International Journal of Industrial Ergonomics 54 (2016) 32–41

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Approaching and stopping behaviors to the intersections of aged drivers compared with young drivers

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ARTICLE INFO

Article history:
Received 21 January 2013
Received in revised form
10 December 2015
Accepted 24 December 2015
Available online xxx

Keywords:
Aged driver
Driving performance
Intersections

ABSTRACT

According to the many reports of the traffic accidents, the number of the accidents near the intersections was increased in the cases of the aged drivers. The purpose of the research was to measure the sensitivity of elder drivers through behavioral responses in approaching and stopping to the intersections and to obtain the difference of the responses for braking and stopping comparing with young drivers. In the field tests of real running on experimental proving ground, elder and young drivers were observed their driving behaviors in various conditions of approaching and stopping at intersections. Comparing the results of the elder with the young, the unstable driving behaviors were examined in elderly and they were apt to run fast in approaching the intersection and also stopping rapidly. The rates of deceleration change (Jerk) with braking operation were unstable and the driving behaviors were affected by the environments or conditions of the intersection. These driving performances should be interfered with the traffic flow and exposed to the risk of accidents. If the features of these aged driver's behaviors were clarified better, the more effective driving assistant systems for elderly could be developed based on characteristics of elderly driver's driving performances and their physical and psychological features of driving.

1. Introduction

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

According to a report of Japan Metropolitan Police Department in 2014-1st half, traffic accidents occurred at intersection (28.0%) and at near intersections (24.1%) as shown in Fig. 1. Hence, regarding the types of traffic accidents occurred elderly drivers, the face to face accidents was 480 cases in total of 916 cases as shown in Fig. 2.

Past researchers examined the effects of attention failures at intersections on driving behaviors. Failures of drawing attention may result from the improper distribution of attention, difficulties of visual recognitions, and/or inappropriate selective attention. Therefore, if the visual ability of a driver is deteriorated and damaged (Hickson et al., 2010; Dukic and Broberg, 2014), he or she has to select the limited driving behavior or give up the driving (Marie Dit Asse et al., 2014). Considering these aspects, the behaviors of elderly drivers pertains to the important variable in driving behavior. When they selected an inappropriate timing on driving behaviors compared to younger drivers, they cause traffic accidents. Many studies reported that the physical ability of elderly drivers deteriorates, because of the limitation of visual function related aging influenced on driving behavior (Kazuya et al., 2010). Therefore, elderly drivers, who make wrong decisions in terms of braking timings (Lucidi et al., 2014) or the force putting a brake pedal due to severe deteriorations by ageing, cause traffic accidents (Green et al., 2013; Keay et al., 2013).

2. Experimental methods

In this study, the driving characteristics of elderly drivers during approaching and stopping to the intersections were investigated through field tests. The characteristics of driving performances between young drivers and elderly drivers were compared. A flow

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http://dx.doi.org/10.1016/j.ergon.2015.12.002
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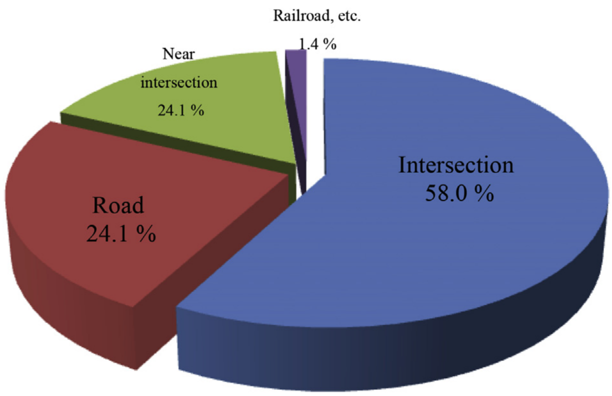

Fig. 1. The traffic accidents in 2014-1st half in termd of road types.

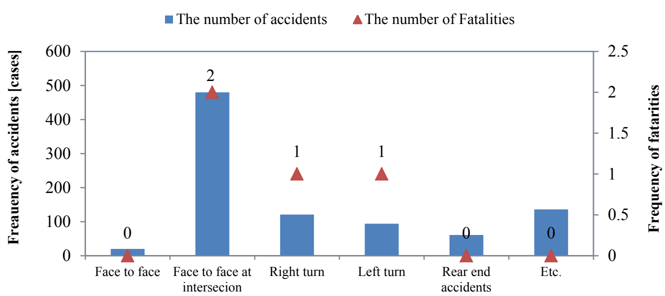

Fig. 2. The traffic accidents occurred by elderly drivers in 2014-1st half in termd of road types.

of the driving experiment is shown in Fig. 3.

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

2.1. The experimental apparatus and the design of experimental intersections

2.1.1. Subjects of the experiment and selection of elderly drivers

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

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

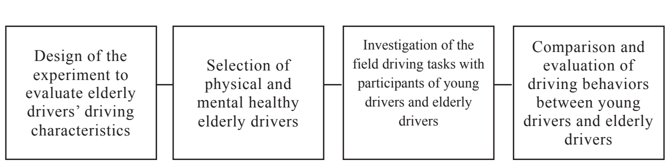

Fig. 3. Experiment process model to evaluate elderly drivers' driving characteristics at intersections.

2.1.2. Experimental vehicle

A car was used at the driving tasks. In this car, a GPS sensor, an optoelectronic switch, four cameras and computer devices were installed. The GPS sensor obtained data regarding the lateral and longitudinal velocity and the position of the car. The optoelectronic switch detected braking operations, and four cameras recorded a forward driving scene, a speed meter scene, a driver's facial scene and a brake pedal behavior scene as shown in Fig. 4. All these data was stored into a personal computer on the car.

2.1.3. Design of intersections and the experimental conditions

The experimental driving was conducted at a driver's license training ground with 230 m $\times$ 130 m in Kagawa prefecture of Japan as shown in Fig. 5.

Three intersections without traffic lights were selected, and separately designated as the intersection A, B and C. In order to set various intersection environments, stop signs, blind corners, rubber stop lines were set. Cameras and graduated rulers to measure stop were used as shown in Fig. 6.

Moreover, for evaluating the effect of environment of intersections on braking behaviors, six conditions using various features of stop signs and blind fences were designed as shown in Fig. 7. An ordinary stop sign and enhanced stop sign which has flashing red LED lamp were selected.

2.1.4. Experimental scenario

After participants rode on the experimental vehicle, the operator in the back seat briefly explained a role of the whole experiment. Then, they had a short driving to learn a sense on the road for 5 min, and returned to the starting point to begin this experiment. The experiments were made of the primary and secondary experiment, and each experiment passed all intersection A, B and C, each trial was carried out twice in 20 min. Numbers of passes of the intersection with the respective conditions are shown as follows in Table 1.

2.1.5. Evaluation methods of deceleration behaviors

Regarding the process of deceleration at intersections, parameters to evaluate driving behaviors were selected. Fig. 8 shows a sequential echogram in terms of deceleration and stopping behaviors near the intersection. The parameters are as follows:

The velocity at braking initiation: Vo [Km/h]
The time from braking initiation to stop: Tp [s]
The distance from stop position to a stop line: Lo[m]
The rate of deceleration change from braking operation: Jerk [m/s3]

3. The results of deceleration behaviors

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

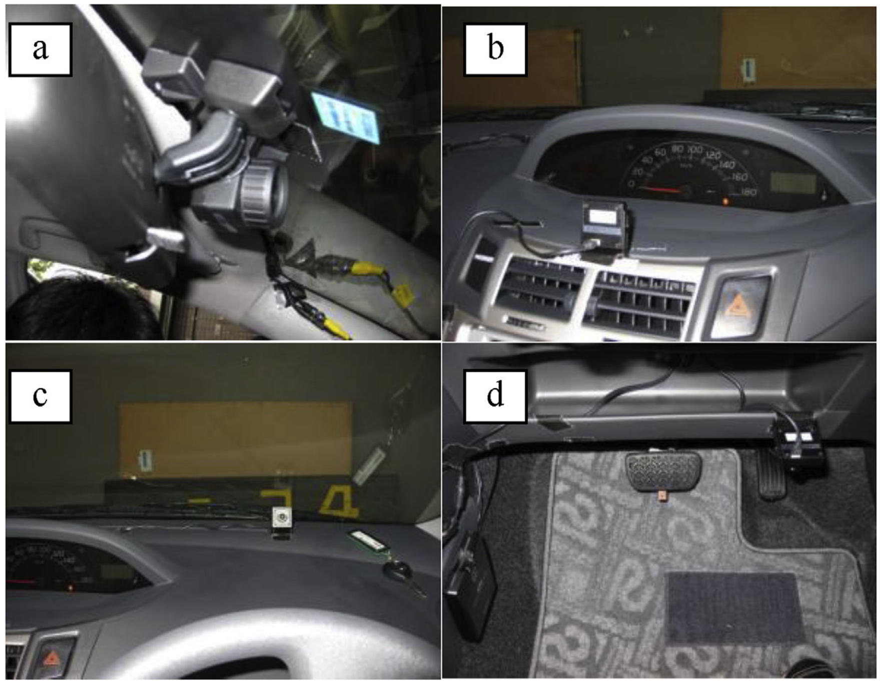

Fig. 4. The cameras to record experimental scene in the car (a: forward scene, b: speedometer scene, c: driver scene, d: brake pedal scene).

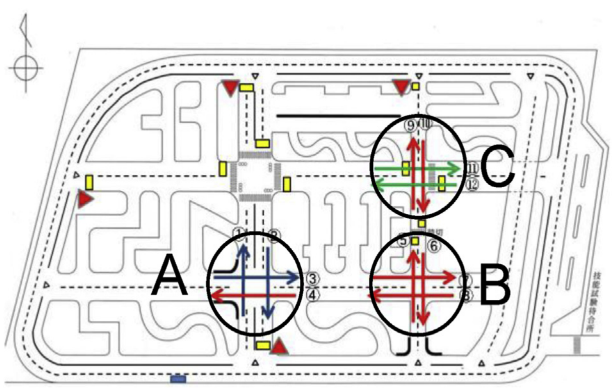

Fig. 5. A car used in the experiment.

3.1. Driving behavior

Because the driving behavioral data, Vo, Tp, Lo and Jerk have the correlation with a series of these braking operations, we set the dependent variable with age and the intersection by Multivariate Tests.

3.1.1. Velocity before the deceleration onset: Vo

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

According to Multivariate Tests in terms of age and intersection, a result of age factor had very significant differences with [MS = 163.614, F (1, 87) = 11.293, p = .001]. Next, according to the results of Paired-Samples T Test (two levels: young and elderly driver), at intersection A, there was no significant difference with [MS = −1.17000, SEM = 1.45450, df = 9, t = −0.804 p = 0 442], at

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

Fig. 6. Experiment devices to investgate stopping behaviors.

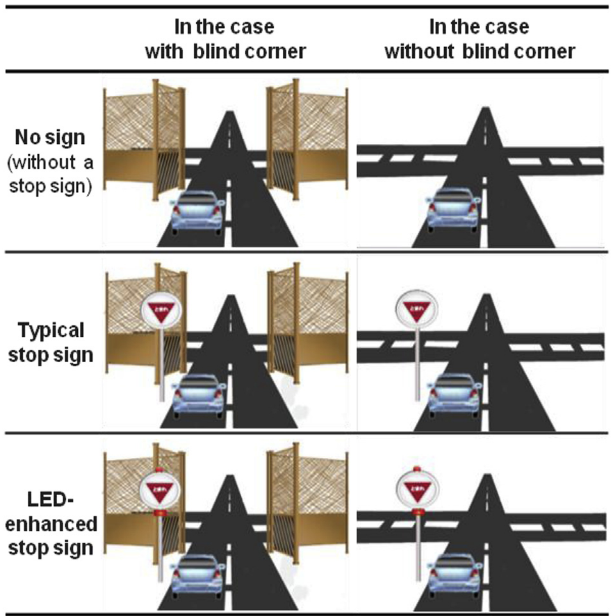

Fig. 7. Six conditions regarding the environment of intersections.

intersection B, there was very significant difference with [MS = −4.58947, SEM = 1.38401, df = 18, t = −0.3.316 p = −0.004], and at intersection C, there was a significant difference with C [MS = −0.3.726, SEM = 1.4375, df = 9, t = −0.2.592 p = 0.018], as shown in Fig. 9.

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

Fig. 10 shows the individual Vo. As the results, both young and

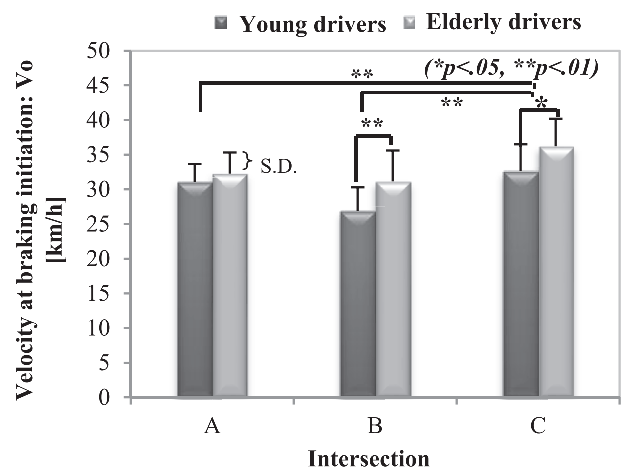

Fig. 9. The average of the velocity at braking initiation: Vo.

Table 1
Number of passes the intersection with the respective conditions.

Intersection combination	Intersection	No sign		Typical sign		LED-enhanced sign	
		With blind corner	Without blind corner	With blind corner	Without blind corner	With blind corner	Without blind corner
I	A		2		2		
	B	2		1			1
	C			1		2	1
II	A	1	1		1		
	B			1		2	2
	C	1	1	1	1		
Total		4	4	4	4	4	4

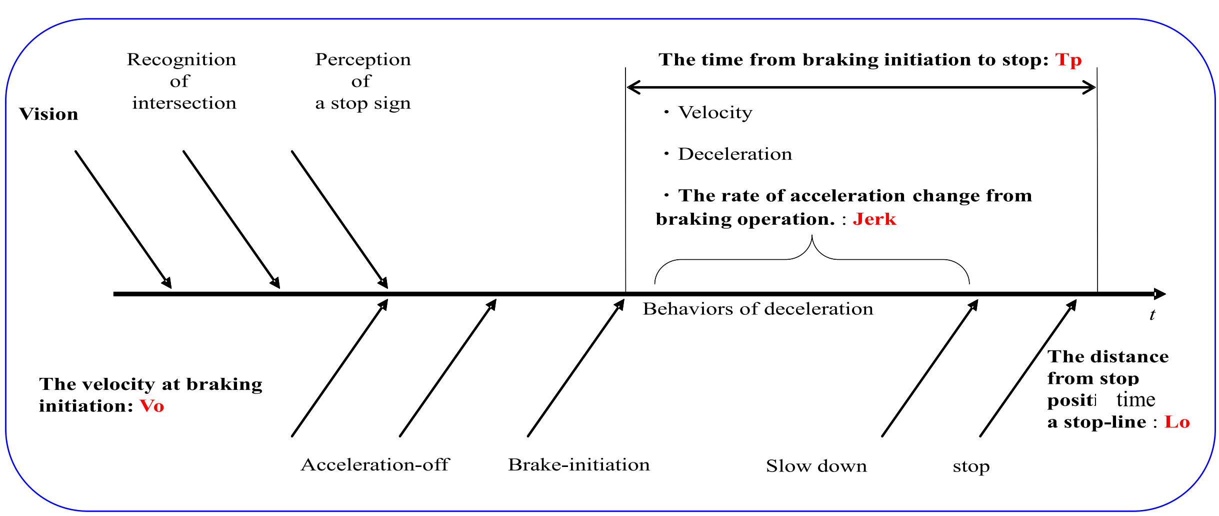

Fig. 8. Sequential ethogram for decelerating and stopping behaviors near the intersection.

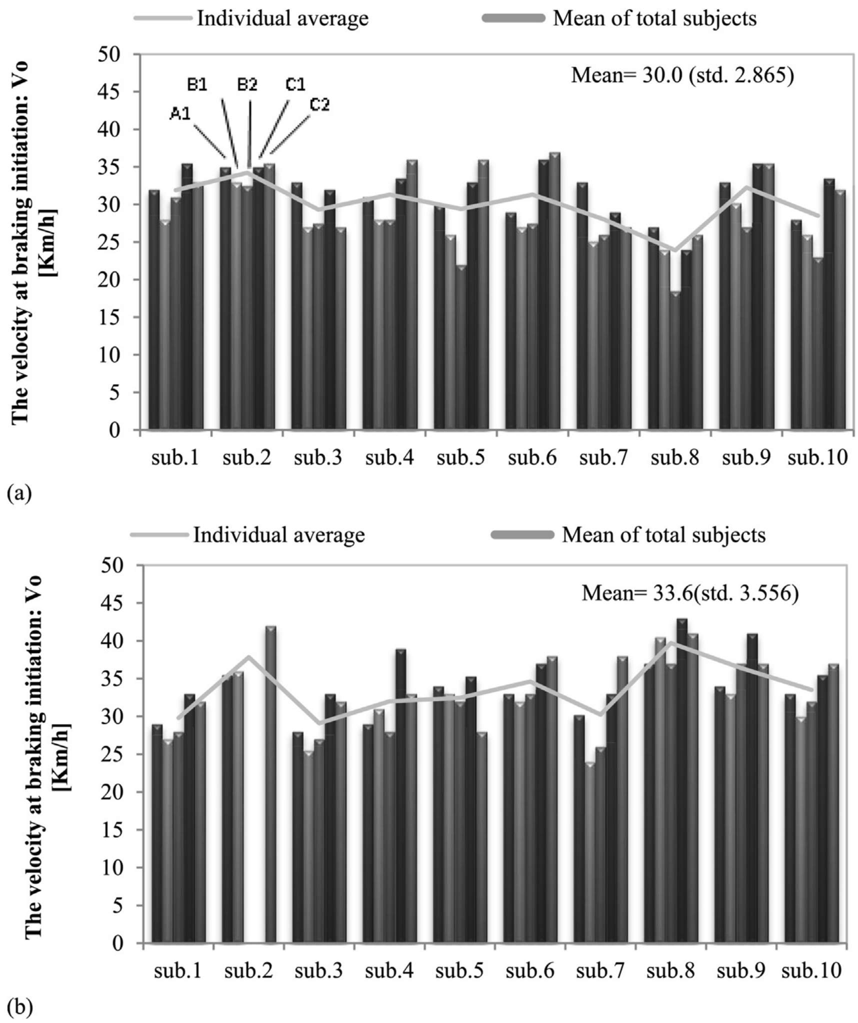

Fig. 10. Individual results of Vo at braking initiation. (a) young drivers, (b) elderly drivers.

elderly driver show difference in the individuals. The elderly divers have higher individual difference.

3.1.2. The time during deceleration: Tp

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

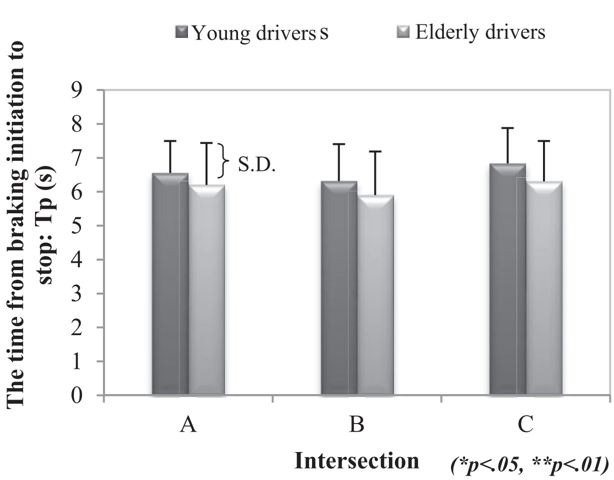

Fig. 11. The average of time from braking initiation to stop: Tp.

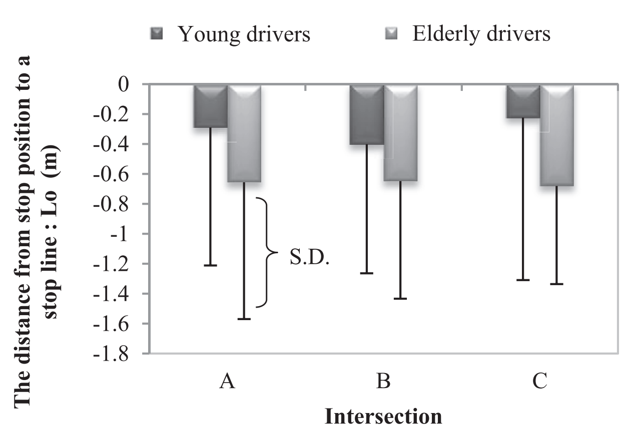

Fig. 12. The average of the distance from stop position to a stop line: Lo.

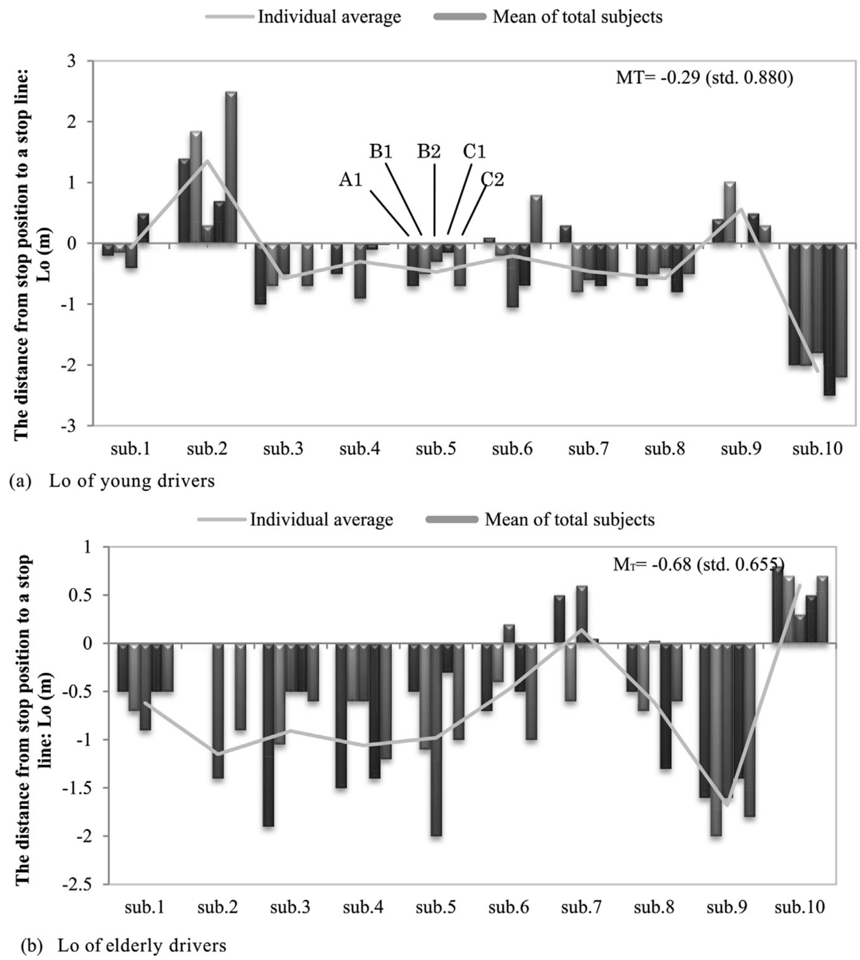

Fig. 13. Individual results of *Lo*. (a) young drivers, (b) elderly drivers.

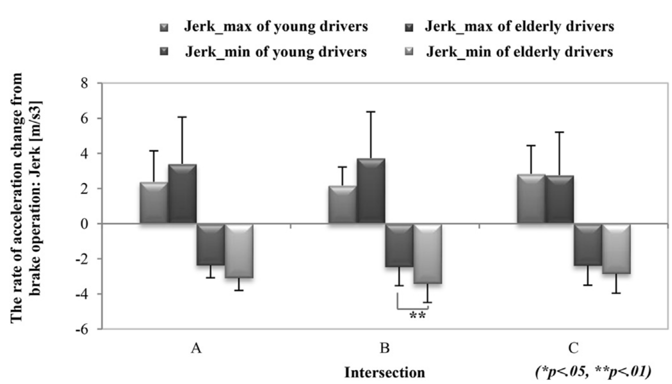

Fig. 14. The rate of acceleration change from brake operation: Jerk.

M = 6.835 ± 1.0414s, that of elderly drivers was M = 6.305 ± 1.1891s.

As the result of Multivariate Tests, "age" as a main factor was shown significantly no difference as [MS = 2.753, F (1, 87) = 2.127, p = .148], "intersection" as a main factor was also shown significantly no difference as [MS = 1.299, F (2, 87) = 1.003, p = 0 371]. Interaction between "age" and "intersection" also was also shown significantly no difference as [MS = 0.238, F (2, 87) = 0.184, p = 0.832], as shown in Fig. 11.

3.1.3. The distance from stop position to a stop line: Lo

Fig. 2.2.13 shows the result of Lo. Lo of young drivers at the intersection of A was M = −0.29 ± 0.9218 m (average ± standard deviation), and that of elderly drivers was M = −0.656 ± 1.240 m. At intersection B, Lo of young drivers was M = −0.401 ± 0.8629 s, and Lo of elderly drivers was M = −0.648421053 ± 0.7854 m. And, Lo of young drivers at the intersection C was M = −0.223 ± 1.0861 m, that of elderly drivers was M = −0.681 ± 0.6560 m.

Next, as the result of Multivariate Tests, "age" as the main factor shown significantly no difference as [MS = 2.475, F (1, 87) = 3.224, p = 0.076], "intersection", a main factor, and interaction between "age" and the "intersection" were also shown significantly no difference as [MS = 0.025, F (2, 87) = 0.033, p = 0.968] and [MS = 0.149, F (2, 87) = 0.194, p = 0.824] (Fig. 12).

Fig. 13 shows individual Lo of young and elderly drives. As a result, Lo of young shows that they stopped at intersections in the range of ± 1 m except for two drivers, but Lo of elderly drivers shows they exceeded over the range of ± 1 m.

3.1.4. The rate of acceleration change from brake operation: Jerk

Jerk_min and Jerk_max as the driver's variation of deceleration were investigated. As shown in Fig. 14, Jerk_min of young drivers at the intersection A was M = −2.37 ± 0.0904 m/s^3 (average ± standard deviation), and Jerk_max of young drivers was M = 2.385 ± 1.7651 m/s^3. Jerk_min of elderly drivers at intersection A was M = −3.09 ± 0.7125 m/s^3, and Jerk_max was M = 3.40 ± 2.6680 m/s^3. At intersection B, Jerk_min of young

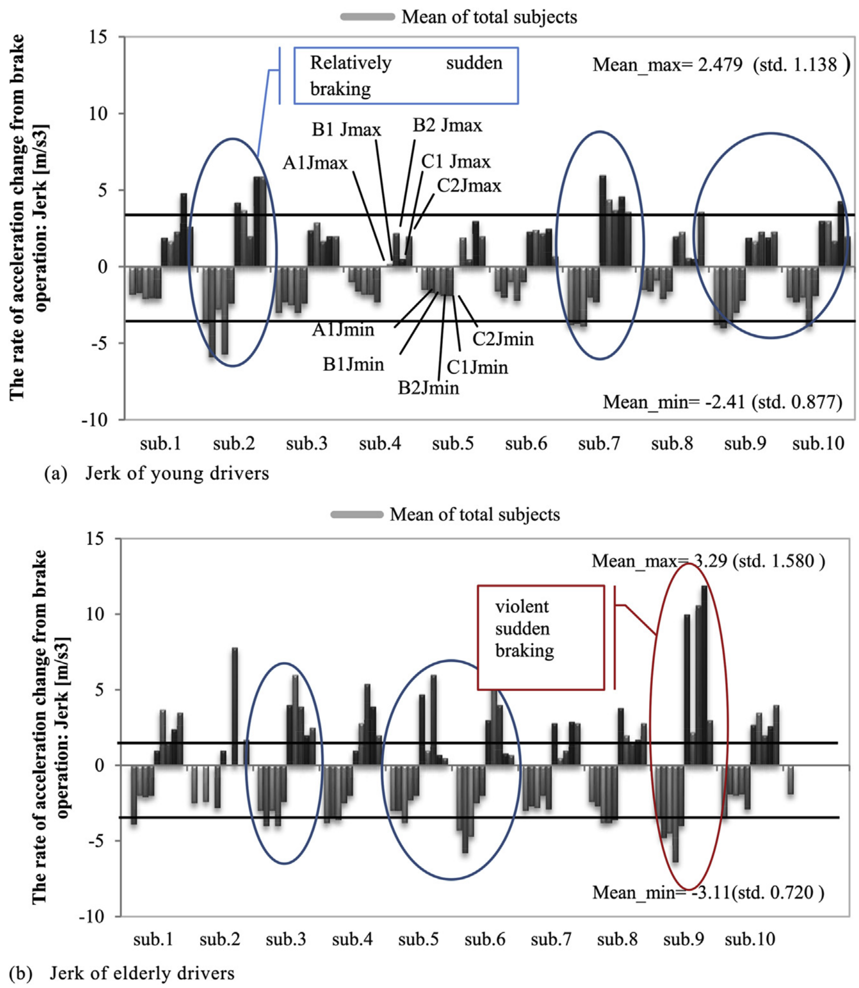

Fig. 15. Individual results of Jerk. (a) young drivers, (b) elderly drivers.

drivers was M = −2.4655 ± 1.2170 m/s^3, Jerk_max of young drivers was M = 2.17 ± 1.0539 m/s^3, Jerk_min of elderly drivers was M = −3.4158 ± 1.0652 m/s^3, and Jerk_max of elderly drivers was M = 3.7312 ± 2.6312 m/s^3. At intersection C, Jerk_min of young drivers was M = −2.3855 ± 0.9775 m/s^3, Jerk_max was M = 2.835 ± 1.6122 m/s^3, Jerk_min of elderly drivers was M = −2.847 ± 1.1192 m/s^3, and Jerk_max M = 2.758 ± 2.4502 m/s^3.

Fig. 15 shows the individual results of Jerk_min and Jerk_max. As a results of young drivers, three subjects operated brake pedal relatively suddenly, and in case of elderly drivers, two subjects operated extremely sudden braking even one subject operated violent sudden braking. it was noted that elderly drivers operated braking more dangerous than young drivers did.

3.2. The results of stopping behaviors

3.2.1. The rates of stop and non-stop

Fig. 16 shows a result regarding the rates of stopping and non-stopping. It was shown that elderly drivers have low rates of stopping than that of young drivers.

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

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

In order to identify influence of age, signs and blind corners on stopping, the multiple regression analysis was performed, and the results are shown in Table 3. The values of relationship between rates of stop and factors in the regression model was significantly correlated as [F = 36.322, and p = 0.000]. An output of Adjusted R Square is 0.932, and an output of Predicted R-squared appears 0.965. Therefore the regression model shows significant explanatory power. Because each tolerance limit is more than 0.1, and VIF is less than 10, thus, there are no problems at multicollinearity of variable factors.

As shown Table 3, the influence of age factor that measured t = 2.782, p = .024 was statistically significant difference within the 5% significance level, which have a positive (+) affects on the age and driving classifications as Standardized Coefficients Beta = 0.275. In addition, the sign factor that measured t = 10.040, p = 0.000 was statistically significant within 1% significance level, which had a positive (+) affects on the age and driving classifications as Standardized Coefficients Beta = 0.928. As the results, an age factor despite of the discovery of signs should be easier to stop

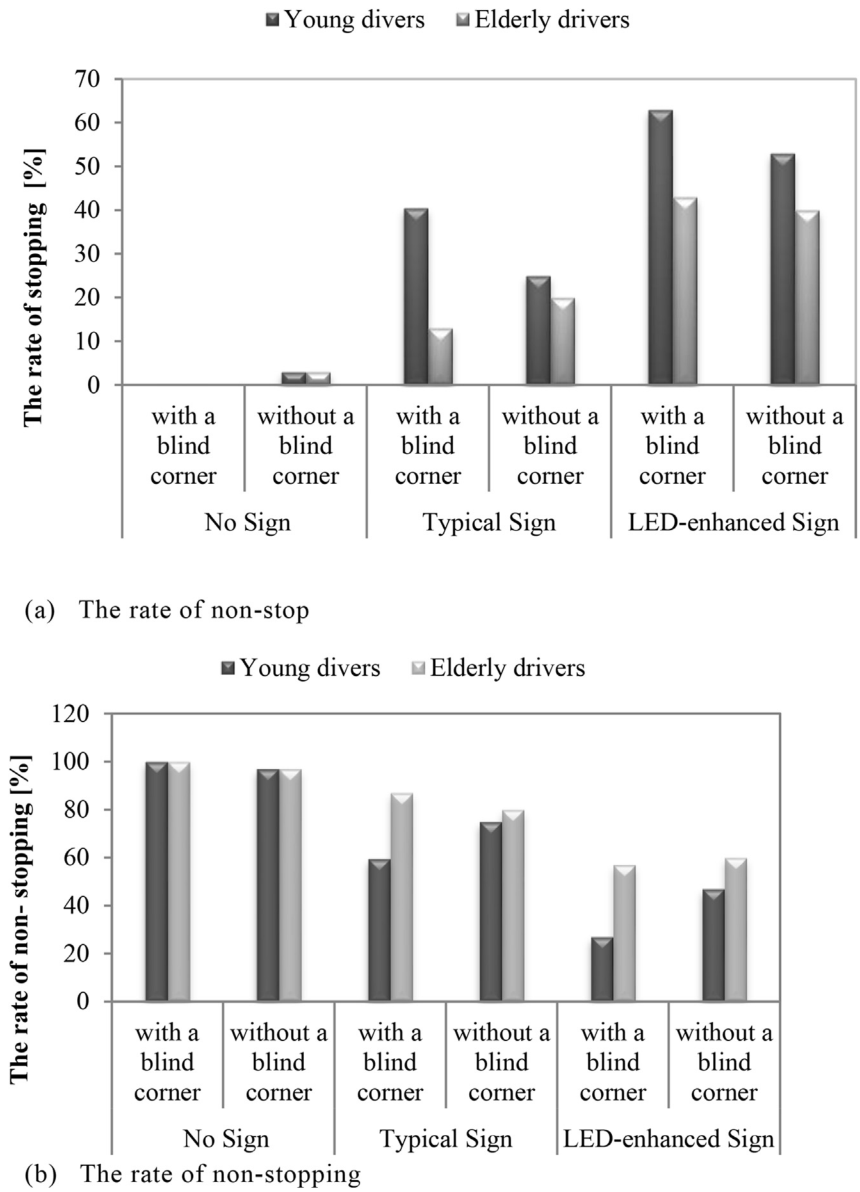

Fig. 16. The rates of stop and non-stop in terms of environments of intersections.

Table 2
Statistical abbreviations and definitions in the chapter.

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

at the intersection with awareness faster, and increase commitment to stop could increase the probability of stopping.

4. Discussion

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

Table 3
The results of multiple regression analysis.

Dependent variable	Independent variable	Unstandardized coefficients		Standardized coefficients	t-value	p-value	Collinearity statistics	
		B	Std. Error	Beta			Tolerance	VIF
stop	(Constant)	−24.833	5.373		−2.371	.045		
	age	10.917	1.962	.257	2.782	.024	1.000	1.000
	sign	24.125	2.403	.928	10.040	.000	1.000	1.000
	blind	−1.292	1.962	−0.061	−0.658	.529	1.000	1.000

R Square = 0.965, Adjusted R Squar = 0.932, df = 6.797, F = 36.322, Sig = 0.000.

Table 4
Database about the aged drivers braking behaviors features.

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

Block occupied the most rates. Block occupied second many rates.

Table 5
Comprehensive countermeasures and individual countermeasure of safe driving regarding the features of elderly drivers.

The feature of braking behaviors for elderly drivers	Comprehensive countermeasures	Individual countermeasures
High speed near intersections	Improvement the consciousness of road safety	Notify approaching a intersection in advance
	1. Notice information of intersections in advance	2. Call attention to intersection with voice and images
Sudden braking and stopping	Suggestion of a prevention regarding sudden braking	Training of braking control
	3. Practice of correct control of brake pedal	4. Brake pedal replace with fly-by-wire
Inaccuracy stopping position	Improve of awareness of operation safety	Inducement of braking timing and stopping position
	5. Education about vehicle principle with a easy book	6. Control of brake pedal by operation profile
Incorrect operation of brake pedal	Visibility improvement of stopping position	Assistance of visual function
	7. Stop-line or sign, etc. make it easy for drivers perceive	8. Stop-line or sign, etc. make it easy for drivers perceive

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

Table 4 shows the rate of stop and non-stop in the various intersection conditions from elderly drivers braking behaviors features. Black blocks show the most occupied rates of stop or non-stop in lateral conditions, and gray blocks show second occupied rates. It is shown that in both elderly and young driver group the rates of stop and non-stop are associated with the sign condition considerably. For example, 43% of elderly driver's stop rates had stop behavior in LED-enhanced Sign and “with a blind corner” considering 0% in the condition with No Sign and “with a blind corner”, also, 63% of young drivers stop in the same condition. However in “with a blind corner” did not show stopping at intersections. These results were associated with the results of Multiple Regression analysis that found significant difference in the factors of age and stop sign considerably.

5. Summary

In this experiment, the features in terms of braking behaviors of elderly drivers were shown obviously. That's the braking behaviors were inapposite as above mentioned, and the enhanced level of stop signs was considerably important. At the sequential deceleration behaviors, individual differences of elderly driver were observed statistically, and several suggestive support methods were expected as shown in Table 5.

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

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