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A STUDY ON THE STRESS AND DRIVING BEHAVIOR OF DRIVERS FORCED TO TRAVEL AT LOW SPEEDS

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Abstract: When we measure travel speeds of road sections, wider range of travel speed would be obtained. Driving in slow-speed sometime increases the stress of other drivers who intend to travel in higher speed. This might lead to hazardous behavior on the part of impatient drivers, such as reckless passing. This study aims to clarify in what situation drivers develop stress and what psychological and behavioral characteristics are manifested under these conditions. A basic survey was conducted to gain an understanding of the driving behavior of drivers under stress and their focus of attention as well as changes in their stressed condition. A full-scale survey was then made to gain insight into the extent of effect the provision of information has on driver stress. From the result of these surveys, it is found that the reduction in the stress differs according to the kind of information supplied from slow-moving vehicles ahead.

Key Words: stress, driving behavior, information

1. INTRODUCTION

The continuous aging of population in Japan has led to a parallel increase in the number of aged drivers. This trend is expected to continue for some time in light of the number of individuals with driving licenses. Compared with ordinary drivers, aged drivers, whose responses are slower than those of younger people, tend to drive with exaggerated caution, often traveling slowly and keeping a longer headway distance. Although safe driving itself is desirable, driving too cautiously increases other drivers' stress because the road space is not designed for the usage of older people only. This also leads to hazardous behavior on the part of impatient drivers, such as reckless passing. By making a survey of automobiles on the road, therefore, this study is aimed to clarify in what situation drivers develop stress and what psychological and behavioral characteristics are manifested under these conditions.

There have been many studies conducted so far that place greater emphasis on what causes stress, such as slow drivers (Mizohata, 1999), but few studies have been carried out on drivers' behavioral characteristics during the process of becoming stressed. While there have

been other studies designed to examine driver fatigue from the psychological aspect (Iwakura, 2000), this paper features a study on drivers' behavioral characteristics in a situation that has actually caused their stress. Specifically, this study is designed to investigate the shift of drivers' focus of attention, and acceleration and deceleration while driving. As a result, it should be possible to identify the points at which drivers gaze more frequently and those at which they look less frequently. This paper proposes a road environment that will help reduce drivers' stress through this type of analysis.

In proposing a road environment such as this, we believe that content of information that needs to be taken in by a driver is a major contributor to stress. Therefore, an investigation and analysis will be made aiming to by identify the changes in their driving behavior under stressed conditions Specifically, the purpose of this study was to examine what kind of information, if provided as stickers on slow-moving vehicles, would best alleviate driver stress, by measuring the stressed conditions according to the differences in the content of that information.

2. BASIC SURVEY AND SURVEY OUTLINE

In this study, a basic survey was conducted to gain an understanding of the driving behavior of drivers under stress and their focus of attention as well as changes in their stressed condition. A full-scale survey was then made to gain insight into the extent of effect the provision of information has on driver stress. In this study use of a driving simulator was considered less effective than recording drivers' behavioral characteristics in the actual environment where they develop stress. Therefore, the survey was conducted using vehicles on the road.

The subjects were equipped with an eye-mark recorder and a cardiograph, and their focus of attention and heart rate were measured. Drivers' driving responses were also recorded using accelerographs installed in the vehicles. Ordinary inter-city national roads with one lane in each direction were chosen as travel routes. During the tests, conditions were intentionally created in which the subjects were subjected to increased stress by having slow-moving vehicles travel ahead of their cars without being given any information in advance.

The survey was conducted according to the following procedures. The subjects drove from the starting point of the outbound trip: "Moshi-Moshi Pit", a service area with parking facilities for drivers to use mobile phones and rest, to a previously designated "Michinoeki" that is a kind of roadside station as public facilities. Michinoeki was designed to offer places for rest, regional exchanges and on-the-spot sales of local products. Michinoeki exists more than 740 sites throughout Japan. After a period of unimpeded driving, the subjects were compelled to follow a slow-going vehicle that appeared ahead of their cars while they were driving back. The slow-going vehicle stayed ahead of the test driver up to the designated Moshi-Moshi Pit at a fixed speed of 50km/h. After the slow-going vehicle turned off to the Moshi-Moshi Pit, the subjects continued driving back to the starting point (Figure 1).

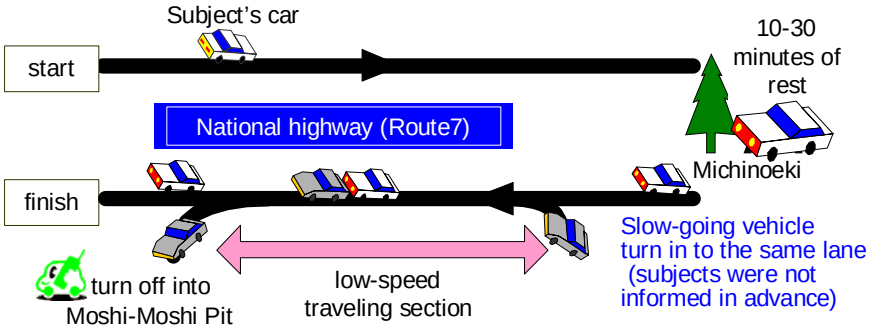

Figure 1. Basic Survey Routes and Survey Procedures

An outline of the survey is shown in Table 1. The survey was conducted along two roads: from Akita to Michinoeki Nishime and Akita to Michinoeki Iwaki between December 6 and December 24, 2002. Data on a total of 12 subjects was obtained.

Table 1. Outline of Basic Survey

survey routes	Nisime route	Iwaki route
road	Akita - Nisime (50km)	Akita – Iwaki (30km)
date	Dec. 6-16, 2002	Dec. 16-24, 2002
time	9:00 to 12:00, and 13:00 to 16:00	
weather	clear or cloudy	
road surface condition	dry	
traffic condition	free flow	
subjects	6	6

3. ANALYSIS OF RRI VARIATIONS

To measure drivers' psychological characteristics under conditions of increased stress, data on R-R interval (RRI) was obtained from an electrocardiogram. RRI refers to the interval between R-waves in an electrocardiogram waveform. RRI decreases when stress and other physical loads are applied, and is caused by the rise in activity of the heart's sympathetic nerves, which in turn increase the heart rate. For this reason, RRI is used as an indicator of stress. Analytical data taken in a slow-traveling section and a stress-free section following the turning off of the slow-going vehicle were used to clarify the relationship between the presence of stress and RRI.

Figure 2 shows the RRI variations in a certain subject. From this Figure, it is clear that the RRI value becomes shorter as the slow traveling time gets longer. After the turning off of the vehicle, RRI increases with the passage of time. In other words, we can say that it was possible in the present survey to apply stress to the drivers and show the increase and decrease of their stress in terms of RRI. What is noteworthy here is that there occurred a time gap of about 10 seconds between the time when the lowest RRI value was indicated and the time when the slow-going vehicle turned off. This suggests that, though it varied with the subjects, there was a time difference in the indication of RRI values after they had experienced stress.

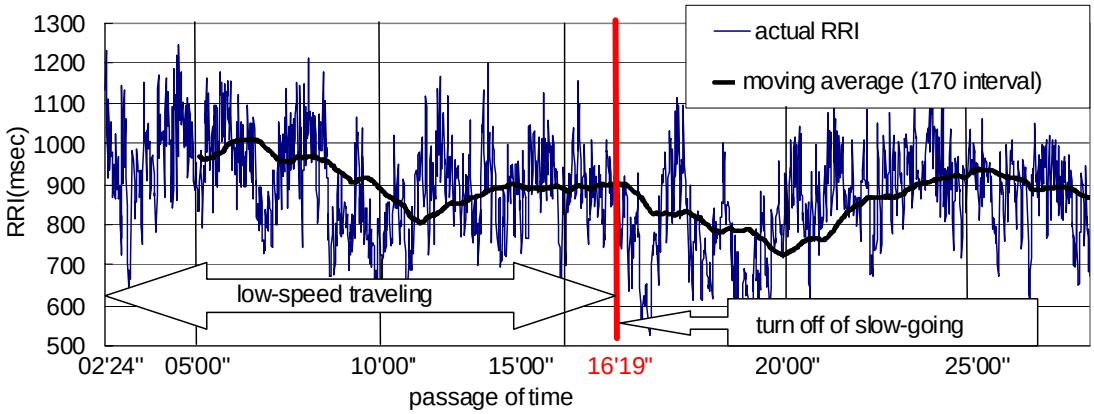

Figure 2. RRI Variations in Situations where Drivers are Forced to Travel at Low Speed

Figure 3 shows 10-second average RRI values registered after the start of low-speed travel, at the time slow-going vehicle turned off, and one minute after slow-going vehicle turned off. It is clear that driver stress increases and builds up as the travel time gets longer, because four subjects out of six had the shortest RRI during low-speed travel, as indicated in this Figure. It can also be seen that the act of letting others go ahead helps reduce stress, since the RRI values of all the subjects were greater after the slow-going vehicles turned off. The average RRI values of all the subjects obtained were 849 one minute after the start of low-speed travel, 735 at the time the slow-going vehicle turned off, and 768 one minute after the slow-going vehicle had turned off. Converted to heart rate, these figures read 70.7 beats per minute one minute after the start of low-speed travel, 81.7 beats per minute at the time the slow-going vehicle turned off, and 78.1 beats per minute after the slow-going vehicle turned off. When a slow-going vehicle joined the traffic, the RRI values declined by approximately 10 in terms of the number of heartbeats per minute. This can be regarded as a significant change.

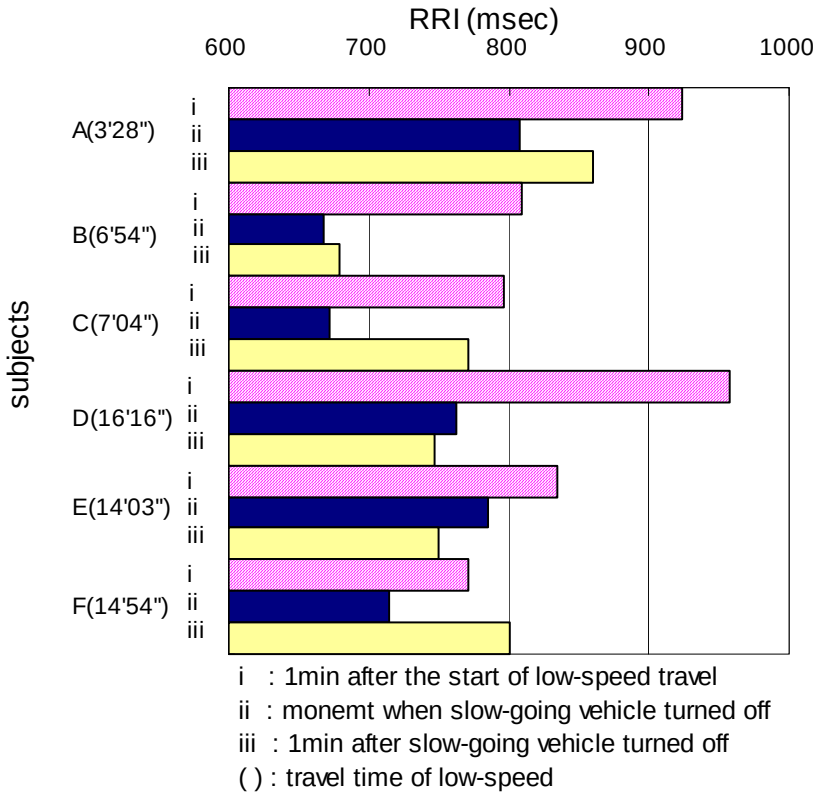

Figure 3. Passage of Time and RRI Variations

4. ANALYSIS OF FOCUS OF ATTENTION

To check the changes in focus of attention at the time drivers were developing stress, data was collected using an eye-mark recorder. In the present study, the focus of attention was divided into several areas (Figure 4) and defined as movements with a speed of not more than 30 deg/sec and holding a position for more than 165 ms (Fukuda, 1996). Specific traffic signs and signboards the subjects observed closely while driving were also counted in order to find out whether drivers in a stressed situation will collect information the same way as under unimpeded driving conditions or what changes will occur. This section analyzed covers the same points in the outbound and homebound trips. On the homebound trip, the slow-going vehicles were traveling ahead of subjects' cars.

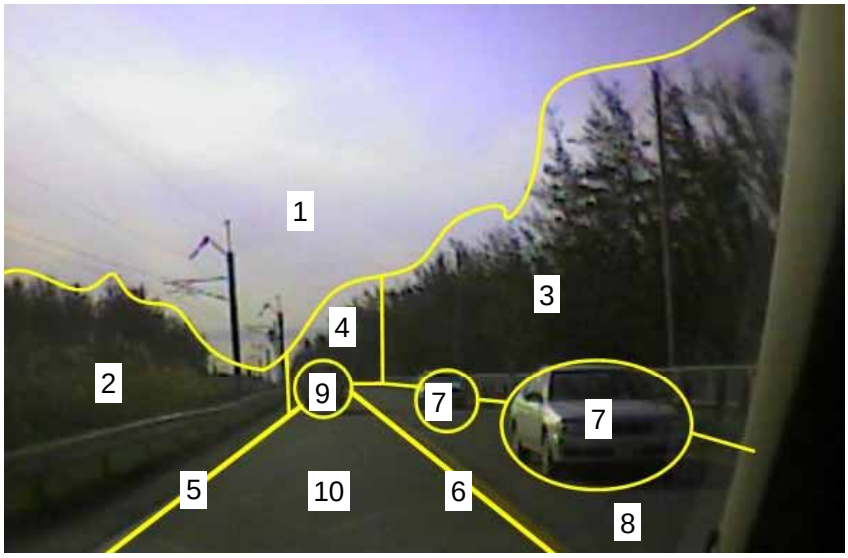

Figure 4. Categorization of Areas on which Driver Focused Their Attention

Figure 5 shows the changes in areas on which drivers focused their attention during low-speed travel and during unimpeded driving. In this survey, no consistent pattern was found, with the change of the number of areas on which drivers focused their attention differing greatly among the subjects.

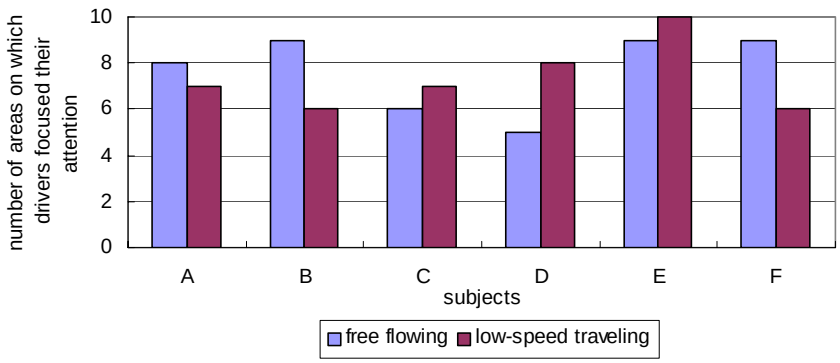

Figure 5. Change in Areas on which Drivers Focused Their Attention by Individual Subjects

Figure 6 shows the frequency of glance per 60 seconds during unimpeded travel and low-speed travel. Averaged over all the subjects, the frequency of glance when the slow-going vehicle turned onto the road increased 1.5 times over that seen during unimpeded travel. We conclude that the subjects closely observed more objects to obtain information on the road ahead and obtain the chance to overtake, as evidenced by the increase in the frequency of glance when the slow-going vehicle turned onto the road.

Shown in Figure 7 are changes in the time spent in watch per 60 seconds. Unlike the frequency of watch, the time spent in watch varies significantly among the subjects at the time the slow-going vehicle turned onto the road: 1.6 times greater than during unimpeded driving. Since the time expended in watch tends to increase during low-speed travel, it appears that the subjects, as revealed by their frequency of watch, immediately considered overtaking when the slow-going vehicle turned onto the road.

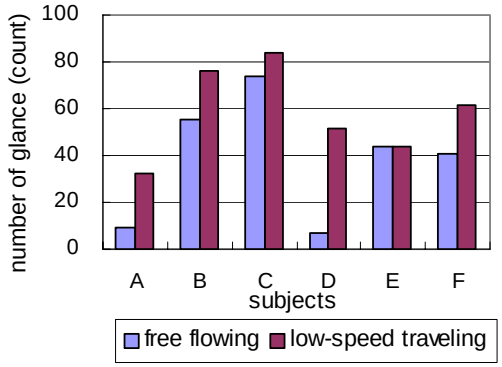

Figure 6. Frequency of Number of Glance

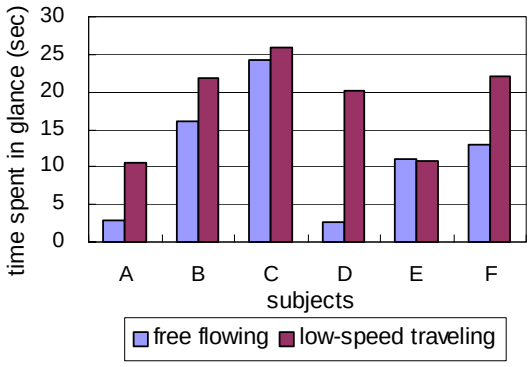

Figure 7. Time Spent in Glance

From Figure 5 and Figure 7 above, it was firstly estimated that the increases in the number of the areas carefully watched and the time expended in watch are attributable to the subjects seeking the opportunity to overtake. Verification was secondly conducted to clarify why the frequency of glance and the time expended in watch differed between unimpeded driving and when the slow-going vehicle turned onto the road. Thirdly, it was necessary to find out what areas the subjects actually watched carefully and what areas they came to observe closely when the slow-going vehicle turned onto the road.

Table 2 indicates changes in the ratio of watch by subject and area. Characters "I" and "D" marks here denote increases and decreases in the ratio of watch when low-speed travel started. From this table, it is clear that the subjects have the tendency to look more closely at such areas as "sky area", "left side" and "center". Since these areas are concerned with the collection of information on the situation ahead, we believe that drivers' awareness is directed forward during low-speed driving. The tendency for drivers to maintain close observation when the road ahead is clear and to slacken that effort during low-speed driving was found on the " right side", "oncoming vehicles", "vehicles traveling ahead", and "subjects' own lanes". Since these are the areas concerned with oncoming vehicles and those traveling ahead, we conclude that drivers' awareness of oncoming vehicles declines and that the drivers cease to look closely at vehicles traveling ahead. This will lead the drivers to feel that there is no need for watch.

Table 2. Changes in Areas Subjected to Glance during Low-Speed Travel

	subjects						change	
	A	B	C	D	E	F	increase	decrease
1 sky area	I	I		D	I	I	4	1
2 left side	I	I	I	D	I	D	4	2
3 right side	D	I	D		D	I	2	3
4 center	I	I	I	D	I	I	5	1
5 left line	D	D		I	I	D	2	3
6 center line	D	D		I	I	D	2	3
7 oncoming vehicle	I	D	D	I	D	D	2	4
8 opposite lane	I		I			D	2	1
9 slow-going vehicle ahead	D	D	I	I	D	D	2	4
10 driving lane	D	D			D	D	0	4

I:increase
D:decrease

From the foregoing, it may be said that, while drivers' watch is likely to be directed forward during low-speed travel, their awareness of the need for careful attention to oncoming vehicles and the position of one's own moving vehicle slips. It was also found that there are more risks involved, due to the difference in speed between unimpeded and low-speed vehicles.

Table 3 shows the percentage of areas where subjects were looking at road signs and signboards while traveling at low speeds. The road signs and signboards were classified by area and tallied. As indicated in this Table, it may be said that subjects had a tendency to obtain a lot of verifiable information from "left side" while driving unimpeded. However, this pattern changed during low-speed travel and the subjects were seen to be gaining a lot of verifiable information from general traffic conditions. As Table-3 shows, this agrees with the increase in the frequency percentage of drivers' glance of "sky area" during low-speed travel. Therefore, it appears that the rise in the frequency of glance of "sky area" has something to do with the amount of information gained from road signs, etc., with emphasis shifting from "left side" to "sky area".

A survey of the changes in these areas found that the sources of information used by drivers during low-speed travel are different from those during unimpeded driving. From this finding, it may be concluded that the changes in the time and the frequency of glance are attributable to drivers' intent to overtake or obtain information from ahead.

Table 3. Percentage of the Frequency of Glance of Specific Objects

	percentage of the frequency to watch	
	longer headway distance	shorter headway distance
1 sky area	74.1	47.1
2 left side	25.9	11.8
3 right side	0.0	17.6
4 center	0.0	20.6
5 left line	0.0	0.0
6 center line	0.0	0.0
7 oncoming vehicle	0.0	0.0
8 opposite lane	0.0	0.0
9 slow-going vehicle ahead	0.0	2.9
10 driving lane	0.0	0.0

5. ANALYSIS OF DRIVING BEHAVIOR

What is termed driver behavior in this study refers to vehicles' acceleration and deceleration. Acceleration and deceleration during normal driving and stress were measured and the factors causing changes in driver behavior were studied by examining and comparing their patterns and changes. The section analyzed is the same as that covered by the survey of focus of attention.

Figure 8 indicates the ratio of deceleration during normal driving and low speed driving. Here the deceleration ratio comprises the deceleration data from all data, shown as a percentage. It can be seen that, compared with the period of unimpeded driving, the deceleration ratio increases during low-speed travel on the outbound trip. This is likely to be due to repeated deceleration by drivers whose impatience prevented them from maintaining a longer headway distance from the car ahead.

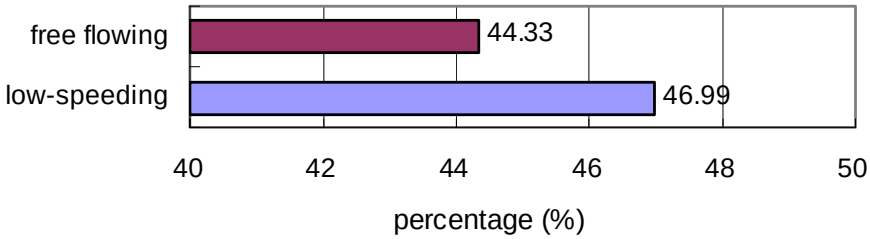

Figure 8. Deceleration Ratio

Figure 9 covers certain subjects, with acceleration and deceleration plotted on the horizontal axis, and the frequency ratio on the vertical axis. From this Figure, it can be seen that the frequency of deceleration increases in situations where vehicles are traveling at low speeds: the frequency of deceleration at Point "A" is far higher during low-speed travel than during unimpeded driving. This is a tendency found in all four subjects. We believe this to be responsible for the increase in deceleration at a certain point because of the need to maintain a safe distance behind the vehicle ahead. From the above, it was possible to verify that the frequency of deceleration increases when vehicles are traveling at low speed. It will help eliminate the increase in the frequency of deceleration if a longer headway distance is secured. During low-speed travel, therefore, it is necessary to gain a clearer understanding of patterns of acceleration and deceleration by checking to see if there is a safe distance between vehicles immediately ahead.

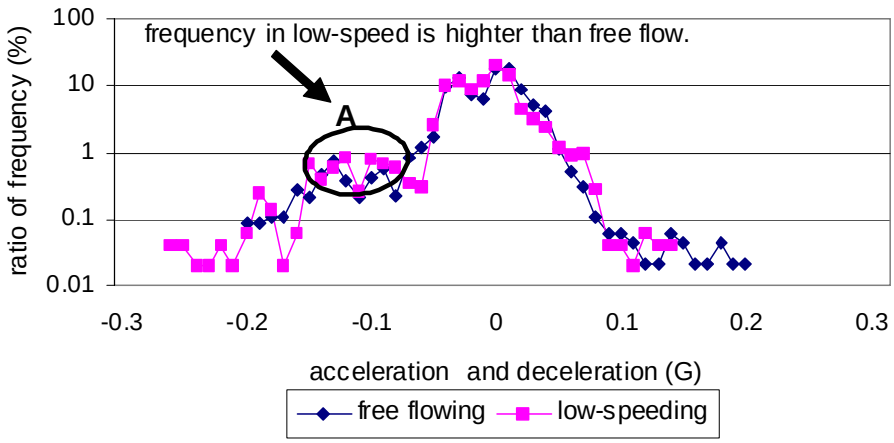

Figure 9. Distribution of Acceleration and Deceleration

As for the long or shorter headway distance, a standard was established from the video-taped images shot by individual subjects on their outward trip. The distance was judged insufficient when it came close to the standard. Figure 10 shows the frequency ratio of acceleration and deceleration made by subjects with at longer headway distance and shorter headway distance on their outbound and inbound trips. Common tendencies found in both cases of longer and shorter headway distances are follows: At points "A" and "D", deceleration increased by a certain amount. At points "B" and "C", there was no major change in the small acceleration amount. This is likely to be due to the need to maintain a distance. A common tendency found in the case of the shorter headway distance was that the frequency of acceleration rose significantly at point "E". This was also necessary to keep the distance short. An examination was then made to see how acceleration and deceleration changed according to sufficiency and insufficiency of inter-vehicle distance.

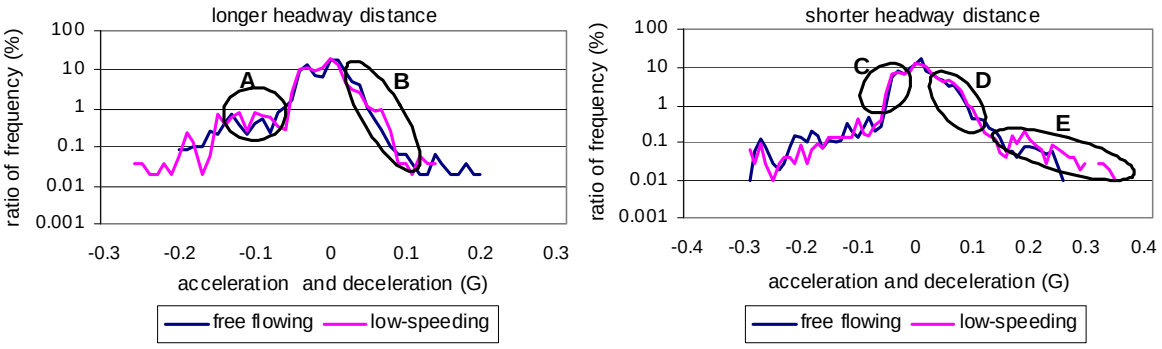

Figure 10. Distribution of Acceleration and Deceleration by Headway Distance

In Figure 11, the frequency ratio of acceleration and deceleration by subjects driving at a longer headway distance and those with a shorter headway distance are superimposed. From Figure-11, tendencies found in subjects following far too close are represented by an increase in the frequency of acceleration at point "B" and an increase in the rate of acceleration at point "C". It is likely that the subjects at shorter headway distance tend to show a greater acceleration frequency and a greater extent of acceleration because they keep the distance shorter through acceleration. From this finding, it was possible to say that drivers who keep a longer headway distance maintain their distance through deceleration and those with a shorter headway distance tend to maintain their distance through acceleration. In both cases, the tendency for acceleration and deceleration by the subjects during low-speed travel was different from that during unimpeded driving.

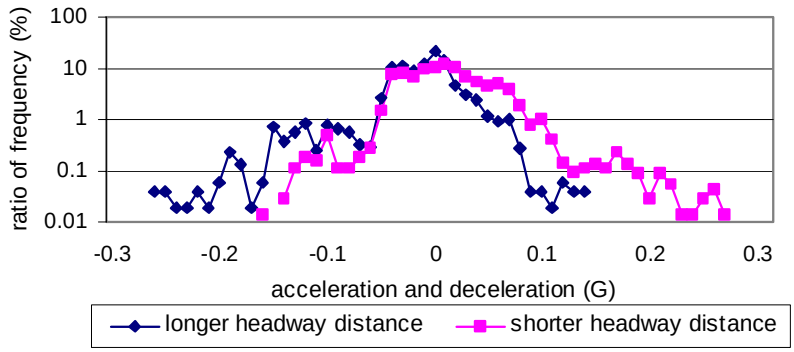

Figure 11. Distribution of Acceleration and Deceleration by Subjects Driving at Longer Headway

6. OUTLINE OF FULL-SCALE SURVEY

In the full-scale survey, stickers were put on slow-going vehicles giving information on them, and drivers' stressed condition was diagnosed in the light of these based on RRI and acceleration and deceleration. This survey was conducted on the Iwaki course using the same equipment as that used for the basic survey and going through the following procedures. The subjects drove from the starting point to the designated Michinoeki on the Iwaki route. The slow-moving vehicles came out in front of the subjects' vehicles during their journey. They followed the low-speed cars. The slow-going vehicles traveled to the Moshi-Moshi Pit at a fixed speed of 50 km/h. After the slow-going vehicles had turned off into the Moshi-Moshi Pit, the subjects' vehicles continued traveling to the station on the Iwaki road. After resting, they returned to the survey starting point. The slow-moving vehicles were classified into four categories: 1) Not carrying anything, i.e., giving no information, 2) carrying a notice saying "Checking Moshi-Moshi Pit", 3) carrying a notice saying "Drive safely", 4) carrying a sticker saying "Elderly driver", and 5) carrying a sticker saying "Newly licensed driver".

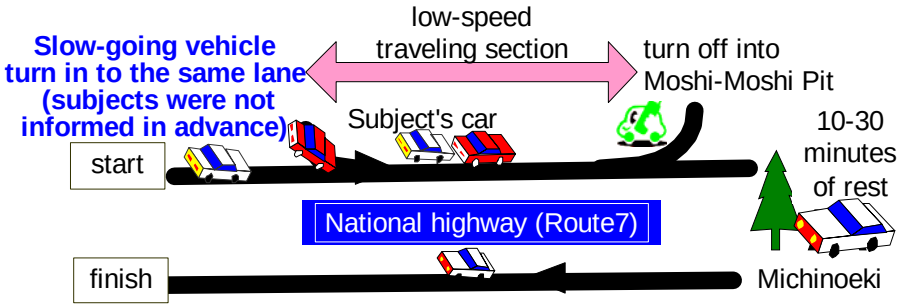

Figure 12. Full-Scale Survey Routes and Survey Procedures

Table 4. Outline of Full-Scale Survey

survey routes	Iwaki route
road	Akita to Iwaki 30km
date	Nov. 20 to Dec. 24, 2003
time	10:00 to 12:00 and 14:00 to 16:00
traffic condition	free flow
subjects	13

Figure 13. Stickers to Show the Stuations

7. RESULTS OF ANALYSIS

Figure 14 shows the ratio of RRI reduction by category of information provision by the subjects on the same section on both ways traveled by the subjects. From this Figure it is clear that the RRI during low-speed travel varied according to the category of information provided. It can also be seen that the RRI reduction ratio was low when traveling behind the "elderly driver"-marked cars, and that they did not experience high stress during low-speed travel under these conditions. The RRI reduction ratio was high for cars marked as "newly licensed drivers" and their stress showed a steady increase.

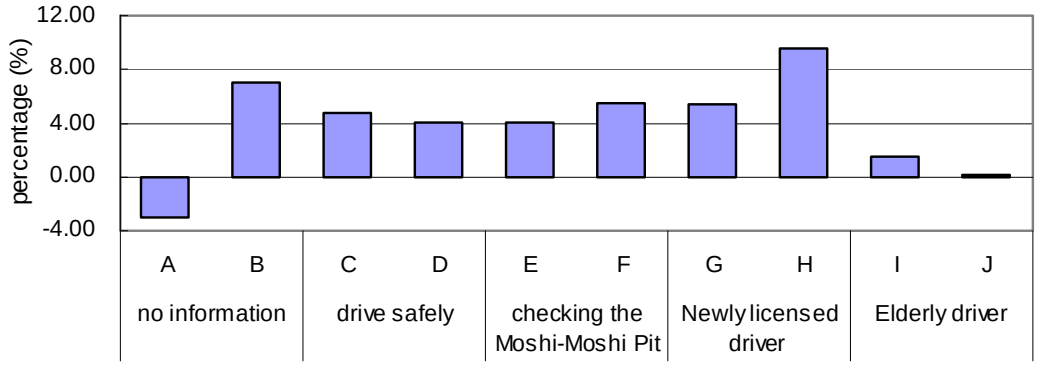

Figure 14. RRI Reduction Ratio

Figure 15 indicates the absolute values of acceleration and deceleration expressed in terms of area. It is clear that the extent of acceleration and deceleration by drivers increased when they were under stress. From this it appears that when the difference between acceleration and deceleration was great, the area became larger, indicating the driver was experiencing high stress.

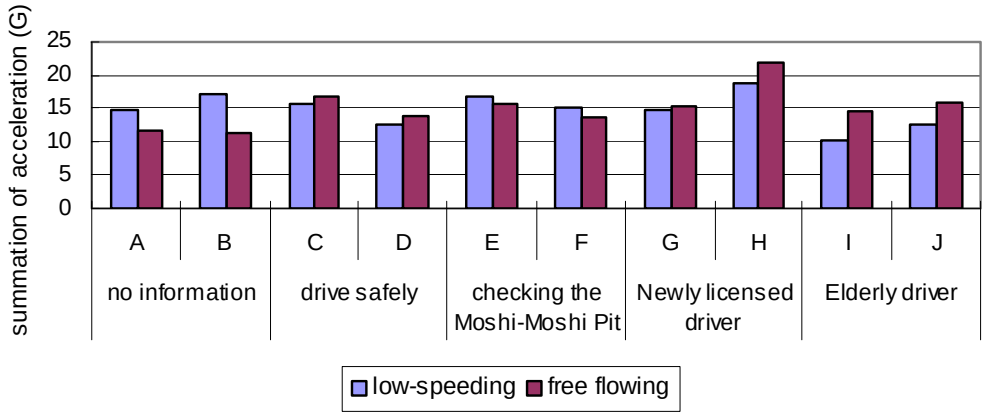

Figure 15. Changes of Acceleration and Deceleration

8. CONCLUSION

From the basic survey, it was possible to gain an understanding of the changes in RRI when the drivers were under stress, their pattern of gazing behavior and their driving behavior. Notably, the effectiveness of this survey was confirmed by discovering the tendency of drivers to obtain information from ahead through the act of glance.

The changes in stressed condition due to the provision of information were examined in terms of acceleration. It was found that stress was most effectively reduced when the drivers were informed that they were behind an elderly driver. Although information that they were following a newly licensed driver also helped reduce stress, it was not as effective. The notice saying "Checking Moshi-Moshi Pit", does not seem to have been very effective. The primary reason appears to be that the sticker did not make it clear to the drivers as to why the "Checking Moshi-Moshi Pit" would need to drive so slowly.

This survey indicated that, in terms of RRI and acceleration and deceleration, the reduction in the stress of drivers following the vehicles ahead differs according to the kind of information supplied from slow-moving vehicles ahead.

From the RRI value obtained from the cardiograph and RRI reduction ratio during low-speed travel classified by the contents of information, the survey also found that the stress reduction ratio differs according to the contents of information provided. Information from elderly drivers had a greater stress-reducing effect and that from newly licensed drivers had a lower stress-reducing effect.

As for changes in stressed conditions caused by the provision of information through acceleration and deceleration, information supplied by the elderly drivers was seen to help reduce driver stress most effectively. Meanwhile, the newly licensed drivers were found to be less helpful than the elderly, though their information had some stress-reducing effect where there is no other information. "Checking Moshi-Moshi Pit" does not seem to have been very effective. The reason appears to be that the sticker did not make it clear to the drivers as to why the "Checking Moshi-Moshi Pit" would need to drive so slowly. Since the "Elderly Driver" sticker was highly effective together with the reduction ratio of RRI and acceleration and deceleration, it may be said that the said sticker is widely recognized among drivers and that they accept slow-driving by the elderly.

Though it was possible to examine the question of stress as well as RRI and acceleration and deceleration, the results of the assessment of the issues other than the "Elderly Driver" sticker differed. This may be attributable to the difference of the evaluation standard. It will be necessary to analyze the standards in terms of RRI and acceleration and deceleration.

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