaviors are examined in a virtual environment (Andrews and Westerman, 2012). However, self-report study is difficult to avoid participant's subjective effects, such as exaggeration, concealment, and bias (McDonald, 2008). Ross et al. (2012) proved that older adults tend to overrate their driving ability. In their research, 85.14% of older participants believed themselves as either good or excellent drivers regardless of their actual previous citation or crash rates. The researchers further noted that the reliability of older drivers' self-report is limited since their feeling is likely not related to actual driving proficiency. About the driving simulator, since no model can ever be a perfect analogue of driving environment itself, the results only reflect characteristics in a simplified virtual environment. Moreover, one easily overlooked fact is that most simulator-based researches are based on an unfamiliar driving environment to participant. It may imperceptibly increase participants' driving stress. Since driver's behavior in the experiment is not completely consistent with that in a real world (Brooks et al, 2010; Reed and Green, 1999), researchers sometimes draw apparently contradictory statements by different driving simulators. For instance, according to Horberry et al. (2006), the driving performance was relatively stable across different driver age groups and different environmental complexities. But Anstey et al. (2012) and Newnam et al. (2014) suggested that the capacity to drive safely declined with chronological age. The inconsistent views and conclusions on older drivers' driving behaviors not only added a further complications to improve their driving skills, but also partially affected the traffic system planning and transportation policy making (Burkhardt et al., 2014).

On the other hand, everyone experiences stress at some time in everyday life. Driving stress has been proved to contribute to traffic accidents because driving performance depends on not only skills but also controlling stress level (Taylor and Dorn, 2006). In a study (Lagarde et al., 2004) of 13,915 participants over 7 years, stress was found to be associated with a remarkably higher risk of serious traffic accidents. Cui et al. (2009) pointed out that the traffic accidents caused by drivers' daily emotional abnormality were increasing gradually from year to year. Conversely, the experience of being in an accident may also cause long-lasting stress and other psychological effects, for example, posttraumatic stress disorder (PTSD) (Clapp et al., 2011). We can, thus, speculate that the positive feedback chain (stress – accidents or dangerous driving behaviors – stress) could possibly be fatal to all drivers.

Several factors influence stress level. Argandar et al. (2016) summarized the five most stressful situations to potentially cause dangerous driving situations out of 22 driving environments. Furthermore, many previous studies reported that physical and mental changes that often come with aging can affect older adults' stress reaction in traffic environments. Hill and Boyle (2007) investigated the effect of age on driving stress and suggested that older drivers generally reported higher stress levels. Some risk behaviors such as ignoring an approaching vehicle, frequent acceleration/deceleration, and longer reaction time partially caused by stress occurred mostly in older drivers (Staubach, 2009; Kaber et al., 2012).

1.2. Objectives

This study examines older adult's travel patterns, driving behaviors, and driving stress by extracting information from probe vehicle (PV) data and physiological data instead of questionnaire survey or simulator. Because a relatively large number of data can be collected in a long-term on-road experiment, the subjective influence in survey research and the inaccuracy in virtual simulator will be avoided.

There were hypotheses before conducting this study.

(1) Older drivers might have more driving or trip characteristics that are risky.

(2) Older adults might often underrate driving stress.

(3) "Older" might significantly affect travel patterns, driving behaviors, and driving stress.

Therefore, the aims of this thesis are listed as follows.

(1) To evaluate the older adult's travel patterns (trip frequency, trip length, destination distribution, NHB trips, etc) by comparison with other age groups both in urban and rural area.

(2) To evaluate the older adult's driving behaviors (road selection, left/right turn, driving speed, etc) by comparison with other age groups.

(3) To examine the stress of older drivers while turning at intersections and driving on straight roads, respectively.

(4) Establish the regression models to confirm the results above and identify the influence factors on older adults' travel patterns, driving behaviors, and driving stress.

1.3. Structure of thesis

This thesis contains the following six chapters.

Chapter 1 introduces background, objectives, and the structure of this thesis. Chapter 2 reviews relevant papers and reports on older drivers' driving behaviors, travel patterns, and driving stress. Chapter 3 compares older drivers' travel patterns with other age groups. A comparative study of driving behaviors between older adults and others is conducted in Chapter 4. Chapter 3 and 4 are based on the same experiment, which was carried out mainly in Aichi Prefecture, Japan from April 1st to May 31st, 2013. In Chapter 5, older male drivers' stress is analyzed on the conditions of intersection and straight road, respectively. Unlike the previous two chapters, the stress-related data was collected in the experiment from November 2014 to February 2015. Finally, conclusions and future studies are drawn in Chapter 6.

Chapter 2. Literature Review

2.1. Background

Although the evidence mentioned in Chapter 1 has led to the perspective that the driving safety of older drivers has become a serious global problem by consensus, whether it is directly caused by older drivers' physical and mental changes is still in dispute. Indeed, the most essential question is how ageing affects older drivers' behavior and stress (improved, stable, or worse?). As Gulian et al. (1990) defined, driving stress is triggered by the whole driving or specific incidents. The former includes afraid of driving, driving in the night, long-time/distance driving, etc. The examples of the latter are traffic jam, wrong route, car behind too close, etc. In the following sections, we will show that there are many studies on the relationship between ageing and driving behavior or stress. However, they often give apparently opposite statements. For instance, an European Commission (EC) report (2013) reviewed some previous papers and suggested that *"an increase in age does not cause higher crash rates per exposure ..., (this finding is) challenging the traditional concept of a direct association between age-related deterioration of safety-relevant driving skills and driving performance."*. If we read the papers mentioned in this report, it is not easy to challenge the statistics or results presented in these papers. However, they also obviously contradict the facts and conclusions listed in the previous paragraph. One important characteristic of these papers is their methodology: most of them relied on questionnaire surveys, a relatively small portion of them tried driving simulators, and only rare occasional research was conducted by on-road experiments. This may result in the gaps among different studies' conclusions. Through the Introduction and Conclusion sections of these papers, we find that previous hypotheses were sometimes confirmed or denied only by asking another participant group to report their driving status. There is no reason to disbelieve questionnaire survey-based research completely, but this methodology seems to deduce different conclusions in an endless circle. By contrast, driving simulator-based or on-road experiments also have their strengths and weaknesses, which will be discussed in detail in the fourth section. As noted by van Wee and Banister (2016) on literature review papers (LRPs), this chapter does not aim to criticize one side of conclusions or completely deny one methodology. By reviewing previous studies, three questions are expected to be answered in this chapter:

(1) What methods and results were used and demonstrated when studying older drivers' behavior and stress?

(2) What are the advantages and disadvantages of these methodologies?

(3) Is there any opportunity for new methods?

We will present an overview that compares different methods and results on older adults' driving behaviors, travel patterns, and driving stress (Section 2.3), states the advantages and disadvantages of the methodologies used (Section 2.4), and introduces a possible improved method (Section 2.5). Section 2.6 provides the conclusions.

2.2. Methods

2.2.1. How to define "Older Driver"?

Ageing, as a worldwide phenomenon, has stimulated more and more researchers to conduct experiments, analyze problems, and introduce their viewpoints. However, one basic but easily overlooked fact is that the definition of older people, the core element of ageing, varies in different organizations, countries, and studies. Differences in the definition may result in differences in conclusions. Moreover, disagreements and debates sometimes come from and grow up around different discussion objects, even if they share the same name (Wittgenstein, 1922). Table 1 gives the definition of older people or older drivers in different organizations and countries. 60 and 65 were the two main age lines for classifying older people and others, but consensus has not been reached among these official definitions. In addition, the meaning of older drivers sometimes varies depending on conditions even in the same country, such as Japan. Another important part is in the subdivision of older people/driver. The EU and UN give definitions of younger and older groups of older people/drivers, respectively.

Although the views on how to divide are different between these two organizations, we will find that the subdivision of age groups is a valuable process among not only older adults but also others. Similarly, in academic research, each study often uses its own definition of older people/driver with different comparison groups (younger groups, middle age group, etc.). More details will be discussed in Section 2.3.3.

Table 2.1. Definition of "older people" or "older driver" in different organizations and countries.

Organizations or countries	Definition of "older people" or "older driver"	Sources
EU	65+* (Younger group: 65-74 years Older group: 75 and above)	EC, 2016; Polders et al, 2015
UN	60+ (Younger group: 60-79 years Older group: 80 and above)	UN, 2015a
Australia	Depending on different sources. (60+, 65+, or divide 60+ into different age groups by 10 years)	Australia Government, 2016
China	60+ or 65+ Driver over 70 years old: must accept physical examination every year.	State Information Center (China), 2016; The Ministry of Public Security of China, 2016
France	65+: with a letter "S" (Senior) car sticker.	Signal Senior association
German	60+ (but the retirement age is 65).	Federal Statistical Office (German), 2006
Japan	65+ (by MIC statistic); 70+: with a senior car sticker; 80+ (by the office of Prime Minister of Japan).	Ministry of Internal Affairs and Communications (MIC), Japan, 2005; National Police Agency, Japan, 2002; Prime Minister of Japan and His Cabinet, 2016
UK	60+	Older Driver Task Force, UK, 2016
US	65+	Granda and Thompson, 2006

*: "+" means "and over".

2.2.2. Data: What data were used? How were they collected? How were they analyzed?

There are mainly four data sources in the studies of older drivers' behaviors and stress: self-reported data, driving simulator-based data, on-road/on-vehicle data, and physiological data (in stress analysis).

Self-reported data are collected through a questionnaire survey or telephone interview (Baker et al., 2014; Baldock et al., 2006; Owsley et al., 1999). In 2011, af Wåhlberg et al. summarized a list of driving behavior-related questionnaires, which included the Driving Behavior Questionnaire, Driving Habits Questionnaire, Driving Behavior Rating Scale, Driving History Survey as well as a number of others without specific names. As noted in the same paper, one of the most commonly used survey was the Manchester Driver Behavior Questionnaire (MDBQ). Sârbescu (2013) briefly traced the MDBQ's theoretical basis and changes over time. He suggested that it is derived from Reason et al. (1990) and evolved to several different versions, with variance in the number of factors (2 to 6) and the number of items (24 to 114). Until now, the results of MDBQ have been widely used not only as indexes of driving behaviors but also as predictors of driver stress and road traffic accidents (Clapp et al., 2011; Lajunen et al., 2004).

Driving simulator-based research constructs a driving environment in the laboratory. Technologies have advanced from one monitor or multiply monitors (Lewis et al., 2011; Lorentzen et al., 2009) to cylindrical edge-blended screen (The Ohio State University; Zeeb, E., 2010) and 3D visual glass (Blissing et al., 2016; Tateyama et al., 2011).

Compared with the previous two categories of data, on-road/on-vehicle data come from relatively wide sources. A Controller Area Network (CAN), on-vehicle cameras, a Global Positioning System (GPS) recorder, etc., help researchers to collect information more objectively in long-term experiments.

Physiological data can be collected in either simulator or on-road experiments. Healey and Picard (2005) summarized the methods for collecting and analyzing physiological data. A series of papers (Kreibig, 2010; Miyake, 2016; Sharma and Gedeon, 2013; Singh et al., 2013) listed frequently used physiological indicators, such as Skin Conductance Response (SCR), Heart Rate (HR), and R-R Interval (RRI), and their relationship with stress.

After data collection, statistical analysis or model establishment was carried out in nearly every study. The researchers compared data among different age groups (e.g., young and old), driving behaviors (e.g., speeding, braking, and turning), multiple data (e.g., self-reported data and on-road/on-vehicle data), etc. Based on the comparison results and mathematical/behavioral models, the researchers usually gave not only conclusions about older drivers' behavior and stress but also suggestions about driving safety and transportation planning.

2.3. Results

2.3.1. Results on older drivers' behavior

In this chapter, both driving behaviors (e.g., accelerating, decelerating, speeding, braking time/distance, turning time) and travel behaviors (e.g., road selection, left/right turn selection, trip frequency, trip length, non-home-based trip rate) are called driving behavior. Each indicator can evaluate participants' behavior as "Good/Bad" compared with a baseline or "Better/Worse" across groups. For instance, speeding can be measured directly during the experiment if the speed limit is known. By contrast, most indicators are relative values that have to be compared between age groups. In Section 2.3.2, some often-used driving behavior indicators will be summarized with physiological indicators in Table 2.4.

There are two main results in the academic papers on older drivers' behavior:

(1) Driving behaviors is STABLE across the lifespan.

(2) Driving behaviors become WORSE with aging.

To the best of our knowledge, no paper in this field reported that driving behaviors improved with age. Even so, the gap between the two views above has already become deep enough to produce different research directions with different suggestions. Table 2 lists eighteen representative papers alphabetically and then chronologically, and six of them gave the former conclusion. Although not equal to the exact proportion of papers with each conclusion, it generally reflects our review result that more researchers claimed that the driving behavior of older adult is not as good as that of others.

As noted in Section 2.2.1, different studies gave various definitions of older drivers and comparison groups. Although the researchers seemed to focus on the same topic, we actually signified different study objects most of the time. For instance, it is obvious that it is better not to consider 36-60 years old (Newnam et al., 2014) and 75+ (Chevalier et al., 2016, 2017; Siren and Meng, 2013) as the same age level. Furthermore, some studies tried to subdivide participants' age groups. Based on the same idea of the UN and EU (See Table 1), Delhomme et al. (2013) defined two groups of older drivers: Older Drivers and Senior Drivers. By contrast, other studies classified comparison participants into different age groups, such as younger and mid-age (Dissanayake et al., 2017; Horberry et al., 2006). All these divisions were based on the assumption that the change in driving behavior in not linear with age, as demonstrated in some related studies. Tahara and Iwadare (1999) concluded that "younger" elderly people tended to move out from metropolitan areas, as opposed to "older" elderly people, who had a higher tendency to move into metropolitan areas. This phenomenon directly affected the results of the NHB trip rate in the two groups of older drivers. Another common experience is that most drivers try to improve their driving behaviors because they often obtained their licenses when young; thus, it is not reasonable to consider all these drivers as one same comparison group. However, whether these two comparison methods (1.older / younger or 2. subdivided age groups) actually cause different results or whether the latter is better remain unclear and need further research.

If we change the angle of view on Table 2.2, we find that most studies were based on self-reported information, and only a small number of studies carried out experiments to collect on-road/on-vehicle data. It is difficult to detect the true reason for the choices of each researcher. In our assumption, the advantage that questionnaire survey-based research can obtain significantly more data in a relatively shorter period might attracted them the most. However, each method has its own strengths and weaknesses. The fact that self-reported data are widely used does not mean its overwhelming superiority over other methodologies. On the contrary, its disadvantages affect older drivers more and thus come to unsolid conclusions. Section 4 will discuss each methods in detail.

In addition, some other driving behavior-related conditions were difficult to classify but are also worth summarizing and discussing in this paper. Hakamies-Blomqvist and Wahlström (1998) suggested that we should not analyze the age-behavior relationship in isolation from other factors, such as gender. As shown in the study of Charlton (2006), female older drivers expressed different driving attitudes from those of male participants of the same age. This supported the idea of subdividing the older age group, and reminded us that interaction analysis between age and other indicators should be carried out when constructing regression models. Andrews and Westerman (2012) agreed with the effect of ageing on driving behaviors but also noted that driving experiences enabled some older drivers to compensate for their declining abilities. Moreover, the National Institute on Aging, USA (2015) showed another way to consider older drivers' behavior. Because ageing usually changes people's living habits first, some behavior might be caused by their different lifestyles rather than driving abilities. For instance, if older adults intend to drive on the weekday rather than the weekend, their driving behaviors such as speeding and road selections, cannot avoid the influence of day and time periods. In summary, all these results by researchers in the field of older drivers' behavior suggested that age plays an important role but should never be considered as a unique factor.

Table 2.2. Methods and results of studies on older drivers’ behavior.

Results / Methods	Driving Behaviors is STABLE across the lifespan.				Driving Be	
	Authors, year	Definition of "Older Driver"	Comparison group(s)	Sample Size	Authors, year	De "Ol
Questionnaire, telephone, or official statistic	Siren and Meng, 2013	75+	None	888	Baldock et al., 2006	60+
	Wickens, 2011	55+	18–34 years old; 35–54 years old.	18–34 years old: 1522; 35–54 years old: 2726; 55+: 1883.	Bunce et al., 2012	Unkno (averag 71.24)
					Delhomme et al., 2013	45-59: 60+: S
					MacLeod et al., 2014	55+
					Newnam et al., 2014	36-60 (Older
					Ross, 2012	65+
					Rothe, 1990	-
Driving simulator	Horberry et al., 2006	60+	< 25: Younger drivers*; 30-45 years old: Mid-age drivers	Younger drivers: 10; Mid-age drivers: 11; Older drivers: 10.	Anstey et al., 2012	65+
					Doroudgar et al., 2017	60+
					Edwards et al., 2013	65+
					Joanisse et al., 2013	65+
					Mather et al., 2009	65+
On-road/on-vehicle experiments	Chevalier et al., 2016	75+	None	344		
	Chevalier et al., 2017	75+	None	182		
	Dissanayake et al., 2017	65+	< 25: Young; 25-65 Middle.	Unknown		

*: Each group’s name in this table is as same as in the original paper.

2.3.2. Results about older drivers' stress

Table 2.3 lists some representative papers on the driving stress of older adults. Their research methods and conclusions, like the review results of driving behaviors, have the following four characteristics:

(1) "Older driver" had various definitions when comparing objects consisting of multiple age groups, single age group, or did not exist.

(2) Most studies introduced questionnaire survey-based studies whereas a few of them carried out on-road experiments.

(3) Questionnaire survey-based studies collected more sample data compared with the studies based on questionnaires, simulators and on-road experiments.

(4) Most research concluded that driving stress escalated with age, whereas fewer found significant difference between older adults and others.

It is also worth mentioning the other results. In the study of Matthews et al. (1998), the mechanism linking driving stress and behaviors was evaluated and discussed in differing traffic situations. According to Dorn's (2008) book, although a stress-behavior relationship existed, it was difficult to establish a fixed connection between stress and behaviors among different age groups. Qu et al. (2016) also confirmed the correlation between driving stress and dangerous behaviors but claimed that gender should be considered as an interaction factor. All of these studies supported the idea that age should not be evaluated as a single influencing factor when studying driving stress.

Table 2.3. Methods and results of studies on older adults' driving stress.

Methods	Results							
	Driving Stress is STABLE across the lifespan.				**Driving Stress level ESCALATES with aging.**			
	Authors, years	**Definition of "Older Driver"**	**Comparison group(s)**	**Sample Size**	**Authors, year**	**Definition of "Older Driver"**	**Comparison group(s)**	**Sample Size**
Questionnaire, telephone, or official statistic	Argandar et al., 2016	Unknown	Unknown	103 (Average age = 33.65)	Conlon et al, 2017	67+	48-67: Baby Boomer	Baby Boomer: 198; Older: 201.
					Hakamies-Blomqvist and Wahlström, 1998	70+	None	Unknown
					Hill and Boyle, 2007	Unknown	Unknown	All participants: 914
					Staubach, 2009	65+	<=24; 25–64 years old	<=24: 109 25–64 years old: 423 65+: 83
Simulator	Horberry et al, 2006	60+	<25: Young drivers* 30-45: Mid-age drivers	Young drivers: 10; Mid-age drivers: 11; Older drivers: 10.	Joanisse et al., 2013	64+	None	99
					Kaber et al, 2012	65+	18-25: Young	Young: 10; Old: 10.
					Mather et al., 2009	65+	18-33: Younger adults	Younger adults: 45; Older adults: 40.
On-road/on-vehicle experiments					Miller, 2013 **	65+	<=25: Younger; 35-55: Middle aged;	Younger: 20; Middle aged: 20; Older: 14;

*: Each group's name in this table is the same as that in the original paper.

**: Using physiological data

On the other hand, unlike driving behavior, driving stress is difficult to measure directly. The paper of Lee and Winston (2016) went straight to the point: because the psychological reaction to driving situations often leads to unsafe behaviors, driving behavior can help evaluate driver's stress conversely. Therefore, there are two methods to detect participants' driving stress in the questionnaire survey-based study: asking drivers to evaluate driving stress by themselves (driving stress questionnaire) or estimating stress level by their driving behaviors. The second method is also used in a driving simulator or on-road experiments. Still, in Lee and Winston's (2016) study, they summarized stress-related driving behaviors and further quantified stress-behavior correlations that could be used in the estimation of other driving stress experiments. However, they also noted that the results were affected by participant's self-feeling, which varied for different factors, such as age, gender, and driving experience.

Another characteristic of the method is the use of physiological data. Although bio-data collection and analysis technology have evolved quickly in the past decades, only a few studies on older adults' driving stress were found to use this method. This might be partially caused by the cost because the same systems should be used in each participant and in the same periods considering the influence of circadian rhythm (Tsuchikawa et al., 2002). On the other hand, the difficulty of constructing a relationship among ageing, stress, and physiological data might reduce the attraction of this method (Kanamori et al., 2015).

In summary, Table 2.4 lists some frequently used behavior indicators and physiological indicators related to driving stress.

Table 2.4. Frequently used behavior indicators and physiological indicators related to driving stress.

Category	Driving stress-related indicator	Performance or change of direction while feeling stress
1. Travel patterns		
	Road selection	Avoiding expressway.
	Left/right turn selection	Avoiding turning right in the left-traffic countries and vice versa.
	Trip frequency	Avoiding or giving up driving.
	Driving area and destination distribution	Preferring driving in familiar area such as near the home area.
	Trip length	Avoiding long-distance driving.
	Driving time period	Avoiding driving at night, commute time, and weekend.

	Non-home-based (NHB) trip rate	Having a lower NHB trip rate of driving with stress because he/she prefers home-based trips.	
2. Driving behaviors			
	Speed	Driving at unstable speed and frequently changing between low-speed mode and a high-speed mode.	
	Speeding	Driver fails to control speed because he is unaware of speeding.	
	Accelerating/Deceleration	Suddenly accelerating or decelerating.	
	Braking time/distance	Braking suddenly with a shorter distance because he finds dangerous objects/conditions later than others do.	
	Turning time	Spending longer than others at the intersection.	
	Lane-keeping	Being unable to control the vehicle in the lane center and hence frequently steering to adjust vehicle position.	
3. Physiological data			
3.1. Skin Potential	Skin Conductance Response (SCR)	Increasing	
	Skin Conductance Level (SCL)	Increasing	
	Skin Potential Response (SPR)	Increasing	
3.2. Cardiovascular system	Diastolic Blood Pressure (DBP)	Increasing	
	Heart Rate (HR)	Increasing	
	Heart Rate Variability (HRV)		Decreasing
	Low Frequency Component of HRV (LF)	Increasing	
	LF/HF	Increasing	
	R-R Interval (RRI)		Decreasing
	Systolic Blood Pressure (SBP)	Increasing	
3.3. Cerebral vascular system	Human Oxy Hemoglobin (Oxy-Hb)	Increasing	
	Human Deoxy Hemoglobin (deOxy-Hb)		Decreasing
3.4. Respiration	Respiration Interval (RI)		Decreasing
	Respiration Rate (RR)	Increasing	
	Peripheral Capillary Oxygen Saturation (SpO2)		Decreasing
3.5. Temperature	Skin Temperature (Temp)		Decreasing

2.3.3. Advantages and disadvantages of methodologies used

The method we will discuss in this section entails how to collect data rather than how to analyze them. The reason is that the latter, which includes regression models, significance analyses, and some other mathematical statistical tools, has more universal strengths and weaknesses including but not limited to the research of older drivers' behavior and stress.

Comparing the cost, experiments period, sample size, and objectivity among different data collection methods, the brief results are shown in Table 2.5.

Table 2.5. Comparison of methodologies used in the study of older drivers' behavior and stress.

Methods	Cost	Experiment period	Sample size	Objectivity
Questionnaire, telephone, or official statistic	+++*	+++	+++	+
Driving simulator	++	++	+	++
On-road/on-vehicle experiments	++	+	++	+++
Experiments collecting physiological data	+	- **	-	+++

*: +++ is better than ++, which is better than +.

**: The experiment period and sample size of physiological data collection depends on what experimental method (simulator or on-road/on-vehicle experiments) on which it is based.

Questionnaire survey-based research can obtain a relatively large amount of data in a more economical way in a shorter period. These advantages have attracted most researchers to perform such studies in this field. However, the objectivity of self-reported data might be its most important disadvantage. According to Ross and Dodson (2012), more than three quarters of older participants thought they drove better than most others regardless of their actual previous citation or crash rates. They indicated that most older adults tended to overrate their driving ability and further noted that the reliability of older drivers' self-reporting was limited because their feeling was likely not related to actual driving proficiency. Hence, before either collecting or explaining the self-reported data, we should understand that in a questionnaire survey-based study, it is difficult to avoid participant's subjective effects, such as exaggeration, concealment and bias. (McDonald, 2008).

The advantages and disadvantages of driving simulator-based research are located somewhere between questionnaire survey-based and on-road experiments. Because no model can perfectly simulate the real diving situations, the results reflect only the characteristics in a simplified virtual environment. Moreover, one can easily overlook the fact that the simulator often shows an unfamiliar driving environment to participants. It may imperceptibly increase participants' driving stress. Therefore, participants' behavior in the experiment is sometimes not completely consistent with that in the real world (Brooks et al., 2010; Reed and Green, 1999).

On-road/on-vehicle experiments often mean repeated trials in a longer experiment period than other methods. However, the results are influenced the least by participants' subjective factors. In GPS-based research, Vhaduri (2014) developed a model named GStress to estimate driving stress and obtained ideal results.

Physiological data can be collected in either simulator or on-road experiments when studying driving stress. It can enhance the objectivity but add more pressure to the research budget at the same time.

In summary, the balance among cost, time and objectivity plays a key role when choosing an experimental method.

2.4. An improved method

Having compared the methods using in the research of older adults' driving behavior and stress, we can conclude that a perfect single method that meets all experimental requirements might not exist. However, many researchers have chosen a possible improvement method we call the "Hybrid Method". They conduct two or more experiments, shown in Table 4, in the same studies not only to achieve all of methods' advantages but also to compensate for one another's deficiencies.

Ross and Dodson (2012) carried out both a questionnaire survey-based study and driving simulator-based experiment. Kanamori et al. (2015) collected questionnaire answers, on-road data, and physiological information, and then explained them together. In 2013, two papers of Yokoyama and Takahashi evaluated both objective and subjective stress in the same experiment and established a mathematical model to connect the two. All of these researchers claimed that the hybrid methods increased the accuracy of the results. Ross and Dodson (2012) found that simulator-based driving training before paper-based education can significantly improve older adults' driving abilities.

Our suggestion is to use the improved method (hybrid method) when studying older drivers' behavior and stress. It consists of three main parts:

(1) Collecting participants' self-reported data before a driving simulator or on-road experiments.

(2) Establishing the relationship between questionnaire survey-based and objective information.

(3) Evaluating the characteristics of driving behavior and/or stress based on 1 and 2.

We also focus on new academic literature about optimized methods and expect technological progress that can offer better tools or systems for both experiments and analyses.

2.5. Summary

This chapter reviewed relevant papers and reports on older drivers' driving behaviors, travel patterns, and driving stress. We found that questionnaires, simulators, and on-road/on-vehicle systems were used to collect driving data in different studies. The researchers compared older drivers and others directly or subdivided participants into additional age groups. It should also be noted that the definition of an "older driver" varied not only in different studies but also in government reports. A questionnaire survey, which can obtain a relatively large sample size economically in a shorter period of time, was the most widely used, but a lack of objectivity is its major disadvantage. By contrast, physiological data can increase the reliability of the results in a driving simulator or on-road experiments when studying driving stress. Regarding the results, some papers claimed that driving behavior and stress were stable across the lifespan, whereas others reported the degeneration of driving abilities and escalation of driving stress among older drivers. In addition, several studies suggested considering not only age but also other influencing factors, such as gender, living area, and driving experience. Finally, we suggest a "hybrid method". It establishes the relation between subjective and objective information and can help researchers evaluate driving behaviour and stress.

Chapter 3. Travel Patterns

3.1. Background

Many studies reported that physical and mental changes that often come with aging can affect older adult's travel behaviors. By a 5 year survey-based study on the relationship between health problems and risk ratio among older drivers, MacLeod et al (2014) suggested to provide more driving training and assistant to older adults. Delhomme et al (2013) found that older drivers have some driving characteristics, such as driving at a steady speed, conservative use of the accelerator, and gear shifting. Ross et al (2012) indicated that most older adults tend to overrate their driving ability. In their research, 85.14% of older participants believed themselves as either good or excellent drivers regardless of their actual previous citation or crash rates. Meanwhile, aging may also change people's living and activity areas. As mentioned in Section 2.3.1, Tahara and Iwadare (1999) concluded that "younger" elderly people tend to move out from metropolitan areas, as opposed to "older" elderly people have a higher tendency to move into metropolitan areas. Benekohal et al (1994) summarized the effects of aging on older drivers' travel characteristics, which included travel frequency, travel time, trip length, etc. It suggested that all these indicators decrease significantly as the age of the driver increase. Moreover, Rothe (1990) associated the high accident ratio of elderly drivers with their prominently frequent around-home driving.

Home-based (HB) and non-home-based (NHB) trips, which play an important role in trip generation, are also important to understand driver's trip characteristics. By HB and NHB trips, the complex driving activities can be converted into number of trips (Verma and Ramanayya, 2014). Because trips must be generated by certain purposes, like from home to work, home to shop, or school to home, HB and NHB reflected drivers' driving intention and travel convenience. Rothe (1990)'s statistics showed that main trip purpose of middle-aged group is commuting and social while that of elderly group is personal and family. On the other hand, one consensus is that living area could affect driver's NHB rate. Victor and Ponnuswamy (2012) estimated that NHB trips might constitute 10 to 15 percent of the total trips in most urban areas. Through an improved calculation model, Schultz and Allen (1996) confirmed that NHB trips accounts for 25 to 30 percent of urban-living driver's travel. Moreover, Gonzalez-Ayala's report (1999) concluded that the NHB rate in urban area is lower than that in rural area. About this phenomenon, Hildebrand et al (2004) explained that rural-living participants tend to chain more activities together because they live further away from their desired destinations. However, it should be noted that Hildebrand's study only focused on older drivers who were living in rural area, hence the comparative analysis between older drivers and other age groups was not conducted.

Another feature of these studies are that most of them mainly based on the questionnaire survey. Although self-report study is widely used, it is difficult to avoid participant's subjective effects, such as exaggeration, concealment, and bias (McDonald, 2008). Ross et al (2012) even recommended to abandon survey-based study on older drivers because their feeling is likely not related to actual driving proficiency. Considering the limited reliability of self-report from older drivers, some studies analyzed trip characteristics by the GPS-based travel diaries which were collected by on-vehicle device (Hanson and Hildebrand, 2011a & 2011b). However, they still lack of the contrastive study of older drivers and others among urban and rural area.

Although some studies (Harrison and Ragland, 2003; Mollenkopf et al, 2005) focused on the consequences of aging-related driving habits change and suggested to improve transportation alternatives, it often lacked specific suggestions on transportation planning for older adults living in different areas. For instance, public transportation has many advantages in urban area, but its demand, cost and efficiency may decreased in suburban area. Even in the same living area, whether older adults driving less than others is still unclear. On the other hand, the development of electric vehicles (EVs) is deeply affecting transportation planning in current years (Kempton and Letendre, 1997). However, although some automobile companies have viewed older adults as potential users, the feature caused by living area has not been considered yet. Associated with some travel behaviors of older adults, transportation infrastructure planning models and related policy issues about EVs may be developed or improved.

The aim of this chapter is to evaluate the older adult's trip characteristics by comparison with other age groups both in urban and rural area. The research objects included trip frequency, trip length, destination distribution, and NHB trips. It should be noted that the trip in this paper was limited to automotive trip which did not consist of bus, walk or any other transportation mode. An official survey (Ministry of Land, Infrastructure and Transport Japan, 2011) suggested that automotive trip accounted for about 67 percentage of all trips in the areas of this study. It could be further estimated that automotive trip occupied more than 83.75% in the trips of this study's participants who were holding driving license and vehicle (Japan Automobile Manufacturers Association Inc., 2011). According to some research (Ogawa, 2003), it can be inferred that the automotive trips rate in suburban/rural is even higher than that in urban area.

Further aims of this chapter are: to confirm whether the indicator of "older driver" could affect trip characteristics; to identify the interaction impact factors with older driver on travel behavior. Except for the basic information such as gender, age, and address, this study mainly relied on probe vehicle (PV) data instead of questionnaire survey. The results may contribute to the improvement of driving assistant, driving training and transportation plan for older drivers.

3.2. Data

Chapter 3 and 4 are based on a same experiment. 121 Drivers were recruited in the data collection experiment, which was carried out mainly in Aichi Prefecture, Japan from April 1st to May 31st, 2013. Before the experiment, they permitted to install data collection devices in their vehicles and then filled in basic information survey. Due to machine faults or operation mistakes, there are 108 valid experiment subjects out of 121 participants. The following three broad categories of data were assembled in this study.

(1) Driver's characteristics (e.g., name, gender, age, address, etc.)

(2) PV data (e.g., location, speed, date & time, engine on/off, etc.)

(3) Region classification by population density (e.g. densely inhabited district or non-densely inhabited district, etc.)

Following the introduction of data, the terminology in this study will be given.

3.2.1. Driver's characteristics

Driver's characteristics were obtained by questionnaire survey before the experiments. Participants were asked eighteen background questions. According to age (*mean* = 40.3; *standard deviation* = 11), gender and employment status, experiment subjects are categorized into different groups as shown in Table 1. The information of employment status is used in the judgment of commute trip which is engaged by only employee, student or self-employed person. It must be admitted that older drivers (10, 9.3%) and non-workers (11, 10.2%) make up a relatively small proportion of the whole sample. However, in order to ensure the long experiment of data collection carried out smoothly, the sample has to bias on workers and students who are below 60 years old. Table 1 also lists the population and proportion of the study area by each age group (Toyota City Government, 2015). It should be noted that although female comprises a relatively higher proportion of older adults, they are fewer in this study because of the lower rate of female license-holding (30.02%) in all older drivers (National Police Agency, Japan, 2014).

Table 3.1. Sample distribution in this study and population distribution of the study area.

Cases	Sample distribution in this study		Population distribution of the study area	
	Numbers	Percentage	Population	Percentage
Total	108		423,961	
Age				
20's of all	8	7.4%	52,585	12.4%
30's of all	27	25.0%	58,083	13.7%
40's of all	38	35.2%	65,696	15.5%
50's of all	25	23.1%	48,140	11.4%
60's & 70's of all	10	9.3%	94,091	22.2%
Male	67	62.0%		
in 20's	5	62.5%	30,399	57.8%
in 30's	17	63.0%	31,978	55.1%
in 40's	23	60.5%	34,838	53.0%
in 50's	13	52.0%	25,289	52.5%
in 60's & 70's	9	90.0%	46,683	49.6%

Commuters	97	89.8%
in 20's	7	87.5%
in 30's	24	88.9%
in 40's	36	94.7%
in 50's	22	88.0%
in 60's & 70's	8	80.0%
DID-living		
in 20's	4	50.0%
in 30's	16	59.3%
in 40's	22	57.9%
In 50's	11	44.0%
in 60's & 70's	3	30.0%

3.2.2. PV data

The PV data was collected by in-vehicle devices which were equipped in each experimental car, separately. After starting the device, data was constantly sent from the moving car to the nearby base stations or receiving nodes. There are 78 channels which record the types of number, string, date, etc. Some of the data describes the road positions or environments, such as GPS (latitude, longitude, altitude, etc.) and road ID. Other data presents vehicle's moving information, such as fuel consumption (0.1km/L), running speed (km/h), and engine speed (rpm). Data is eliminated while engine is off or GPS data is invalid (e.g., driving in tunnel, on mountain road, underneath the viaduct, etc.). It should be noted that once GPS signal is missed (e.g., after entering tunnel), localization estimation algorithm (LEA) embedded in the in-vehicle device will be operated automatically. Based on this algorithm, the vehicle is assumed in the extension line of last recorded direction at a constant speed which maintains the last recorded speed. Considering the low credibility, the estimated records are also deleted in this study.

3.2.3. Region classification by population density

Based on the 2010's population census conducted by Statistics Bureau of Japan, Densely Inhabited Districts (DID) are designated in units of census basic unit blocks, and census enumeration districts if there are several census enumeration districts in a census basic unit block, and should coincide with the following criteria.

1. (1) A district containing basic unit blocks, etc. with a population density of 4,000 or more per square kilometer, such districts being adjacent to each other in a municipality
2. (2) A district consisting of the above adjacent basic unit blocks, etc. whose population is 5,000 or more at the time of the Population Census of Japan

Based on the definition above, DID could be viewed as urban areas while non-DID represents rural areas, suburban areas, etc. Then the address of each participant could be located into DID or non-DID areas.

3.2.4. Terminology

Following words and concepts should be clearly defined.

(1) Older driver: driver who is 60 years old or older (Because "Age" options in survey were "20+", "30+", … "60+", "70+".).

(2) Trip: automotive trip (abbreviation: trip) which does not consist of bus, walk or any other transportation mode.

(3) Commute trip: trip from home to office/school.
Discretionary trip: otherwise.

(4) Peak periods (rush time): 7:00-10:00 and 15:00-20:00 on weekday (Figure 1).
Off-peak periods: otherwise.

(5) HB trip: a trip which has at least one end of the trip at the home of the trip maker.
NHB trip: otherwise.

(6) Long trip: a trip which is longer than 50 km.

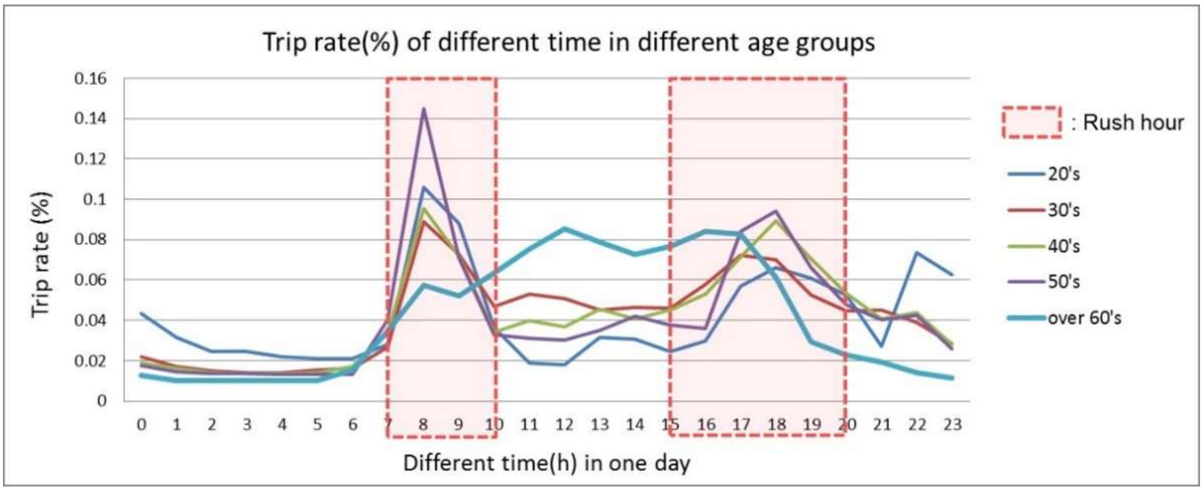

Figure 3.1. Sample distribution on time of day of trip.

3.3. Methods

3.3.1. Trip frequency and length

Participants are classified by DID-living or non-DID-living, which is hypothesized to affect trip frequency and length. The data of some frequently-driving participants may have an excessively high influence on the results. To avoid this condition, after calculated each driver's trips per day, trip frequency are further averaged by living area and age groups respectively. About trips length, similar data process is operated. For the comparative analysis between older driver and others both in DID and non-DID, t-test is used to evaluate whether there is significant difference among two age groups.

Since commute trips usually comprise of a certain route in constant time, discretionary trips in off-peak periods are calculated (the same in the analysis of destination distribution and NHB rate) in this research. Each driver's home can be located by comparing their address information and the PV data of the first most frequently visited destination. For driver who is working or student, the second most frequently visited destination (only lower than home) on weekdays is considered as his/her commute destination.

3.3.2. Destination distribution

Different with trip length, the analysis of destination distribution is expected to help understand older drivers' driving range around home. Participants are also classified by age groups and living areas. Regardless of the origin, the distance from home to destination can be measured by GPS records. Considering that most trips might distributed in a region not far away from home, this study further investigate the destination distribution in a radius of 5 km away from home.

3.3.3. NHB trips

By comparison the locations of trip's end point (origin and destination) and driver's home, each trip can be broadly classified as HB trips and NHB trips. Because the two age groups are mutually interdependent and have different sample sizes, Z-test is used to analyze the statistical significance between older drivers and others.

Regression model is used to identify the impact factors on all trip characteristics of this study. Because each GPS data point could be considered as a single sample case, and multiple samples with unequal sizes were collected from each person, the random effects regression model is constructed to consider unobserved heterogeneity among drivers (Wooldridge, 2005; Jaccard, 2003). The model consists of 1 constant term (β_0) and 11 binary independent variables ($X_1, X_2 \ldots X_{11}$): one is gender, five are age, the other five are working/at school, living area, weekday, rush time and commute trip. It should be noted that because the trip frequency is classified by person and day rather than trip or hour, it is described by poisson regression model which is usually used for multi-layer data. Meanwhile, for the same reason, the factors of rush time and commute trip are not included in the regression model of trip frequency. Furthermore, the interaction terms between the variable "Age (60's or older)" and the latter five factors are also added into the model. Through significance test, each variable's effect on trip characteristics will be examined. Because the association between the interaction variables may exist, association is also measured by a Pearson correlation coefficient (also referred to as "phi coefficient" for two binary variables) (Warrens, 2008). If two variables interact, they may or may not be associated. However, if two interaction variables are associated (correlation between them is high), one variable should be eliminated from the regression model because the interaction effect is deduced to be caused by the association. Furthermore, elasticity information reflects the responsiveness of dependent variable to an independent variable change, and it depends on where the calculation starts (Gary, 2004). If the elasticity is less than 1, we can claim that the dependent variable is inelastic, and vice versa. Thus, the elasticity at each age group is calculated to confirm the responsiveness of dependent variables to age.

3.4. Results

3.4.1. Trip frequency and length

The average daily trip frequency and average trip length are shown in Table 2 and Table 3, respectively. Sample size means the amount of trips (the same in destination distribution and NHB rate) It reflected that in DID area, both indicators of older drivers are almost the same as those of other participants. In contrast, the older drivers in non-DID area drive significantly less and shorter than participants who are younger than 60.

Table 3.2. Average daily trip frequency (trips/day).

	DID (e.g. Urban)		Non-DID (e.g. Suburban, Rural)	
	Older drivers	Others	Older drivers	Others
Sample size	229	4967	951	5373
Mean	1.20	1.14	0.46	0.90
Std	0.99	0.54	0.19	0.61
t Stat	0.86		-42.49**	

* P < .1

** P < .05

Table 3.3. Average trip length (km/trip).

	DID		Non-DID	
	Older drivers	Others	Older drivers	Others
Sample size	229	4967	951	5373
Mean	18.75	17.70	12.70	19.45

Std	10.70	8.43	6.40	8.24
t Stat	1.47		-28.58**	

* P < .1

** P < .05

Considering the traffic environment in urban area, such as intersection of multiple directions, complex road network, a large number of pedestrians and nearly unpredictable traffic congestion, driving is often not a recommended transportation mode not only for older drivers but also for younger drivers (Japan National Tourism Organization, 2015). On the other hand, urban usually supplies more travel options which include bus, metro, taxi and car-sharing. One possible reason why DID-living older drivers do not drive less or shorter than others is that the former have more free time to avoid rush hours. The relatively smooth traffic flow in off-peak period may increase their driving intention. Meanwhile, unlike moving from other region, aging is a gradual process which could not lead older adults to abandon their habit of driving immediately. As noted in the section of introduction, some physiological changes with aging are more easily to cause traffic accident. For the older driver who are living in the DID area, the promotion of public transportation mode and the training of safety driving are therefore needed.

In some previous survey-based studies (Adler and Rottunda, 2006; Hassan et al, 2015; Johnson, 1998), most of rural-living older drivers claimed that giving up driving, so-called driving cessation, meant isolation for them. However, the data in this research shows that older drivers living far from urban areas tend to reduce travel by driving. It can be inferred that older driver tend to buy a larger quantity of goods while shopping and hence drive less than others. Another possible reason is that the reduction of tour, entertainment and social with aging may directly cut down both trip frequency and length. Meanwhile, in the long journey, middle-age people in family may be required to drive and older adult are pleased to be passenger.

3.4.2. Destination distribution

Unlike trip length, destination distribution reveals the travel range in a center of drivers' home. Regardless of origins, all trips can be imaged as distributed in concentric circles. As trip frequency and length, Table

4 shows that there is no significant difference between two age groups in DID area. Meanwhile, non-DID-living older drivers' travel range is smaller than others.

As noted in Section 3.4.1, more training and education should be given to DID-living older driver for the prevention of accidents. On the other hand, since most of older drivers who are living in non-DID area inclined to drive near home, it should be further investigated and explained with the result of NHB trips in the next section.

Table 3.4. Destination distribution (km).

		DID		Non-DID	
		Older drivers	Others	Older drivers	Others
All trips	Sample size	229	4967	951	5373
	Mean	16.61	14.22	9.30	15.14
	Std	18.79	22.36	15.36	16.37
	t Stat	1.86		-10.70**	
Trips with the destination in 5 km range from home	Sample size	101	1980	580	2840
	Mean	2.43	2.94	2.00	2.78
	Std	1.37	1.26	1.09	2.46
	t Stat	-3.67		-12.00**	

* P < .1
** P < .05

3.4.3. NHB trips

NHB trips reflect the process of trips generation. Because driver, usually as trip planner, attempts to quantify the relationship between multiply activities and travel, a relatively high NHB rate means efficient travel plan. As shown in the Table 5, the NHB rates of both age groups in DID area remains within the range between 25% and 30%, which is consistent with Schultz and Allen (1996)'s model. However, in the non-DID area, the NHB rate of older drivers is significant lower than that of others. Moreover, older drivers' NHB rate does not corroborate Gonzalez-Ayala (1999)'s conclusion that NHB rate in urban area was lower than that in rural area. It should be noted that "z Stat" in the Table 5 is the result of Z-test.

With the smaller driving range from home (Section 4.2), it can be inferred that older adults in non-DID do not prefer continuous driving to different position far away from home. It reveals some older drivers' life style: driving for single purpose around home, such as farming, social, shopping in convenient store; rely on other drivers or other transportation mode while going to a further destination.

Table 3.5. HB and NHB trips rate.

	DID		Non-DID	
	HB trips	NHB trips	HB trips	NHB trips
Older drivers	161	68	764	187
	(70.31%)	(29.69%)	(80.34%)	(19.66%)
Others	3538	1429	3356	2017
	(71.23%)	(28.77%)	(62.46%)	(37.54%)
z Stat	-0.30		10.66**	

* P < .1

** P < .05

3.4.4. Regression analysis

The result of regression analysis is shown in Table 6. If one older driver-related independent variable significantly affects the research object, the number will be in a bold color and the cell will be in gray color and with black borders.

Trip frequency, length and NHB trip, except for the destination distribution, are influenced significantly by older driver (X_6) even considering the interaction effect. As analyzed in the previous section, the interaction between older driver and living-area is a significant influence factor on each travel behavior. Moreover, about the trip frequency, older driver also has a positive interaction effect (X_{14}) with the impact factor of weekday/weekend, which implies that older adults driving on weekday can increase the trip frequency. It accords with some reports (Maryland Department of Transportation, 2015; National Institute on Aging, USA, 2015) and may be caused by their expectation of avoiding the traffic congestion during the weekends. As mentioned in the Method section, correlation between interaction variables is measured by Pearson correlation test. The correlation coefficients are -0.4922 (X_6 and X_7), -0.1751 (X_6 and X_8), 0.0566 (X_6 and X_9), -0.0186 (X_6 and X_{10}) and -0.0244 (X_6 and X_{11}) respectively. And all of them are non-significant at the 0.05 level. Thus, we can conclude that the interaction effects are not caused by the correlation between independent variables. The regression analysis also demonstrates that living area (X_8) plays an important role in the trip characteristics, which confirms that it is necessary to divide the participants of this research into DID-living and non-DID-living groups. Furthermore, the elasticity information is also computed and indicated by superscript "IE (inelastic)" or "E (elastic)". It shows that the responsiveness of each dependent variable to "Age (60's or older)" has high elasticity, which means that the change of former is strongly influenced by the latter.

Table 3.6. Regression analysis of trip frequency, trip length, destination distribution and NHB trips.

Independent variable	Description	Possible values	Trip Frequency (Possion model)		Trip Length (Log model)		Destination Distribution (Log model)		NHB trip (Logit model)	
			Coef. (β)	t-stat	Coef. (β)	t-stat	Coef. (β)	t-stat	Coef. (β)	t-stat
β_0	Constant term		-0.52	-1.99*	2.08	7.03**	2.81	8.90**	-1.46	-4.51**
Driver attributes										
X_1	Gender	1. Male, 0. Female	0.03	0.22	0.27	1.95	0.21	1.84	0.27	1.56
X_2	Age (20's)	1. 20's, 0. Others	-0.19 ^{E}	-0.80	0.29 ^{E}	1.24	0.36	1.49	0.03 ^{E}	0.10
X_3	Age (30's)	1. 30's, 0. Others	-0.07 ^{E}	-0.43	0.23 ^{E}	1.47	0.29 ^{E}	1.31	-0.07	-0.33
X_4	Age (40's)	1. 40's, 0. Others	base		base		base		base	
X_5	Age (50's)	1. 50's, 0. Others	-0.02 ^{E}	-0.13	0.20	1.24	0.23	1.17	-0.04 ^{E}	-0.19
X_6	Age (60's or older)	1. 60's or older, 0. Others	**-1.12** ^{E}	**-2.59****	**-0.81** ^{E}	**-2.6***	-0.70 ^{E}	-0.96	**0.57** ^{E}	**1.87***
X_7	Working / at School	1. Working or at school, 0.Others	0.15	0.57	0.26	0.98	0.24	0.71	0.81	2.56*
X_8	Living area	1. DID, 0. Non-DID	0.40	3.05**	0.06	0.49	0.39	1.66*	-0.07	-0.44
Day										
X_9	Weekday	1. Weekday, 0. Weekend	0.02	0.74	0.54	5.87**	0.94	2.34*	0.21	2.89**
Time										
X_{10}	Rush time	1. Yes, 0. No			0.91	8.49**	1.13	6.35**	0.27	3.97**
Commute trip										
X_{11}	Commute trip	1. Yes, 0. No			-1.40	-10.42**	-1.22	-8.77**	-21.77	-0.02
Interaction effects between age and living area										

X_{12}	X6 × X7	1. Yes, 0. No	-0.33	-0.61	0.97	0.90	0.65	0.83	-0.88	-1.09
X_{13}	X6 × X8	1. Yes, 0. No	**1.41**	**2.43***	**0.49**	**3.46***	**0.96**	**2.92***	**0.22**	**3.29****
X_{14}	X6 × X9	1. Yes, 0. No	**0.43**	**3.30****	-0.15	-0.21	-0.23	-0.38	0.03	0.08
X_{15}	X6 × X10	1. Yes, 0. No			0.20	0.28	0.23	0.25	-0.45	-1.73
X_{16}	X6 × X11	1. Yes, 0. No			0.05	0.04	0.03	0.05	0.29	0.00
Number of observations			6588		16320 (Trips amount)		16320 (Trips amount)		16320 (Trips amount)	
Number of groups			108		108		108		108	
Log likelihood			-10189		-17187		-14272		-3086	
R^2			0.106		0.095		0.092		0.484	

*p < 0.05.

**p < 0.01.

E: elastic (greater than 1) at this independent variable.

3.5. Summary

At first, we found that there was no significant difference between the trip characteristics of older drivers and others who were living in DID. Many reports have warned that some physiological and psychological changes with aging are easily to cause driving mistakes. The other unavoidable fact is that the complex traffic environment in urban area is one important reason for traffic accidents. Thus, we suggest that the education of safety driving should be given to DID-living older drivers. On the other hand, more convenient public transportation modes in DID, such as bus, metro and taxi, should be further promoted for older adults.

Unlike the results in DID, trip characteristics had great difference between two age groups in non-DID. The results shown that older drivers' trip frequency, trip length, destination and NHB trips rate were shorter or lower than others'. The first three indicators reflected that older drivers living in non-DID tended to drive less and travel in a relatively small range, meanwhile NHB trips demonstrated that most non-DID living older drivers had a tendency to travel for fewer purposes. It should be noted that some previous studies claimed that the NHB rate of rural-living drivers was higher than that of urban-living drivers because the former lived further away from their desired destinations. However, in this study, this phenomenon was verified to exist only in the participants who were younger than 60. It reflected that aging might have greater effect on non-DID-living older drivers than living area. All these characteristics suggested that EVs might be suitable for promotion among older drivers in rural area, because EVs' weaknesses of charging space/time and endurance ability are relatively easily to be accepted while their advantages of cleaner and greener could be developed.

Furthermore, to identify the impact factors on all trip characteristics of this study, regression analysis was conducted. The results shown that "older drivers" was a significant independent factor on trip frequency, trip length and NHB trips. Moreover, it had interaction effects with "living areas" on all trip characteristics during this study. It also confirmed the necessity of grouping not only by age but also by living area in this chapter.

Chapter 4. Driving Behaviors

4.1. Background

This chapter examines older adult's driving behaviors by extracting information from probe vehicle (PV) data instead of questionnaire survey or simulator. Because a relatively large number of PV data can be collected in a long-term on-road experiment, the subjective influence in survey research and the inaccuracy in virtual simulator will be avoided. In this study, the driving behaviors including road selection, left/right turn, and driving speed are investigated.

As a prerequisite to effective road network generalization, road selection supports real-time navigational features within advanced driver-assistance systems (ADAS) (Liu et al., 2010; Najjar et al., 2007). Because each road type has unique characteristics, road selection reflects driver's attitude towards not only his/her own driving ability but also driving safety. For instance, low-speed-averse driver is considered to drive on expressway, while traffic-jam-averse driver may be reluctant to drive on urban local road in rush hour. Moreover, road selection characteristics also vary according to trip purposes, locations, vehicle types (Fouque, 2008; Najjar and Bonnifait, 2005), etc. Touya (2010) established a generic process model for road network selection by dividing large scale city road network databases. Although accident data have supported that expressway is far safer than other roads (O'Cinneide et al., 2004), considering the fear of high speed and possible fatal crash, we assume that older drivers tend to avoid expressway and investigate it in this chapter.

In Japan, a country with left lane traffic, data analysis (ITARDA, 2012) shows that most crossroad-related accident occurred in right turn (over 44%). Moreover, right-turn maneuvers at intersections are known to be particularly critical for older drivers (Sato and Akamatsu, 2008; Hakamies-Blomqvist and Wahlström, 1998). According to the report from Japan Ministry of Land, Infra-structure, Transport and Tourism (MLIT, 2012), the average age (=59) in right turn accident exceeded that in any other accident type. Many studies (Charlton et al., 2006; Sullivan et al., 2011; Unsworth et al., 2007) claimed that older drivers tended to avoid right turns while driving on the left (left turns when driving on the right). However, the conclusion was obtained mainly from self-reported questionnaire survey. Moreover, the possible effect of road type on left/right turn rate was not discussed. With the development and popularization of navigation system, which could be not only carried on the car but also installed in smart phone, more and more drivers follow a computer-planned route instead of arranging it by themselves. For older drivers, although they understand the potential danger at the intersections, the reliance on car navigation might decrease their tendency to detour.

Some studies showed that driving speed and the speed limit in different roads were related to accident (Friedman et al., 2009; Kweon and Kockelman, 2005). Peer (2011), Figueroa Medina and Tarko (2005), and Liu (2014) listed a number of factors, such as age, gender, license years, and time of day, and used mixed-effects model (MEM) to quantify each variable's impact on driving speed. It was confirmed that the speed limit influenced the driving speed and the regression models changed with different roads types (Mannering, 2009). However, most studies considered the speed-age relationship as linear, and drew diametrically opposite conclusions. For example, Boylea and Mannering (2004) suggested that the impact of driver's age was not statistically significant on driving speed, while Liu (2014)'s conclusion was opposite. Regarding the possible different regression models in each age level, this chapter classified age into 20's, 30's, 40's, 50's, and over 60's and analyzed their relationship with speed, separately.

4.2. Data

The study of this chapter used the same data and terminology in Chapter 3.

4.3. Methods

4.3.1. Road Selection

Compared with other road types, expressway has several features: enclosed, high-speed, long-distance, hard to change a wrong route, etc. The special environment in expressway increases older driver's driving stress and correlates with risky driving behaviors (Schwebel et al., 2007). In this study, road type 1) intercity expressway and 2) urban expressway are assembled into expressway while non-expressway includes 3) national road, 4) principal prefectural road, 5) principal municipal road, 6) ordinary prefectural road, 7) ordinary municipal road and 8) others. It should be noted that road type 9) uninvestigated is excluded since they may belong to either group.

Since commute trips usually comprise of a certain route (Hao et al. 2016), discretionary trips in off-peak periods are calculated (the same in the analysis of left/right turn and driving speed) in this research. Although each driver's home can be located by comparing their address information and PV data, the position of commute destination was not asked in the questionnaire before the experiment. For driver who is working or student, the second most frequently visited destination (only lower than home) on weekdays is considered as his/her commute destination.

Because the two age groups are mutually interdependent and have different sample sizes, Z-test is used to analyze the statistical significance between older drivers and others. Additionally, for the reason that short trips around home rarely use expressways, driving around home frequently may cause low expressway utilization rate. Thus, long trips (over 50km) are also investigated in this study.

4.3.2. Left/right Turn

Left/right turn is detected by GPS and road link ID. While road link changing, the new driving direction could be detected by the latitude and longitude of vehicle. Previous driving direction is calculated by the latest two GPS positions on the former road link, while new direction is estimated by the data on current road link. The left/right turn could be confirmed by comparing the angle between these two directions. If the driver turned right, the clockwise angle from the former road link direction to the current road link direction would be between 0°and 180°. Otherwise, the clockwise angle would be between 180° and 360°. It should be noted that turning behavior could also be estimated by the indicators of handle angle, blinker signal and driving speed (Healey and Picard, 2005). However, considering that relatively frequent lane-change behavior has similar characteristics with turning, this method is not utilized in present study.

The data of some frequently-driving participants may have an excessively high influence on the results. To avoid this condition, we use average left/right rate of each driver instead of summing up amounts of all left/right turn. At first, each driver's left/right turn rates in different road types are aggregated, separately. And then, average left/right turn rates of older drivers and others are calculated in each road types. Considering the unequal sample sizes of older drivers and others, Welch's t-test is used to investigate the significant difference.

Due to the insufficient sample size of older drivers in some road types, the amounts of left and right turning are aggregated and compared in this situation. Z-test examines whether a significant difference exists between two age groups' left/right turn rates. Because there is no intersections in expressway, the analysis is carried out in non-expressway only.

4.3.3. Driving Speed

Speed data were continuously recorded by on-vehicle device while driving. As noted in the previous section, estimated data are not utilized in this study. Moreover, considering temporary stop or parking caused by traffic congestion, intersection or some personal reasons, records of 0 km/h are eliminated. The abnormal instantaneous speeds (faster than 180km/h or slower than 0km/h), which are mostly caused by device error, are also removed.

Because each GPS data point could be considered as a single sample case, and multiple samples with unequal sizes were collected from each person, the random effects regression model is constructed to consider unobserved heterogeneity among drivers. The model consists of four independent variables: age, road type, trip length, and trip time. Age has six dummy variables/levels of attributes; road type has eight dummy variables; trip length is a numerical continuous variable; and trip time is a binary variable with two dummy variables. Assuming that road types could affect driving speed (e.g. driving on expressway is faster than on other roads) while age is related to the inclination of road selection (see section: Result – Road selection), the interaction terms between age and road types (the number of interaction terms =35) are added into the model. Through significance testing, each variable's effect on driving speed will be examined. Further, coefficient estimate results of interaction terms describe older driver's speed in different road types compared with other age groups.

4.4. Results

4.4.1. Road Selection

Excluding uninvestigated roads, the sum and proportion of expressway and non-expressway roads are shown in Table 2. The same calculation process is operated to compare the data between older drivers and others. The results illustrate that discretionary trips in off-peak periods consisted primarily of non-expressway.

Table 4.1. Average one-month driving distance per driver (km).

	Long trips (over 50km)		All trips	
	Older drivers	Others	Older drivers	Others
Expressway	10	28	13	42
	(11.4%)	(16.0%)	(2.1%)	(5.2%)
Non-expressway	76	148	616	762
	(88.6%)	(84.1%)	(98.0%)	(94.8%)
Z	-6.1476*		-17.3760**	

* $p < .05$,
** $p < .01$

In Table 4.1, the Z-test results show that older drivers use expressway significantly fewer than others did in long trips. Similarly, although driving on expressway seems inevitable during the long trips, older drivers still tended to choose non-expressway. As expected, for either age group, rate of expressway in long trips is higher than that in all trips. Moreover, in all trips, older driver's expressway utilization rate is less than half of other participants'. However, while travel in the long trips, the former reaches 71.4% of the latter. It can be thought that while older driver is going to a far-away destination, their resistance to expressway has to be compromised with the need of travel efficiency.

O'Cinneide et al. (2014) proved that expressway is safer than other road types because the former has a relatively smooth traffic flow, accurate road information and better warning system. Additionally, long trips with non-expressway lead drivers to face intersections, pedestrians and uncertain environments more frequently. Therefore, it is necessary to promote driving on expressway and introduce driving safety knowledge/skills among older drivers.

4.4.2. Left/right Turn

Table 4.2 shows the mean and standard deviation of left/right turn rate in each age group among all road types. The result in all non-expressway is also aggregated in the end of this table. Besides, the sample size means the total number of drivers in each age group and road type.

Table 4.2. Comparison of left/right turn rates between older drivers and others.

Road type	3) National road		4) Principal prefectural road		5) Principal municipal road	
	Older drivers	Others	Older drivers	Others	Older drivers	Others
Sample size	7	103	9	105	1	5
mean	1.36	1.73	1.27	1.40	2.00	3.63
std	0.53	12.69	0.61	3.02	N/A	4.02
t Stat	0.8365		0.4179		N/A	

6) Ordinary prefectural road		7) Ordinary municipal road		All non-expressway	
Older drivers	Others	Older drivers	Others	Older drivers	Others
8	100	1	12	10	98
1.33	1.10	1.00	0.75	1.20	1.19
2.33	1.07	N/A	0.81	0.15	1.24
-0.4117		N/A		-0.0134	

*$p < .1$,
**$p < .05$

A high left/right turn rate refers driver's avoidance of right turning at the intersections. Unlike our assumption, the results in Table 3 reveal that older driver's left/right turn rates are not significantly different from others in all road types except 5) Principal municipal road and 7) Ordinary municipal road, in which the sample size of older driver is not enough (sample size = 1).

To compare the left/right turn rates between two age groups in 5) Principal municipal road and 7) Ordinary municipal road respectively, the numbers of left turn and right turn are aggregated and shown in Table 4. Being consistent with the result in Table 3, the Z-tests suggested that older driver's left/right turn rate is not significantly different from others' in these two road types.

Table 4.3. Comparison of left/right turn rates in road 5) and 7).

Road type	5) Principal municipal road		7) Ordinary municipal road	
	Older drivers	Others	Older drivers	Others
Left	33	238	36	489
	(67.4%)	(72.1%)	(55.4%)	(55.2%)
Right	16	92	29	397
	(32.7%)	(27.9%)	(44.6%)	(44.8%)
Z	-0.6909		0.0302	

* p < .05,
** p < .01

4.4.3. Driving Speed

The influence of each independent variable on driving speed is examined by establishing a random effects regression model. Table 5 lists all 52 terms of 4 variables, which include independent variables and interaction terms between age and road types. The older driver-related variables are outlined with the bold line.

Results of this model failed to find that age (60's or older) and gender significantly affect driving speed. But age (20's), age (30's), and age (50's) are significant at the five percent level. It refuted some previous questionnaire survey-based results which suggested that the speed of older drivers was slower than that of others. The t-test results also show that road types, trips length (long trips or not) and driving time (peak periods or not, weekday or not) are significant variables on driving speed. Moreover, the results show that interaction effects occur between older driver and road types except in 1) Expressway. The positive value of interaction effects reflects that older adults drive faster than other drivers do when they change roads from others to 3) National road or 7) Ordinary municipal road. It corresponds to some previous studies which claimed that aging could result in more instability behaviors such as speeding and unsmooth acceleration/deceleration. High speed in these two non-expressway may increase the risk of accidents because of more complex driving environment, which includes pedestrians, intersections and heavy traffic. This study has proved that older drivers tend to avoid expressway. Thus it could be assumed as a possible reason of older driver's higher speed in road 3) National road or 7) Ordinary municipal road since they are more familiar with these roads. In Japan, there are mainly two levels of speed limit: 100 km/h in expressway (road type 1 and 2) and 60 km/h in others (road type 3-7). We further assume that the trend of driving speed varied in different road types because of not only speed limits, but also some other reasons, such as traffic jam and road width.

Table 4.4. Random-effects regression model of driving speed.

Variable	Description	Possible values	Coef. (β)	t-stat.
β_0	Constant term		33.88	30.00**
Driver's attributes				
X1	Gender	1. Male, 0. Female	1.21	1.08
X2	Age (20's)	1. Yes, 0. No	6.34	2.94**
X3	Age (30's)	1. Yes, 0. No	3.9	2.79**
X4	Age (40's)	1. Yes, 0. No	Base	
X5	Age (50's)	1. Yes, 0. No	5.72	3.99**
X6	Age (60's or older)	1. Yes, 0. No	1.59	0.82
Road types				
X7	1) Intercity expressway	1. Yes, 0. No	19.81	52.06**
X8	2) Urban expressway	1. Yes, 0. No	40.63	45.19**
X9	3) National road	1. Yes, 0. No	3.01	25.10**
X10	4) Principal prefectural road	1. Yes, 0. No	Base	
X11	5) Principal municipal road	1. Yes, 0. No	0.39	3.45**
X12	6) Ordinary prefectural road	1. Yes, 0. No	3.65	2.75**
X13	7) Ordinary municipal road	1. Yes, 0. No	2.65	19.12**
X14	9) Uninvestigated	1. Yes, 0. No	-7.09	-7.31**

Trip length				
X15	Trip length	1. Long trip, 0. Short trip	2.05	32.19**
Driving time				
X16	Peak periods	1. Yes, 0. No	-1.83	-26.71**
X17	Weekday or weekend	1. Weekday, 0. Weekend	-0.8	-13.22**
Two-way interaction effects between age and road types				
X18	20s × Road 1	X2 × X7 [a]	-13.97	-20.80**
X19	30s × Road 1	X3 × X7	-10.36	-17.75**
X20	40s × Road 1	X4 × X7	Base	
X21	50s × Road 1	X5 × X7	-15.54	-24.28**
X22	60s and over × Road 1	X6 × X7	0.04	0.04
X23	20s × Road 2	X2 × X8	-35.79	-19.06**
X24	30s × Road 2	X3 × X8	-27.48	-23.53**
X25	40s × Road 2	X4 × X8	Base	
X26	50s × Road 2	X5 × X8	-34.61	-26.80**
X27	60s and over × Road 2	X6 × X8	-25.04	-13.40**
X28	20s × Road 3	X2 × X9	-4.03	-13.62**
X29	30s × Road 3	X3 × X9	-2.73	-14.01**
X30	40s × Road 3	X4 × X9	Base	
X31	50s × Road 3	X5 × X9	-2.95	-14.35**
X32	60s and over × Road 3	X6 × X9	2.06	5.90**
X33	20s × Road 4	X2 × X10	-2.34	-8.52**
X34	30s × Road 4	X3 × X10	-2.46	-12.97**
X35	40s × Road 4	X4 × X10	Base	
X36	50s × Road 4	X5 × X10	-2.56	-12.44**
X37	60s and over × Road 4	X6 × X10	-1.74	-4.41**
X38	20s × Road 5	X2 × X11	-3.45	-0.73
X39	30s × Road 5	X3 × X11	-7.24	-4.08**
X40	40s × Road 5	X4 × X11	Base	
X41	50s × Road 5	X5 × X11	-6.26	-4.01**
X42	60s and over × Road 5	X6 × X11	-6.29	-4.03**
X43	20s × Road 6	X2 × X12	-5.42	-16.76**
X44	30s × Road 6	X3 × X12	-2.38	-10.73**
X45	40s × Road 6	X4 × X12	Base	
X46	50s × Road 6	X5 × X12	-4.6	-19.59**
X47	60s and over × Road 6	X6 × X12	-5.82	-14.62**
X48	20s × Road 7	X2 × X13	1.81	0.69
X49	30s × Road 7	X3 × X13	9.85	5.59**
X50	40s × Road 7	X4 × X13	Base	

X51	50s × Road 7	X5 × X13	-1.42	-0.99
X52	60s and over × Road 7	X6 × X13	7.16	4.37**

Number of observations	534,900
Number of drivers	108
R^2	8.89e-2
Adjusted R^2	8.88e-2
Mean squared error	18.69

*p < .05, **p < .01

a. X2 × X7 means that it takes a value of '1' if 20's drivers (X2) is driving on road type 1 (X7) and '0' otherwise. Similarly hereinafter.

In addition, we calculated the residual (observed minus fitted values) of the regression model and the sample distribution is shown in Fig. 2. It shows that the error term follows normal distribution.

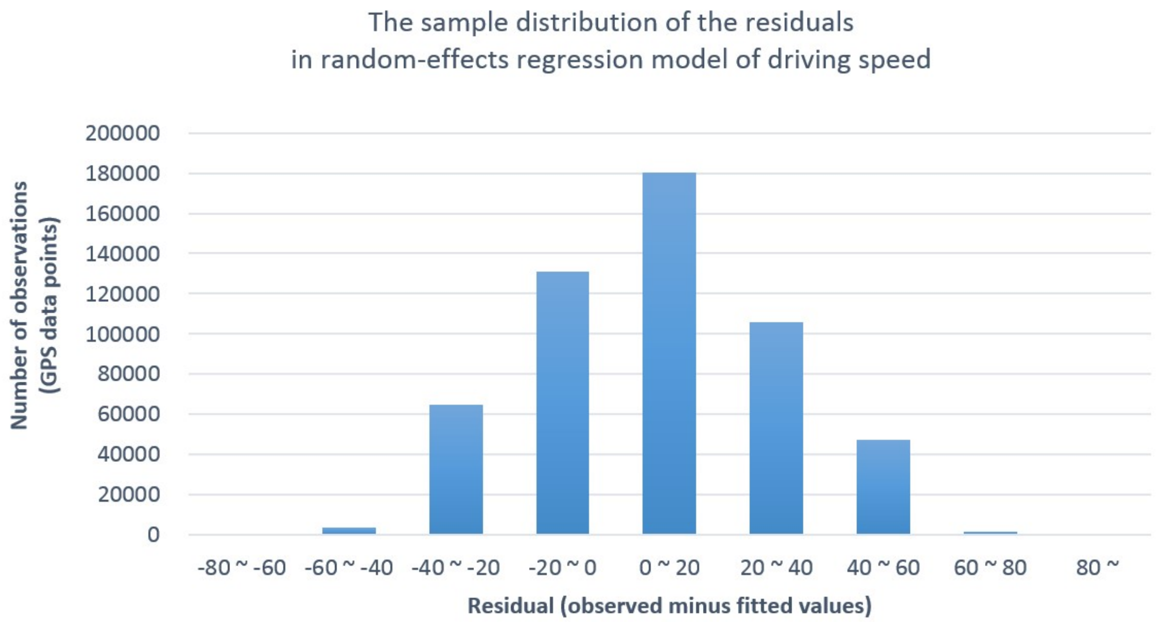

Figure 4.1. Sample distribution of the residuals.

4.5. Summary

At first, this chapter confirmed that older drivers are more reluctant to drive on expressway than other participants. This tendency exists even in long trips. Considering that driving in non-expressway with long time may cause frequently facing complex and unsafe conditions, more efforts should be carried out to promote and train expressway driving among older drivers. Moreover, further investigation is needed to determine why older drivers do not use expressways. For instance, if economic factors (e.g. expensive toll) are important, economic policies such as the adoption of discount mechanisms may also be effective.

Most questionnaire survey-based studies claimed that older drivers preferred detouring or driving straight across the intersection to turning right when driving on the left (turning left when driving on the right) for the reason of driving safety. However, this self-proclaimed inclination could not be supported by the PV data in this study. One possible reason is that the reliance on car navigation system increasingly affects their behaviors while deciding whether to avoid intersections. The results indicate that more intersection assistant system, aiming at improving the older adult's driving safety at intersections, should be developed and equipped on vehicles and roads.

Similarly, the results of driving speed are also inconsistent with older drivers' self-perception. Although most studies concluded that older drivers inclined to drive slowly, this research fails to confirm that age (60's or over) is a significant impact factor on driving speed. On the contrary, older adults drive even faster than other drivers do in 3) National road and 7) Ordinary municipal road. Because older drivers are more reluctant to drive on expressway, they might have to drive faster on some normal roads (especially national roads in long trip) if they are in a hurry. Thus, traffic control departments aiming to decrease the number of speeding-related accidents should place emphasis on older driver's driving speed. On the other hand, educating and encouraging older drivers to pay more attention to driving speed may help them to evaluate and control their speed properly. The results in this chapter are expected to help improve transportation planning and develop driver assistance systems for older drivers

Chapter 5. Driving Stress

5.1. Background

5.1.1. Driving at intersections

Many previous studies reported that physical and mental changes which often come with aging can affect older adults' traffic behaviors. Vichitvanichphong et al. (2015) summarized several papers on older's driving behaviors and identified eight groups of driving errors, which could be affected by physical, visual, and cognitive declines among older drivers. A report released by U.S. Department of Transportation (1995) claimed that elderly drivers might more often choose to use signalized intersections and avoid unsignalized intersections because of the potential danger while turning. Moreover, the complex and sometimes even dangerous condition at intersections might lead inappropriate driving behaviors. By a simulator-based research, Edwards et al. (2003) suggested that older drivers ran the yellow light under the time pressure at intersections more than younger ones. However, he also claimed that the conclusions derived from driving simulators might be limited because the prevalence of simulator sickness could affect participants' driving performance (Johnson, 2005). Zhou et al. (2015) focused on the driving behaviors at unsignalized intersections. The results showed that older drivers stopped much more frequently under the same traffic conditions. Dissanayake et al. (2002) investigated the older drivers' gap acceptance capabilities between left turn and go-through maneuvers in different day time. However, they found no significant difference among older, middle and young age groups, and thus suggested to improve the traffic control and road way design for turning and merging.

Although we knew that older drivers had problems while turning into or out of the intersections, the driving stress and its relationship with turning behaviors was still unclear. The current condition that relatively less research focuses on this topic may be caused by the difficulty to evaluate the stress and individual difference while reporting the stress. Moreover, the fact that stress, as a moral behavior, sometimes appears suddenly but sometimes increases gradually, also makes it hard to collect data and compare with behaviors. Another problem is to establish a fixed connection between stress and behaviors among different age groups (Dorn, 2008). For example, young drivers sometimes seek to reduce stress by high-speed driving, which could only escalate the stress level for older drivers (Anna et al. 2013). The similar phenomenon may also exist in turning behavior. All these difficulties may obstruct the experimental design, data collection and analysis while examining driving stress.

5.1.2. Driving on straight roads

Transportation networks generally consists of a set of nodes and links that connected two nodes (Sheffi, Y., 1985). There are mainly two scenarios for a driver on a straight roadway: 1) driving on uninterrupted straight links, or 2) proceeding straight through intersections. Compared with turning at intersections, drivers sometimes are inclined to underestimate the danger and the potential accidents that can occur while going straight because of the relatively simple driving environment and behaviors (Cooper, 1990). However, according to Malaysia official statistics (Bukit Aman Traffic Police Division, 2014), the rate of fatal and serious injuries on straight roads reached 61.4% in 2013 (accidents on straight roads: 10,721; fatalities: 4,387; serious injuries: 2,196), and the data was still growing. Japan Science and Technology Agency (JST)'s CREST program (2013) summarized the errors in thinking that could easily result in driving mistakes or even accidents on straight roads. For instance, drivers might not accurately distinguish between climbing roads and downward roads, and then accelerate or decelerate in the wrong conditions. A more dangerous scenario identified by CREST was that drivers got used to driving straight or following the preceding vehicle, but then crashed in the curve at the end of a long, straight road. Kenworthy (2015) described these roads as "killer roads" and analyzed their characteristics in different states in the US. Similarly, Hokkaido, a prefecture famous for its long, straight roads, had nearly the highest death rate from vehicle accidents in Japan. The local police office (Toyohira-syo) pointed out that 24.2% of these fatal accidents occurred without even brake marks or evidence of other avoidance behaviors.

Although our previous study analyzed the stress that can occur while turning at intersections, driving straight through intersections was analyzed in this study compared to the results of driving in straight links because we believed these two behaviors at intersections were perceived by drivers quite differently. When making a left turn or a right turn at intersections, drivers should focus on the lateral side as they turn the steering wheel. However, going straight across intersections required drivers to watch the preceding vehicles and control acceleration and deceleration. The latter was more similar to the behaviors of drivers in straight links of road, and its results was thus compared with straight links and included in this article.

5.1.3. Stress measurement and analysis

Stress can be measured by questionnaire survey, physiological data, or both. Mucci et al (2015) compared detailed information about the reliability and validity of several most commonly used questionnaire surveys and gave suggestions about how to explain or improve them. However, an inevitable fact is that the self-reported stress (SRS) provided by questionnaire is often skewed by participants' subjective effects, such as exaggeration, concealment, and bias. According to Ross et al (2012), 85.14% of older participants believed themselves as either good or excellent drivers, even with a history of traffic violation or crash. The researchers indicated that most older adults tend to overrate their driving ability and, further, suggested not to rely on older adults' self-reported data. On the other hand, experimental design sometimes influences participants' response because drivers might pay more attention to their behaviors and driving environments once they are clearly aware of the experimental process and targets (Reimer et al., 2010).

Physiological measurement, as a more objective method, is developed and applied to evaluate stress and avoid the deficiencies of SRS (CSHS, 2007). A set of physiological reactions that indicate that we are stressed will be triggered during the perception of environmental pressures or physical changes. Table 1 summarizes 16 frequently used physiological indicators and their variation characteristics while feeling stress (Miyake, 2016; Singh et al. 2013; Sharma and Gedeon, 2014; Kreibig, 2010). However, there are two features that require attention. First, it might be difficult to evaluate stress by a single indicator. In the previous study carried out by Kanamori et al. (2015), the correlation between SRS and each physiological parameter was low and insignificant (the correlation between SRS and Oxy-Hb: 0.15; deoxy-Hb: -0.10; perspiration: 0.12; Temp: 0.07; LF/HF: -0.02; RRI: 0.02; Sp02: -0.01). Second, further conclusions should not be inferred from numerical comparison among physiological indicators because they could be explained by change of direction only (increasing or decreasing) rather than by values (Miyake, 2016).

Healey and Picard (2005) proposed methods to evaluate relative stress level during several driving tasks by questionnaire, physiological data, and driving video at the same time. They asked participants to rate stress of a number of events during the rest, city road, and highway periods, and finally concluded that skin conductivity and heart rate reflected stress level better than any other physiological indicator.

Table 5.1. The physiological indicators (excerpt) and their change directions while feeling stress.

No.	Physiological indicator		Abbreviation	Change Direction While Feeling Stress
1	Skin potential	Skin Conductance Response	SCR	Increasing
2		Skin Conductance Level	SCL	Increasing
3		Skin Potential Response	SPR	Increasing
4	Cardiovascular system	Diastolic Blood Pressure	DBP	Increasing
5		Heart Rate	HR	Increasing
6		Heart Rate Variability	HRV	Decreasing
7		Low Frequency Component of HRV	LF	Increasing
8		LF/HF	LF/HF	Increasing
9		R-R Interval	RRI	Decreasing
10		Systolic Blood Pressure	SBP	Increasing
11	Cerebral vascular system	Human Oxy Hemoglobin	Oxy-Hb	Increasing
12		Human Deoxy Hemoglobin	deOxy-Hb	Decreasing
13	Respiration	Respiration Interval	RI	Decreasing
14		Respiration Rate	RR	Increasing
15		Peripheral Capillary Oxygen Saturation	SpO2	Decreasing
16	Temperature	Skin Temperature	Temp	Decreasing

5.1.4. Objectives of this chapter

In this chapter, we focused on the following three topics.

(1) To evaluate the relationship between SRS and intersection areas/straight roads, and compare it with young groups;

(2) To confirm the correlation among SRS, principal component analysis (PCA) of physiological variables, and intersection areas/straight roads;

(3) To identify the influence factors on older drivers' stress by regression models.

5.2. Data

5.2.1. Participants and experimental procedure

From Dec 2014 to Feb 2015, 6 male drivers (3 older drivers and 3 young drivers) who did not suffer from psychiatric and neurological diseases were recruited in this experiment. Older drivers were older than 60 (60, 62, and 66 years old, respectively) and living in Aichi Prefecture, Japan. Young drivers, who are students in Nagoya University, are 20 - 24 years old. The participants were represented by O1 (the 1st older participant), O2, O3, Y1 (the 1st young participant), Y2 and Y3 in this paper.

Each participant drove more than 3 times in different days, total of 23 times (O1: 5; O2:4; O3: 5; Y1: 3; Y2: 3; Y3:3) on the experimental route. It should be noted that all participants answered 38 questions about their driving frequency, habits, stress-related reflections, etc before the experiment. It shows that four participants (two were older drivers and two were younger) were driving nearly every day. The other two participants (one was older driver and the other one was younger) drove 1-2 times or less per week. Both age groups, hence, had two "high-frequency drivers" and one "low-frequency driver" respectively. Because all of the participants drove each week, we estimated that they could accept the driving frequency (3 times/experimental day, 1-2 experiments/month) in this experiment. Moreover, the experiments were also arranged to avoid rainy days and commute times. Before driving, a questionnaire about mental and physical state of the day was answered by the driver. Moreover, 5 minutes at-rest physiological data was collected before and after driving (pre-experiment and post-experiment), respectively.

5.2.2. Route, intersections, and straight roads

The experimental route which is 22.4 km length is demonstrated in Figure 1. The locations of the intersections are marked by sequential numbers which represent the sequence of crossing. The roads from the start point to the 4th intersection were in the residential area. Urban area and shopping streets located from the 4th to the 13th intersection. After the 13th intersection, participants passed through the mountain area and then finished the driving at the same place where the route started. Table 5.3 lists each intersection's details, which were used in the regression analysis as independent variables of intersection conditions.

Figure 5.1. Experimental route and the location of each intersection.

Table 5.2. The detailed information of intersections.

No.	Left/right Turn	Road Segments	Traffic Light	Number of Lanes	Turn lane	Opposite-direction Lane
1	Left	4-way intersection	None	2	None	-
2	Right	T junction	None	1	None	None
3	Right	4-way intersection	For going straight	1	None	Yes
4	Left	4-way intersection	None	4	1	-
5	Right	Straight or turn right	For going straight	4	1	None
6	Right	T junction	For turning right	2	None	None
7	Right	4-way intersection	For going straight	5	1	Yes
8	Left	4-way intersection	For going straight	1	None	-
9	Left	5-way intersection	For going straight	2	1	-
10	Left	4-way intersection	For going straight	6	1	-
11	Right	4-way intersection	For going straight and turning right	3	1	Yes

12	Left	4-way intersection	For going straight	3	1	-
13	Right	4-way intersection	For going straight	4	1	Yes
14	Right	Straight or turn right	None	1	None	Yes
15	Right	T junction	For going straight	1	None	None

The entrance and exit of each intersection were located by latitude and longitude. The travel process around or at intersections was then divided into 3 steps: 1) preparing to turn (pre-turn); 2) turning at intersections (in-turn); 3) driving straight after the turning behavior (post-turn).

(1) Pre-turn: driving in the 50 m long road segment before the entrance of intersection.

(2) In-turn: driving from the entrance to the exit of intersection.

(3) Post-turn: driving in the 50 m long road segment after the exit of intersection.

Table 5.4 lists the details of each straight road.

Table 5.3. The detailed information about the straight roads.

No.	Range (Marked by intersections*)	Road segments	Length (km)	Number of Traffic Lights**	Traffic Lights/km
1	Start → No. 1 *	General road	0.8	2	2.5
2	No. 1 → No. 3	Residential area	1.1	0	0.0
3	No. 4 → No. 5	General road	2.0	7	3.5
4	No. 5 → No. 6	General road	1.5	9	6.0
5	No. 6 → No. 7	General road	1.0	4	4.0
6	No. 7 → No. 8	Shopping street	1.0	3	3.0
7	No. 8 → No. 9	General road	1.8	8	4.4
8	No. 9 → No. 10	General road	1.5	4	2.7
9	No. 10 → No. 11	General road, Bus lane area	2.8	10	3.6
10	No. 11 → No. 12	General road	1.9	2	1.1
11	No. 12 → No. 13	General road	2.6	8	3.1
12	No. 13 → No. 15	Mountain road	3.5	3	0.9
13	No. 15 → Finish	General road	0.9	2	2.2

* Intersection serial number. See Fig.1.

** The traffic lights in the first or the last intersection of each road range are not included.

5.2.3. CAN and GPS

CAN and GPS data were collected by in-vehicle devices which were quipped in the experimental car. In this study, CAN transmitted 219 categories of vehicle data, which included speed, acceleration, brake hydraulic pressure, yaw rate, turn signal, etc. The time interval of CAN data was 0.0167s, but GPS receiver recorded position data per 1s. The synchronism and interpolation for these two kinds of data will be introduced in Section 5.2.5.

5.2.4. Self-reported stress

The self-reported stress (SRS) data was obtained by two approaches. First, a switch could be pressed by the driver and the passenger while the former started or stopped feeling stress, and the switch data was recorded into CAN data at the same time. However, because stress was frequently accompanied by the complex driving environment, drivers sometimes could not immediately report their feelings while driving. Thus, drivers were asked to confirm or report driving stress after the experiment by watching the driving videos which were taken by front, back and driver-facing in-vehicle cameras (Figure 5.2).

Moreover, as mentioned in 1.3 and 1.4, it was considered that stress should not be defined by some certain threshold among different individuals. To prevent obstruction in reporting stress, the drivers in this study were not given the strict definition of driving stress level.

Figure 5.2. Driving videos taken by front (upper left screen), back (lower left screen) and driver-facing (upper right screen) in-vehicle cameras. The driver in this frame of video was waiting for turning right across the intersection.

5.2.5. Physiological data

To avoid adding another burden to drivers, downsizing and lightening physiological measurement devices were selected in this study. As shown in Fig. 3, the sensors of Skin Temperature (Temp), Electrocardiogram (ECG), Skin Conductance (SC), and Respiration were placed on each participant's body. All physiological information was sent wirelessly to the electronics data recorder per 0.001s. In order to prevent information loss, synchronism among CAN (by 0.0167s) and GPS (by 1s) was carried out based on the time series of physiological data. Interpolation of CAN and GPS was operated at equal distance between two neighboring data.

Skin temperature reveals the human stress (Herborn et al, 2015; Vinkers, et al. 2013). The normal response to stress is peripheral vasoconstriction which decrease the skin temperature. In this study, one

Temp sensor (thermistor) was adhered on the left cheek and near the nose where skin temperature reacted more sensitively to the stress change of the participant. During post-processing, not only the invalid data but also the Temp records lower than 35 degree Celsius were deleted as error data.

ECG sensor recorded the electrocardiogram which could estimate heartbeat. The inter-beat interval (RRI) was obtained by searching peak position in each heartbeat cycle. The high frequency (HF, 0.15Hz – 0.40Hz) component of heart rate variability (HRV) reflects respiratory change and efferent vagal (parasympathetic) activity. On the other hand, the low frequency (LF, 0.05Hz – 0.15Hz) component is associated with the Mayer wave which shows the blood pressure change (Takalo et al. 1999). LF component can reflect stress in either sympathetic or parasympathetic nervous system, so it has been widely used as an evaluation indicator of human stress (Malik, 1996). Moreover, the higher ratio between LF and HF (LF/HF) also directly demonstrates the increase of stress, because LF is related with respiratory change and HF reflected the blood pressure change.

Jacobs et al (1994) concluded that skin conductance increased in response to mental stress. In this study, four skin conductance (SC) sensors were placed on participant's belly, back, calf of the left leg, and instep of the left foot, respectively. The reason for choosing left foot was that it nearly did not move while driving the experimental car which was equipped with an automatic transmission. The electromyography (EMG) data obtained by SC sensors reflected muscle potential. It was also used to find the error physiological records in the experiment. Moreover, the skin potential response (SPR) sensor on the sole of the left foot recorded participant's mental sweating data whose absolute value could reflect stress level.

According to several previous studies (Dishman, 2000; Srikandakumar et al. 2003; Zucker et al. 2009), stress could be evaluated by respiratory rate (RR). In the experiment, we used the strain sensor to draw the breath waveform, and then estimate each respiratory cycle by searching wave's peaks and valleys. However, considering RR's term (per minute), it might not reflect the stress immediately because of the hysteresis. For this reason, respiratory interval (RI) which was obtained by two adjacent breaths was applied in this study. The raising of stress level was expected to decrease RI.

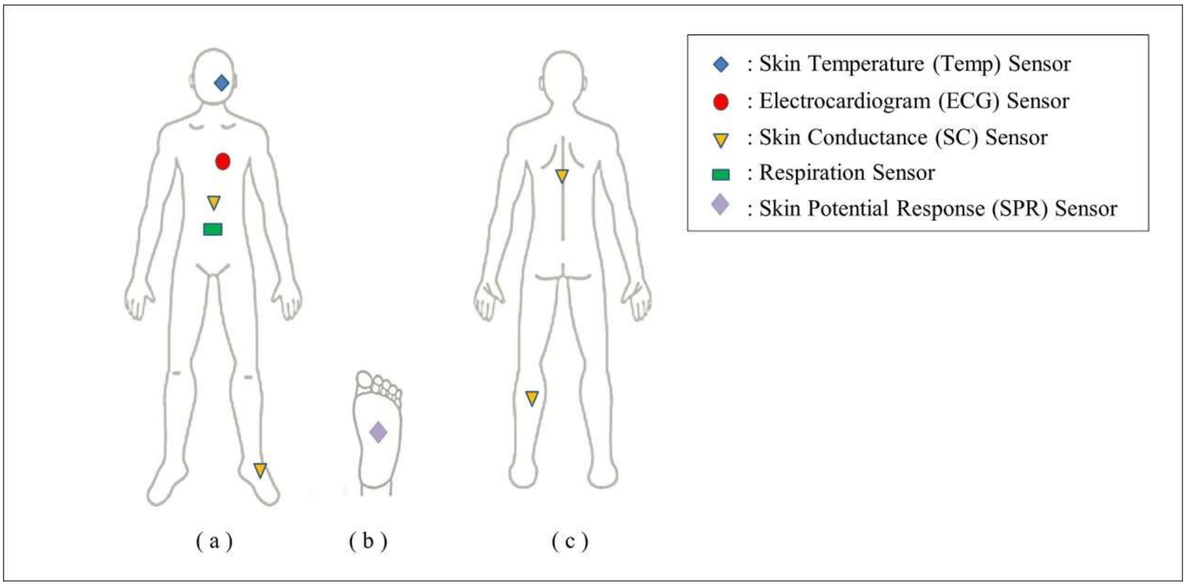

Figure 5.3. The positions of sensors on participant's body. (a) Front of the body; (b) Bottom of left foot; (c) Back of the body.

5.3. Methods

The data analysis in this chapter mainly included the following three parts.

(1) Comparing SRS between older drivers and young drivers;

(2) Analyzing the correlation between SRS and principal components (PCs) of physiological data in two age groups;

(3) Regression analysis of factors that influence driver stress on straight roads.

For the SRS at intersections, the amounts of all SRS, SRS in left turn, and SRS in right turn per trip were calculated in older group and young group, respectively. Significance analysis was operated not only among different age groups but also between left turn and right turn. The proportion of SRS per left/right turn was expected to reveal the SRS difference with aging between two turning directions. As introduced in Section 5.2.2, the turning process was divided into three steps: 1) pre-turn; 2) in-turn; and 3) post-turn. Thus, the SRS in these three processes was also compared among two age groups, respectively. It should be noted that the significance of proportions (%) was tested by Chi-Square Tests (Marascuilo Procedure). Z-test, which could also test the significance analysis of proportions, was not used in this study because it is only for two comparison subjects (UW).

In the analysis of SRS on straight roads, SRS were calculated for both the entire trip and for the straight portions of road only. Furthermore, the SRS at signalized intersections was also compared to examine the influence of signals. The "signalized intersection" was defined as an area from the starting point at 30 meters before reaching the intersection, to the actual point of the intersection.

Principal component analysis (PCA) is a technique used to bring out one or more strong combination of variables to reduce data dimensionality but still contain most information of the original dataset (Abdi and Williams, 2010). It is often used to make multidimensional data easy to explore and compare with others as a whole dataset. Before principal component (PC) calculation, physiological indicators were normalized. The process of normalization rescaled variables by the maximum and minimum of each participant's at-rest data. PC coefficients (also known as loading or component loadings) of different variables were then calculated by the normalized data. The eigenvalues which were proportional to the explained variance were obtained in each PC. Finally, we could conclude that the PCs whose eigenvectors cumulative sum was over 99% of the variance reflected the original dataset. To explore the relationships among SRS, PCs and the turning behavior at intersections, their correlations were compared between two age groups. Through this process, we could confirm whether intersections affect older drivers' physiological indicators and SRS. Moreover, the relativity between SRS area and physiological data's change could also be investigated.

In the third part of data analysis, the regression models were established to show the influence of age and driving environment (intersection, straight road, etc.) on SRS and PCs of physiological data. The interaction effects between age and other intersection-related independent variables were also analyzed. The results were expected to confirm whether age was a significant factor on SRS and PCs at intersections. Because each data set of CAN, GPS and physiology data in the same time could be considered as a single sample case, and multiple samples with unequal sizes were collected from each person, a random effects regression model was constructed to consider unobserved heterogeneity among drivers (Jaccard, 2003).

Moreover, we also compared the time of turning in pre-turn, in-turn and post-turn between two age groups. The results were expected to reflect their turning behaviors which were often affected by the environment of intersections. As mentioned in Sections 5.1.1 and 5.1.2, inadequate design of intersection could lead to dangerous turning behaviors of older drivers.

5.4. Results

5.4.1. Self-reported stress (SRS)

Table 5.4 shows the average amount of SRS per trip and proportion of SRS per left/right turn. Significant differences were identified between two age groups. Older driver tended to report stress less frequently than young participants both in the whole trip and at intersections. While comparing the proportion of SRS in different turning directions, we found that older drivers' SRS rate of right turn was nearly twice that of left turn. However, this phenomenon was not observed in the group of young drivers. It should be noted that whether SRS reflected participants' real driving stress will be analyzed in 5.4.2.

Table 5.4. The average amount of SRS per trip and proportion of SRS per left/right turn.

	Average amount of SRS per trip							Proportion of SRS per left/right turn		
	All		Left-turn		Right-turn					
	Mean	SD	Mean	SD	Mean	SD		Left-turn[1]	Right-turn	χ^2
Older drivers	8.75	2.05	0.38	0.48	1.25	0.97		6.25%	13.89%	4.76*
Young drivers	28.00	28.70	1.79	2.08	2.86	2.95		29.76%	31.75%	1.74
t-test	-1.81*		-1.80*		-1.37*		χ^2	10.10**	7.74**	

*: p<0.1

**: p<0.05

1. Proportion of SRS per left turn = the amount of SRS during left-turn / the amount of left turn × 100%. Similarly in the right turn.

Tables 5.5 and 5.6 compared two age groups' SRS of pre-turn, in-turn and post-turn in left turn and right turn, respectively. As the result in Table 5.4, older drivers reported less stress than young drivers in the whole turning process, and the difference was statistically significant. However, while comparing the proportions of SRS in pre-turn, in-turn and post-turn, significant difference was not found in each age group.

Table 5.5. Average amount of SRS in left turn per trip and proportion of SRS per left turn.

	Average amount of SRS in left turn per trip							Proportion of SRS per left turn			
	Pre-turn		In-turn		Post-turn						
	Mean	SD	Mean	SD	Mean	SD		Pre-turn[1]	In-turn	Post-turn	χ^2
Older drivers	0.13	0.33	0.38	0.48	0.38	0.48		2.08%	6.25%	6.25%	1.20
Young drivers	1.43	1.99	1.64	1.84	1.07	1.22		23.81%	27.38%	17.86%	2.19
t-test	-1.27**		-0.97**		-1.02*		χ^2	10.78**	8.62**	3.49**	

*: p<0.1

**: p<0.05

1. Proportion of SRS per left turn (pre-turn) = the amount of pre-turn SRS during left turn / the amount of left turn × 100%. Similarly in the in-turn and post-turn.

Table 5.6. Average amount of SRS in right turn per trip and proportion of SRS per right turn.

	Average amount of SRS in right-turn per trip							Proportion of SRS per right turn			
	Pre-turn		In-turn		Post-turn						
	Mean	SD	Mean	SD	Mean	SD		Pre-turn[1]	In-turn	Post-turn	χ^2
Older drivers	0.25	0.43	1.00	0.87	0.88	0.78		2.78%	11.11%	9.72%	3.96
Young drivers	2.43	2.77	2.71	2.94	2.36	2.38		26.98%	30.16%	26.19%	0.55
t-test	-2.46**		-1.67**		-2.11**		χ^2	18.05**	9.32**	7.71**	

*: p<0.1

**: p<0.05

1. Proportion of SRS per right turn (pre-turn) = the amount of pre-turn SRS during right turn / the amount of right turn × 100%. Similarly in the in-turn and post-turn.

Table 5.7 shows the means, standard deviations, and the significant test results (t-test) between two age groups of SRS area per trip. Unlike the research on SRS while turning, the characteristics of SRS on straight roads were reflected not only in amount but also in length (m). A comparison was then made on each characteristic individually. The results of the average amount of SRS per trip were in agreement with the results of turning at intersections: older drivers reported SRS significantly less than did young drivers. However, when comparing the results at signalized intersections, the difference between the two age groups was not statistically significant. On the right side of Table 5.7, the results of the SRS's average length shows that significant difference between older and young drivers did not exist, either in the entire trips or on straight roads.

Table 5.7. Means, standard deviations, and the significant test results (t-test) between two age groups of the average amount and length (m) of SRS per trip.

	Average amount of SRS per trip						Average length (m) of SRS area per trip			
	All		Straight road		Signalized intersection[1]		All		Straight road	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Older drivers	8.75	2.05	7.96	2.31	2.13	0.93	0.30	0.44	0.26	0.38
Young drivers	28.00	28.70	34.21	29.11	5.93	9.22	0.44	0.59	0.39	0.52
t-test	-1.81*		-2.57**		-1.15		-0.58		-0.62	

**: P<0.05, *: P<0.1

1. Signalized intersection: an area from the start point which was 30 meters before reaching the signalized intersection to the existence position of the intersection.

5.4.2. Principal component analysis (PCA) of physiological data

Table 5.8 provides the PC coefficient of each physiological indicator. The variance, proportion of PC, and proportion of cumulative sum of PC are also shown in the bottom three rows of Table 4. It shows that the 1st PC had the highest variance, and the first two eigenvectors (in bold) alone accounted for over 80% of the variance of the original data. The low coefficients of EMG1-4 (muscle potential) in the first two columns indicate that they contributed less to 1st and 2nd PC than did other variables, which was consistent with the analysis in the previous study (Kanamori et al., 2015).

Table 5.8. PC coefficients of different physiological variables.

Physiological variable	1st PC	2nd PC	3rd PC	4th PC	5th PC	6th PC	7th PC	8th PC	9th PC	10th PC
EMG1	-2.05E-06	6.06E-06	-1.08E-05	-1.67E-05	1.55E-05	1.79E-05	8.64E-04	9.98E-01	-4.83E-02	-3.39E-02
EMG2	7.95E-06	9.38E-06	7.07E-07	-9.17E-06	-2.66E-05	-4.60E-05	1.00E+00	-1.22E-03	-5.66E-03	-2.53E-03
EMG3	-3.81E-07	-1.10E-05	1.57E-06	1.37E-05	-1.47E-05	-9.05E-06	3.87E-03	4.46E-02	2.40E-01	9.70E-01
EMG4	3.94E-06	8.34E-06	9.55E-06	-1.34E-05	1.47E-05	1.04E-04	4.92E-03	3.87E-02	9.69E-01	-2.42E-01
RRI	1.18E-01	-1.93E-01	9.67E-01	-6.90E-02	6.97E-02	6.32E-02	4.24E-06	7.76E-06	-1.68E-05	2.71E-06
LF	1.45E-02	9.54E-01	1.78E-01	-2.34E-01	-3.86E-02	-4.70E-02	-1.45E-05	-6.01E-06	-3.77E-06	1.41E-05
LF/HF	7.98E-02	2.21E-01	9.81E-02	9.66E-01	3.40E-02	4.18E-02	8.91E-06	1.45E-05	1.65E-06	-1.15E-05
RI	-6.50E-03	3.75E-02	-5.80E-02	-3.21E-02	9.91E-01	-1.13E-01	2.06E-05	-1.42E-05	1.24E-06	1.52E-05
Temp	9.90E-01	-8.36E-03	-1.26E-01	-6.66E-02	-3.56E-03	-7.22E-03	-8.75E-06	-2.49E-07	-2.26E-06	1.92E-06
SPR	-3.71E-03	5.25E-02	-6.50E-02	-5.17E-02	1.05E-01	9.90E-01	4.69E-05	-2.48E-05	-9.85E-05	3.76E-05
Variance	5.56E-01	8.74E-02	6.05E-02	4.27E-02	2.30E-02	7.42E-03	1.18E-03	2.02E-04	1.40E-04	6.24E-05
The proportion of PC	**71.39%**	**11.22%**	7.78%	5.49%	2.96%	0.95%	0.15%	0.03%	0.02%	0.01%
The proportion of cumulative sum of PC	**71.39%**	**82.62%**	90.39%	95.89%	98.84%	99.80%	99.95%	99.97%	99.99%	100.00%

Table 5.9 and Table 5.10 show the values of 1st and 2nd PCs in the conditions of straight road, signalized intersection, and following a preceding vehicle. Table 5 shows that older drivers' 1st PC was significantly lower than young drivers in each driving condition. Because Temp contributed most to 1st PC, and the lower skin temperature reflects increasing stress level, we could conclude that older drivers were more stressed than were young drivers. It also indicates that both age groups had lower values of 1st PC when driving out of signalized intersections or without a preceding vehicle. However, while investigating the results of 2nd PC, a significant difference was not found between older and young drivers in any driving conditions.

Table 5.9. The 1st PC of physiological data (normalized) in different conditions.

	The 1st PC of physiological data (normalized) in different conditions						
	Straight road	Signalized intersection[1]			Preceding vehicle[2]		
		Yes	No	t-test	Exist	Not exist	t-test
Older drivers	0.54	0.58	0.54	5.17**	0.58	0.54	8.38**
Young drivers	0.61	0.63	0.61	2.35*	0.61	0.62	-3.64**
t-test	-48.30**	-3.68**	-48.18**		-7.40**	-47.60**	

*: P<0.05, **: P<0.01

1. Signalized intersection: an area from the starting point, which was 30 meters before reaching the signalized intersection to the actual point of the intersection.

2. Preceding vehicle: a vehicle exists in front of the experimental vehicle, and the distance between the two vehicles is shorter than the safety distance (= speed of experimental car × 2 seconds).

Table 5.10. The 2nd PC of physiological data (normalized) in different conditions.

	The 2nd PC of physiological data (normalized) in different conditions						
	Straight road	Signalized intersection[1]			Preceding vehicle[2]		
		Yes	No	t-test	Exist	Not exist	t-test
Older drivers	0.40	0.39	0.38	1.88	0.41	0.38	1.45
Young drivers	0.39	0.40	0.40	1.63	0.39	0.39	0.80
t-test	1.26	-0.07	-1.38		1.62	-1.03	

*: P<0.05, **: P<0.01

1. Signalized intersection: an area from the starting point, which was 30 meters before reaching the signalized intersection to the actual point of the intersection.
2. Preceding vehicle: a vehicle exists in front of the experimental vehicle, and the distance between the two vehicles is shorter than the safety distance (= speed of experimental car × 2 seconds).

5.4.3. Comparison between SRS and PCs of physiological data

Table 5.11 shows the correlations among PC (1st, 2nd and 3rd), SRS and turning at intersections (1: turning right/left, 0: otherwise). It demonstrated that the 1st/2nd PC, SRS and turning behaviors were correlated with each other in older drivers group. However, the correlations were not significant in young drivers group. The significant correlations are in bold with asterisk.

Table 5.11. The correlations among PC (1st, 2nd and 3rd), SRS and turning at intersections.

Age	Participant	The correlation among PC (1st, 2nd and 3rd), SRS and turning at intersections						
		1st PC and SRS	1st PC and Intersection	2nd PC and SRS	2nd PC and Intersection	3rd PC and SRS	3rd PC and Intersection	SRS and Intersection
Old	O1	**-0.45***	**-0.43***	**-0.44***	-0.34	0.37	0.18	**0.74****
	O2	**-0.46***	-0.38	**-0.57***	**-0.67***	0.30	0.14	**0.78****
	O3	-0.29	**-0.48***	-0.39	-0.27	0.20	0.20	**0.62***
	Mean	**-0.40***	**-0.43***	**-0.47***	**-0.43***	0.29	0.17	**0.71****
Young	Y1	-0.12	-0.34	-0.12	-0.15	0.25	0.24	0.24
	Y2	**-0.44***	-0.27	-0.10	0.07	0.13	0.08	0.15
	Y3	0.06	0.23	-0.02	0.14	0.02	-0.03	0.01
	Mean	-0.17	-0.13	-0.08	0.02	0.13	0.10	0.13

**: High correlation (|Corr| = 0.70 to 1.00)
*: Moderate correlation (|Corr| = 0.40 to 0.70)
Others: low or no correlation (|Corr| = 0.00 to 0.40)

Table 5.12 shows the correlations between SRS and the 1st PC. Moderate correlation (|Corr| = 0.40-0.70) existed while young participants were driving in the signalized intersection or following a preceding vehicle. However, correlation was low or not observed among older participants in the experiment. Moreover, Table 5.13 indicates that there was low or no correlation between SRS and the 2nd PC.

Table 5.12. The correlations between SRS and 1st PC in different conditions.

	The correlation between SRS and the 1st PC				
	Straight road	Signalized intersection		Preceding vehicle	
		Yes	No	Exist	Not exist
Older drivers	-0.14	-0.24	-0.14	-0.35	-0.11
Young drivers	-0.28	**-0.48***	-0.27	**-0.45***	-0.24

**: High correlation (|Corr| = 0.70 to 1.00)

*: Moderate correlation (|Corr| = 0.40 to 0.70)

Others: low or no correlation (|Corr| = 0.00 to 0.40)

Table 5.13. The correlations between SRS and 2nd PC in different conditions.

	The correlation between SRS and the 2nd PC				
	Straight road	Signalized intersection		Preceding vehicle	
		Yes	No	Exist	Not exist
Older drivers	-0.02	-0.03	-0.02	-0.03	-0.02
Young drivers	0.00	-0.01	0.00	0.00	0.00

**: High correlation (|Corr| = 0.70 to 1.00)

*: Moderate correlation (|Corr| = 0.40 to 0.70)

Others: low or no correlation (|Corr| = 0.00 to 0.40)

5.4.4. Regression analysis

The random effects regression models of SRS, 1st PC, 2nd PC and 3rd PC are established (Table 5.14: at intersections; Table 5.15: on straight roads). If an independent variable significantly affected the research object, its value would be in bold. The number of observations (151,317,529) means the number of experimental records in terms of physiological data (0.001s). Data groups were divided by participants considering the data correlation among different trips of the same driver.

Table 5.14. The random effects regression models of SRS, 1st PC, 2nd PC and 3rd PC at intersection.

Independent variable	Description	Possible values	Self-report stress		1st PC		2nd PC		3rd PC	
			Estimate (β)	tStat	Estimate (β)	tStat	Estimate (β)	tStat	Estimate (β)	tStat
β_0			6.20E-03	1.23	1.43E-01	53.78**	8.54E-02	7.65**	1.86E-01	9.63**
X1	Age	*1. Old, 0. Young*	**-1.90E-02**	**-1.35***	**-1.95E-02**	**-3.16****	**1.46E-02**	**48.52***	1.89E-02	0.64
X2	Intersection direction	*1. Left-turn, 0. Right-turn*	**-8.26E-04**	**-8.36****	**1.35E-02**	**157.22****	**5.20E-03**	**89.11****	**1.56E-02**	**141.35****
X3	Traffic light for turning	*1. Has, 0. None*	**-6.80E-03**	**-52.79****	**4.28E-03**	**69.23****	**-6.37E-03**	**-85.33****	**-1.43E-02**	**-125.14****
X4	Number of lanes	*1. Two or more, 0. One*	**6.30E-03**	**46.27****	**-3.50E-02**	**-116.34****	**2.31E-02**	**212.74****	**1.14E-02**	**219.28****
X5	Turn lane	*1. Has, 0. None*	**-4.80E-03**	**-23.59****	**7.45E-02**	**95.25****	**-6.60E-03**	**-68.46****	**-2.89E-01**	**-537.22****
X6	Opposite-direction lane	*1. Has, 0. None*	**1.26E-02**	**87.00****	**-5.63E-02**	**-6.34****	**8.23E-02**	**634.62****	**-3.49E-02**	**-639.45****
Interaction effects between age and other independent variables										
X7	X1 × X2	*1. Yes, 0. No*	**-6.30E-03**	**-21.50****	**-8.90E-03**	**56.19****	**-2.50E-02**	**-135.19****	**-2.13E-02**	**-162.08****
X8	X1 × X3	*1. Yes, 1. No*	**-1.94E-02**	**-82.00***	**-6.85E-03**	**-68.46****	**6.80E-03**	**56.48****	**3.12E-02**	**205.99****
X9	X1 × X4	*1. Yes, 2. No*	**2.39E-02**	**87.11***	**5.26E-02**	**56.49****	**-1.18E-02**	**-75.16****	**-6.53E-02**	**-196.24****
X10	X1 × X5	*1. Yes, 3. No*	**-1.59E-02**	**-53.69***	**-6.54E-02**	**-79.12***	**6.94E-03**	**52.09****	**2.47E-02**	**106.33****
X11	X1 × X6	*1. Yes, 4. No*	**5.90E-03**	**31.67****	**-4.60E-03**	**-10.99****	**-2.64E-02**	**-189.14****	**-6.38E-02**	**-226.39****
Number of observations			151,317,529		151,317,529		151,317,529		151,317,529	
Number of groups			6		6		6		6	
Log likelihood			1.30E+07		1.65E+07		2.57E+07		1.56E+07	
R^2 (Adjusted R^2)			0.33 (0.33)		0.62 (0.62)		0.98(0.98)		0.92(0.92)	

*p < 0.05

**p < 0.01

Table 5.15. The random effects regression models of SRS, 1st PC, and 2nd PC on straight roads.

Independent variable	Description	Possible values	Self-report stress		1st PC		2nd PC	
			Estimate (β)	tStat	Estimate (β)	tStat	Estimate (β)	tStat
β_0			**0.0109**	**19.7183****	**0.6820**	**612.2872****	**0.3996**	**5692.2000****
X1	Age	*1. Old, 0. Young*	**-0.0049**	**-4.9293****	**-0.2425**	**-122.8063****	**0.0015**	**11.9062****
X2	Signalized intersection	*1. Yes, 0. No*	0.0038	0.8468	**0.0173**	**4.8044****	0.0002	0.2962
X3	Preceding vehicle	*1. Exist, 0. None*	-0.0145	-0.4127	0.0668	0.9515	0.0002	0.0389
X4	Vehicle speed	*0. Minimum, 1. Maximum*	**0.0342**	**19.1720****	**0.0116**	**3.2301****	**0.0020**	**8.8595****
Interaction effects between age and other independent variables								
X5	X1 × X2	-	-0.0016	-0.2029	**-0.2266**	**-2.1045****	-0.0005	-0.5274
X6	X1 × X3	-	0.0027	0.0441	**-0.3036**	**-2.4949***	-0.0014	-0.1889
X7	X1 × X4	-	**-0.0118**	**-3.7100****	**0.2409**	**37.7248****	**-0.0013**	**-3.2890****
Number of observations			151,317,529		151,317,529		151,317,529	
Number of groups			6		6		6	
Log likelihood			7.37E+04		-6.10E+02		2.95E+05	
R^2 (Adjusted R^2)			0.0050(0.0049)		0.1429(0.1429)		0.0022(0.0021)	

*p < 0.05.

**p < 0.01.

5.4.5. Turning time at intersections

Table 5.16 compares turning time of pre-turn, in-turn and post-turn between two age groups. The results show that there is no significant difference in the time of the turning process. The t-test revealed that older drivers turned as fast as young drivers in the whole turning process.

Table 5.16. The comparison of turning time between older and young drivers.

		mean (SD)		
		Pre-turn	In-turn	Post-turn
Left-turn	Older drivers	32.85 (34.79)	20.79 (29.01)	6.96 (3.78)
	Young drivers	34.68 (35.25)	19.65 (27.84)	6.99 (4.85)
	t-test (p-value)	0.29 (0.77)	-0.22 (0.82)	0.04 (0.97)
Right-turn	Older drivers	22.68 (24.04)	27.38 (31.46)	13.11 (14.95)
	Young drivers	22.63 (26.04)	25.10 (30.67)	12.80 (15.16)
	t-test (p-value)	-0.01 (0.99)	-0.50 (0.62)	-0.14 (0.89)

5.4.6. Driving speed

Table 5.17 compares driving speed (km/h) between two older drivers and young drivers. First, the results show that there was no significant difference between the two age groups, no matter whether they were driving in the SRS area or not. The t-test shows that young drivers drove significantly faster in the SRS area than out of the SRS area, but the phenomenon did not exist in older drivers. Second, the effect of a preceding vehicle on driving speed was investigated in each age group. Similar to the results of SRS area, statistical significance was not found between older and young drivers with or without a preceding vehicle. Moreover, young drivers drove faster when following a vehicle than without a preceding vehicle. However, the existence of a preceding vehicle did not significantly influence the driving speed of older drivers.

Table 5.17. Comparison of driving speed (km/h).

	SRS area					Preceding vehicle				
	Yes		No			Exist		Not exist		
	Mean	SD	Mean	SD	t-test	Mean	SD	Mean	SD	t-test
Older drivers	16.38	7.78	13.75	0.90	0.95	18.84	4.04	13.38	4.31	0.72

Young drivers	18.18	6.03	13.46	1.37	2.86**	17.62	1.52	13.40	4.33	2.26**
t-test	0.61		0.53			0.41		-0.19		

**: P<0.05, *: P<0.1

5.5. Discussion

5.5.1. SRS and PCA of physiological data at intersections

Through the experimental driving which was 22.4 km long and more than three times per participant, SRS and physiological data at intersections was collected. By comparing the SRS of older drivers and young drivers, we found that the former reported significantly less (< 1/3) than the latter. This phenomenon existed not only at intersections (both left turn and right turn) but also in the whole experiment. The turning process was then divided into 3 steps: pre-turn, in-turn and post-turn. The SRS in each process also showed that older drivers claimed less stress than young drivers both at left turn and right turn intersections. It seemed consistent with Ross and Dodson (2012) who cautioned that older drivers tended to overate their driving abilities and underestimate the personal and environmental risks while driving. However, we could not easily reach the conclusion because there were two possible explanations: 1) older drivers was apt to underrate the driving risk at intersections and ignore their stress; or 2) young drivers were hypersensitive to the driving environment, so they reported too much driving stress. We thus compared the proportions of SRS between left turn and right turn in each age group, respectively. The proportions revealed that older drivers' SRS in the right turn was twice as much as that in the left turn, but young drivers reported nearly equally much SRS in both turning directions. In Japan where people drives on the left, turning right at intersection are dangerous because drivers have to wait at the center of the intersection for traffic to clear and head-on collisions may happen easily. Therefore, older drivers' SRS proportions in left turn and right turn could be explained as their automatic response to the more complex environment of right turn intersections. However, the SRS proportions of young drivers did not reflect the difference between the reactions of two turning directions. The result of SRS tended to support the second hypothesis that young drivers were overly sensitive to the driving environments, and hence reported much more stress than older drivers not only at intersections but also in the whole driving. Since SRS could be viewed as a kind of real time survey-based data that is difficult to avoid participant's subjective effects, such as exaggeration, concealment, and bias (McDonald, 2008), further validation study was carried out by physiological data.

Ten physiological variables (EMG in four positions on the body, RRI, LF, LF/HF, RI, Temp, and SPR) were evaluated in this study. To reduce dimension but retain most information of original data simultaneously, PCA was used in the analysis of physiological data. Through the proportion of cumulative sum of PCs, we concluded that the first three PCs which accounted for over 60% of the variance could reflect the physiological data. It should be noted that skin temperature and ECG (Heart-related) data had the highest values in PC1 and PC2, respectively. So, we can conclude that skin temperature and heart rate are two most accurate reflections of bio-data. The correlations were then calculated among SRS, PCs of physiological data and interaction area in two age groups, respectively. The results suggested that correlation existed among older drivers' SRS, 1st and 2nd PCs, and intersections. Moreover, their SRS were also confirmed to be related to turning at intersections. On the other hand, the correlation was not significant in young age group. The findings of this part supported two assumptions. First, it proved that SRS was significantly affected by intersections only in the group of older drivers. The previous results about the SRS could thus be explained as that older drivers reported their stress at intersections more objectively than young drivers, and the latter might overrate their stress in the experiment. Secondly, the similarity between SRS and PCs confirmed the approach to evaluate SRS by PCA. A similar method was proposed by Miyake (2016). Only 1st and 2nd PCs were focused on by the researcher, but the evaluation objects were the whole driver's states which included negative (anger, anxiety, embarrassment, etc.) and positive (amusement, contentment, happiness, etc.) emotions. In his study, the measurement system was so complex that the practicability of this method had not been proved. Based on the measurement methods and results of our study, further research could be carried out on the evaluation or estimation of other driving emotions by PCA of physiological data.

The regression models were constructed to identify the impact factors on SRS and 1st to 3rd PCs at intersections. The results demonstrated that drivers' age significantly affected their SRS, 1st PC, and 2nd PC even considering the variables of intersection environment such as traffic light, number of lanes, and with or without turn lane. The significant effect of age on SRS might be caused by the over-reported stress of young drivers as mentioned in the results of SRS. But the results of the regression models of PCs confirmed the influence of age on the psychological changes at intersections. It was also consistent with the previous results about PCA in this study. Moreover, it should be noted that all intersection-related independent variables significantly influenced drivers' stress. It supported several previous studies (Onelcin and Alver, 2015; Sato and Akamatsu, 2007; Oxley et al., 2006) which claimed that some inappropriate design of interaction might lead dangerous turning behaviors or even incidents significantly.

Following the study of SRS and PCA of physiological data, we further investigated whether stress affected turning behaviors which might be affected by stress. The time of pre-turn, in-turn, and post-turn was selected to reflect the speed in the turning process. However, the results revealed that older drivers drove as fast as young drivers at intersections. We could estimate that stress at intersections might result in the following two possible driving patterns. One scenario was that drivers decided to decelerate in order to drive more safely once felt stress. The other possibility was that stress of the drivers and the cars behind them interfered their driving behaviors and push them to drive faster. The situation of older drivers in this study might have belonged to the latter situation. Onelcin and Alver (2015) claimed that the design of intersections could affect drivers' driving characteristics such as gap acceptance. On the other hand, Hamaoka et al (2005) warned that the acceleration caused by stress might further aggravate the stress conversely. Since the stress and not low speed of older drivers at or near intersections have been identified, we can estimate that the positive feedback chain (stress – acceleration – stress) sometimes would be fatal to them while driving. The findings suggest us to provide turning assistant for older drivers just as increasing car manufacturers are doing. The system helps to optimize the driving behaviors when it determines the driver is about to turn at an intersection. For older drivers, it is expected to decrease driving stress and improve turning process. On the other hand, the safety at intersections also relies on the policy maker and transportation planner who plan and design the intersection and transportation system.

5.5.2. SRS and PCA of physiological data on straight roads

In the study about driving stress while turning at intersections (Section 5.5.1), we found that older drivers evaluated their stress more objectively than did young drivers, and the latter tended to overrate driving stress while turning. However, whether the same conclusions could be drawn on the straight roads was still unclear. The present study therefore focused on four purposes: 1) to evaluate the relationship between SRS and straight road, and compare it between older and young groups; 2) to simplify physiological data by PCA and confirm the correlation between SRS and PCs of physiological variables on straight roads; 3) to identify the factors that influence driving stress on straight road by regression analysis; 4) to examine whether the stress affected older drivers' behaviors, which was reflected by driving speed.

First, the SRS of older drivers was nearly one-fourth of that of young drivers, not only on straight roads but also over the entire trips. Considering the possible bias and exaggeration in the self-reported study, the results, which were consistent with the findings of turning at intersections, could be explained by two possible explanations. One explanation was that older drivers were overconfident on driving abilities and underrate their stress, as Ross and Dodson (2012) claimed. The other possibility was that young drivers were hypersensitive to the driving environment and therefore reported too much driving stress. Which hypothesis reflected the reality in the experiments will be examined with the PCA of physiological data. Moreover, the SRS in the signalized intersection was also compared between older and young drivers. However, the result showed that no significant difference was made by entering the signalized intersection. It could be deduced that its driving environment (e.g., relatively low speed, possibly following a preceding vehicle, and traffic light) relieved the stress or reduced the willingness to report stress. On the other hand, while surveying the length of SRS per trip, we found that the two age groups reported stress with nearly the same overall length. Thus, we can generalize from the results of SRS that older drivers were inclined to report less stress, but each stress area lasted for a relatively longer distance. The result might accurately reflect the stress in the experiments, or be caused by the reason that older drivers reported the end of stress slowly. Further validation studies based on physiological data should be performed.

To simultaneously reduce dimension but retain most of the original data, PCA was used in the analysis of physiological data, which included 10 physiological variables (EMG in four positions on the body, RRI, LF, LF/HF, RI, temp, and SPR). Because the first two eigenvectors alone accounted for over 80% of the variance of the whole dataset, we investigated the 1st and 2nd PCs in this study, as they represented a majority of physiological data. Moreover, because temp and LF contributed most to 1st and 2nd PCs, respectively, we could deduce that a decreasing 1st PC might illustrate an increasing stress level, and the 2nd PC was opposite. The lower value of the 1st PC demonstrated that older drivers might be driving with a higher stress level. It contradicted the stress records from the self-reports of the drivers. Moreover, differing from the results of turning at intersections, which was that older drivers had higher correlation value between SRS and PCs of physiological data than young drivers, the correlation was not found on straight roads among older drivers. We could, thus, conclude that older drivers might rate their driving stress objectively only when turning at intersections, and underrate it during the rest of the trip. On the other hand, older driver had higher 1st PC value (lower stress level) when entering the signalized intersection and when following a preceding vehicle. Another noticeable phenomenon was that a preceding vehicle led opposite-changing directions of stress level. For older drivers, the fact that following another vehicle reduced stress might be because a preceding vehicle could help to control driving speed, detect the path, and prevent road risks. But the preceding vehicle might be viewed by young drivers as an obstacle. Unlike the 1st PC of physiological data, meaningful conclusions could not be drawn by the 2nd PC. Considering that the 2nd PC contributed less to the variance of the original data (1st PC: 71.39%; 2nd PC: 11.22%), it may not represent the physiological data as well as the 1st PC.

Third, the results of random effects regression models confirmed that age was a significant impact factor on SRS and physiological data. The coefficients also supported the previous results about SRS and PCA in this study: that older drivers were inclined to report less SRS but had lower 1st PC value of physiological indicators (increasing stress level). In the study of Siren and Meng (2013), the majority of older drivers assessed their driving abilities as unchanged, improved, or even at a higher level than others. However, the present study proved that older drivers might be overconfident in their driving skills and ignore stress when driving on straight roads.

Moreover, the variable of vehicle speed was also identified as an influence factor that significantly affected each dependent variable. Thus, the driving speed was also investigated as an important indicator that reflected participants' driving behaviors. However, since no difference was found between the two age groups, it could be deduced that older participants have to accelerate or decelerate to follow the traffic flow, even with the driving stress. In the first section of this article, the relationship between stress and accidents was introduced. On the other hand, driving speed is also an important factor in road safety, since most accidents are related to speed (Aarts and Schagen, 2006; Lajunen and Summala, 1997). Therefore, more attention should be paid to the speed of older drivers.

The result that older drivers overrate their driving abilities is consistent with previous studies (Ross et al. 2012). Moreover, we know that physical and mental changes with aging can negatively affect older adults' behaviors. For example, they have difficulties on turning and speed control exist among older drivers (NIH, US.). Therefore, the findings suggest to us to provide a driving assistant, such as a speed assistant system or automatic tracking system, for older drivers. Meanwhile, further education and training about driving stress and behaviors should be given to older drivers, so that they can understand their driving characteristics and evaluate stress more objectively.

5.6. Summary

Through the controller area network (CAN), self-reported stress (SRS), and physiological data collected in more than three 22.4-km-long trips per participant from older and young age groups, older male drivers' stress while driving in straight links and while proceeding through intersections is investigated. First, this study finds that older drivers reported much less stress than did young drivers. However, principal components (PCs) of the physiological data demonstrate that older drivers might underrate their driving stress in entire trips, except regarding turning at intersections. Moreover, following other vehicles reduced older drivers' driving stress because preceding vehicles might help them control driving speed, detect the path, and prevent road risks. In contrast, the similar condition increased the stress level of young drivers. The results are summarized in Table 5.18 and Table 5.19. It demonstrates that while evaluating older driver's stress, SRS is reliable at intersections. But PC1 and PC2 of bio-data should be used on straight roads because older drivers tend to report less stress. For young driver, their SRS is reliable at straight roads' signalized intersections or following other vehicles. On the other hand, PC1 of bio-data could be used while following other vehicles.

Table 5.18. Evaluation reliable of SRS, PC1 and PC2 of physiological data on older drivers' stress.

Evaluation objects →	SRS	Stress			
		Intersection	Straight road		
			Whole	Signalized intersection	Preceding vehicle
SRS	-	○	×	×	×
PC1	○	○	○	○	○
PC2	○	○	○	○	○

Table 5.19. Evaluation reliable of SRS, PC1 and PC2 of physiological data on young drivers' stress

Evaluation objects →	SRS	Stress			
		Intersection	Straight road		
			Whole	Signalized intersection	Preceding vehicle
SRS	-	×	×	○	○
PC1	×	×	×	×	○
PC2	×	×	×	×	×

The results of random effects regression models confirm that age was the significant impact factor on SRS and physiological data. While examining whether the stress at intersections could affect their driving behaviors, no significant difference was found between two age groups' turning time. It suggests that we should provide more turning assistance system and improve the intersection design for older drivers. On the other hand, no difference was found in the driving speed between the two age groups. Considering the relationships among stress, speed, and accidents, we suggest the provision of more driver assistance systems, training, and education for older drivers.

Chapter 6. Conclusions and Future Works

6.1. Conclusions

As listed in Section 1.2, there were mainly four objectives in this thesis.

(1) To evaluate the older adult’s travel patterns;

(2) To evaluate the older adult’s driving behaviors;

(3) To examine the stress of older drivers while turning at intersections and driving on straight roads, respectively;

(4) To establish regression models to confirm the results above and identify the influence factors on older adults’ travel patterns, driving behaviors, and driving stress.

First, we examined older driver's travel patterns which include trip frequency, trip length, destination distribution and non-home-based (NHB) trips. A two-month experiment of 108 participants was carried out to collect GPS tracking data in Aichi Prefecture, Japan. Since apparently contradictory statements were often drawn in survey-based or simulators-based research, this study collects not only drivers’ basic information but also GPS data. To identify the effect of living area, comparative analysis between older drivers and others was conducted in densely inhabited district (DID, i.e. urban) and other areas (non-DID, i.e. suburban, rural), separately. The present study found that there was no significant difference between the trip characteristics of older drivers and others who were living in DID. Thus, we suggest that the education of safety driving and the recommendation of public transportation should be given to DID-living older drivers. However, the results of non-DID reflected that older drivers' trip frequency, trip length, destination and NHB trips rate were shorter and lower than others'. This implies that electric vehicles (EVs) may be suitable for promotion among older drivers in suburban and rural area.

Second, this paper examined older adult’s driving behaviors which includes road selection, left/right turn and driving speed. Analysis of road selection demonstrates that older drivers are reluctant to drive on expressway not only in short trips but also in long trips. The present study did not find significant difference between older drivers and others while turning at the intersections. To investigate the impact factors on driving speed, a random-effects regression model is constructed with explanatory variables including age, gender, road types and the interaction terms between age and road types. Compared with other variables, age (60’s or over) in this model fails to prove its significant impact on driving speed. Moreover, the results reflect that older drivers drove even faster than others at particular road types: national road and ordinary municipal road. The results in this study are expected to help improve transportation planning and develop driver assistance systems for older drivers.

In the fifth chapter, older drivers' stress is investigated not only by self-reported data but also by physiological indicators. The analyses were conducted on the conditions of intersections and straight roads, respectively. At first, the results suggest that older drivers reported much less stress than young drivers not only at intersections but also on the straight roads. It seems to support some previous studies which claimed that older drivers tended to overestimate their driving abilities. However, principal components (PCs) of the physiological data demonstrate that older drivers might underrate their driving stress in entire trips, except regarding turning at intersections. While examining whether the stress at intersections could affect their driving behaviors, no significant difference was found between two age groups' turning time. It suggests that we should provide more turning assistance system and improve the intersection design for older drivers. Meanwhile, no difference was found in the driving speed between the two age groups. Considering the relationships among stress, speed, and accidents, we suggest the provision of more driver assistance systems, training, and education for older drivers.

Regression models of travel patterns, driving behaviors, and driving stress were established in the previous three chapters, respectively. The regression analyses confirmed that age had significant influence on these dependent factors.

Therefore, the results of hypotheses raised before this study (Section 1.2) could be summarized as follows.

1) Older drivers might have more driving or trip characteristics that are risky.

Result: Partially correct. Older drivers did not drive less or more slowly than others. Considering that physical and mental changes with aging can negatively affect older adults' behaviors, we could conclude that older drivers' characteristics are risky.

2) Older adults might often underrate their driving stress.

Result: Correct. The previous conclusions that driving stress were stable across age might be caused by older adults' undervaluation on their stress.

3) "Older" might significantly affect travel patterns, driving behaviors, and driving stress.

Result: Correct. Age was significant variable in regression models of travel patterns, driving behaviors, and driving stress.

6.2. Future works

The main limitations of this study were its small sample size (travel patterns and driving behaviors: number of older drivers = 10; driving stress: number of older drivers = 3) and limited geographic coverage (Aichi Prefecture, Japan). Therefore, caution should be exercised when extrapolating the results to a general population or a wide area.

Further research is planned to recruit a larger representative sample, which will include more older and young drivers that are male and female. The experimental trips will also be conducted in wider areas and more complex traffic environments.

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