PHYSICAL LOAD RELATED TO HIGHWAY-DRIVING AMONG DISABLED PEOPLE

Hiroshi IKEDA
Interdisciplinary Graduate School of Science and Technology
Kinki University
Osaka, Japan

Akihiro MIHOSHI
Faculty of Civil Engineering
Kinki University
Osaka, Japan

Hajimu IKEDA
Institute for ErgoSciences
Osaka, Japan

Yoshio HISARI
Hanshin Expressway Co.,Ltd.
Osaka, Japan

(Received November 17, 2006)

Driving environments have been designed basically for travel by physically and mentally unimpaired people. On the other hand, sufficient, special considerations are not given to the vehicles driven by disabled people. In order to examine the ergonomic driving load put on both disabled and physically unimpaired people while they are on highways, the driving conditions and the muscle-stress of disabled people were evaluated on the approach to curves. Also the influence of acceleration-and-deceleration and centrifugal force on vehicles were evaluated in straight, split and inter-flows of traffic. The subjects of this study consisted of 5 physically unimpaired people and 10 disabled people who required auxiliaries for their vehicles due to handicaps of their lower limbs or to both upper and lower limbs. The study was conducted on the loop line of the Hanshin Expressway in Osaka, Japan. As a result of measuring the accelerated velocity of vehicles in motion and electromyograms of drivers of the vehicles, it was found that the driving load of disabled people is heavier than that of physically unimpaired people. It was also found that certain driving conditions are different for disabled people to travel at high speed.

Key Words: Disabled people, Vehicle, Highway acceleration, Electromyogram, Steering angle

1. INTRODUCTION

The number of physically disabled people with a driver's license has been increasing by 4,000 drivers every year, and it is expected to reach a total of 246,804 in 2004. The National Police Agency[1] reported that of these people, 206,480 are limited to driving vehicles specially designed for disabled people, 35,908 people are permitted to drive provided they use hearing aids, and 4,416 people wear a prosthetic limb and/or foot for driving a vehicle. In Japan, the provisional acquisition of a driving license by disabled people was legalized under Article 88 of the Road Traffic Law in 1960[2]. In addition, the acquisition of a driver's license by disabled people with impediments to both upper limbs was legalized in 1982. Recently, the development of barrier-free environments in facilities and on roads in order to support the independence of elderly and disabled people has come under closer scrutiny as a social issue.

In November 2002, the Barrier-free Transportation Law was implemented. This law involves the promotion of smoother transportation for elderly and disabled people in the public-transportation system. The research conducted by Hisari et al.[3] into the usage of highways shows that the development of urban expressway networks has raised the highway use of physically impaired people as a means to expand their positive contributions to society. However, driving environments are designed on the premise of travel by physically unimpaired people. In order to assure disabled people's needs, comfort and safety when they get involved with society as well as when they travel, there is demand for: (1) development with an emphasis on vehicles' ergonomic requirements; and (2) technical support for the safety of disabled people when they drive at high speed[4].

According to Dols et al.[5], the operational procedures and environmental set up for physically impaired people are unsatisfactory, and almost no ergonomic considerations, which assure their safety and comfort during driving, are taken into account. Road signs and information provided on highways are also basically for physically unimpaired drivers, thus it can be said that there is no safety and risk management existing for physically impaired people on highways. If these problems are improved and a stable environment for driving is developed, not only the improvement of safety and risk management but also the reduction of the physical load for drivers will be realized.

As Kroemer and Grandjean[6] point out, myoelectric activity has been studied systematically in various fields as an evaluation metrics for reducing the physical load which was described earlier. Wikström[7] conducted a study on the twist of the driver's body and the effect of vibration of vehicles while traveling, and Hostens and Ramon[8] studied the evaluation of physical load during the monotonous operation of vehicles. Salvucci and Liu[9], Imsland et al.[10], and Kitahama and Sakai[11] use accelerated velocity and steering angles as evaluation metrics in order to understand the traveling conditions of vehicles.

The development of a mobile environment is essential for physically impaired people to participate in society. However, so far, only small numbers of ergonomic studies on their driving conditions on highways have been conducted. For this paper, experiments were conducted on the Hanshin Highway Loop Lines and accelerated velocity, electromyogram, and steering angles were studied in order to understand the driving conditions on highways. Based on the experiments' results, this paper explains differences between physically impaired people and unimpaired people and examines the driving load from the view of ergonomics.

2. METHOD

Drivers sense vibrations or the centrifugal force of traveling vehicles both consciously and unconsciously, and the driver's feedback from the information supports safe driving. The changes of accelerated velocity in traveling and the driver's muscle tension reflect the driving conditions. These are important indicators for evaluating the safety of driving. Acceleration and deceleration of vehicles are shown as accelerated velocity in a front-back direction, while the information on centrifugal force created by driving on curves or by sudden turning of the steering wheel is indicated in accelerated velocity in a right-left direction. Using these indicators, the differences of driving conditions between disabled and unimpaired people were evaluated and examined to study whether the safety conditions of highways, which were designed based on travel by unimpaired people, satisfy the requirements for the driving of vehicles by disabled people.

2.1 Procedure for measuring the steering angles, accelerated velocity and electromyogram in order to examine driving conditions

In order to examine vital reactions when driving on highways and traveling conditions of vehicles, both electromyogram and accelerated velocity were measured with a Biopack System MP30 (Monte System Corp.), a portable 4-channel measurement system. All of the measured data were recorded onto a personal computer (PowerBook 2400/Apple Computer, Inc.) online. Video images were also used in order to examine driving performance.

The drivers' responses were recorded while they were driving on highways and while they were taking a 10-minute break before they began driving. The average driving time was 29 minutes 23 seconds (24min 47sec - 34min 47sec). Figure 1 is a diagrammatic illustration of the Hanshin Expressway loop line route no.1, which was used in this examination. Examiners explained to the subjects of this study about the purpose, method and possible risks of this experiment. An electrode was attached and the conditions for measurement were checked. Then the shoulders' trapezius muscle of the subjects was measured as an indicator during their rest. Measuring equipment was set inside the vehicle, and the personal computer was turned on by using the power source in the vehicle. The experiment was conducted with the subject's consent.

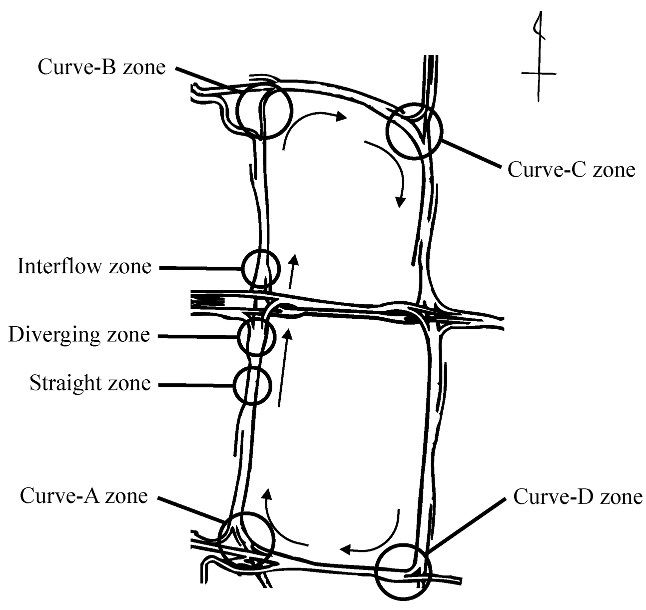


Fig. 1 Diagrammatic illustration of the travel route on the Hanshin Expressway for the experiment

2.1.1 Measuring steering angle

The steering angle is one of the indicators to evaluate driving techniques. Video images of subjects driving on motorways were shown on the computer screen, and the steering angles were measured from the selected curves according to the frame numbers. The upper part of the steering wheel on the frontal parallel plane was set as 0%, and rotation to the right was set as "minus" and rotation to the left as "plus". The time required for driving on a curve was divided into 10 segments, and the starting point of the curve was set. The associations between the size of steering angles and the time required on these 11 points were compared.

2.1.2 Measuring accelerated velocity

The conditions of a driving situation were evaluated by right-left and front-back acceleration indicators. The gauge for measuring accelerated velocity was set in different places inside the vehicles since the vehicles used for the measurement were owned by each subject. In order to obtain the best information about the influence on the drivers, the acceleration sensors were set on the most stable place near the driver's seat. The gauge for measuring accelerated velocity was a tri-axial acceleration gauge SS26L (5g) of the Biopack System (Monte System Corp.). The sampling speed was 500Hz. The detection zones were DC-500Hz, and the detection range was 0-5G. Noise which was detected during the drive over the joints of highways was erased.

2.1.3 Measuring with an electromyogram

The load on the shoulder area of the driver's trapezius muscle was measured during driving and the measurement was used as an indicator. The trapezius muscle relates to movements of the head which occur when one's shoulder is lifted or when one's upper limb is fixed. These kinds of muscle movements indicate people's muscle stress, and this is often observed in driving postures and other movements related to driving. The sampling speed of electromyography was set to 2500Hz, and a band-pass filter was used. The myoelectric activity of the right shoulders' trapezius muscle was recorded by the bipolar electrode induction method, and a shield electrode lead (SS2L) was used. Blue Sensor N-00-S (Medicotest Corp.) was used for the electrode on the skin surface to induct vital reactions for the electromyogram.

2.2 Characteristics of the subjects of the experiment

Ten disabled people and five unimpaired people participated in this experiment. All of them were volunteers and all of the vehicles used for this experiment were their own. The average age of the disabled subjects was 46.2 years old (33-66 years old). Five of them obtained a driving license after they became disabled. Their average period of driving experience after becoming disabled was 22.8 years (11-43 years). Among the 10 disabled people, 7 subjects had impairment in their lower limbs and 3 of them had impairment in both their upper and lower limbs. All of them belong to the first grade of disability, and eight were classified as first class and two were classified as second class. They had spinal damage in their cervical spines and thoracic spine regions. When they were outside, they used manual wheelchairs for mobility. The average age of the unimpaired people was 33.6 years old (23-61 years old), and the average period of driving experience was 14 years (3-44 years).

Four of the vehicles of the disabled people were Toyota's, 2 were Honda's, 2 were Nissan's and 2 were Mitsubishi's. The displacement of one vehicle was 2400cc, 8 were 2000cc and 1 was 1500cc. Five vehicles had modified steering in order to assist driving. The accelerator and brake of 9 vehicles had been remolded, and the alteration was due to impairment in lower limbs. The direction indicators of five vehicles had been remodeled. Examples of these remodelling are shown in Figure 2. The left picture shows an example of an assisting aid for subjects with impairments in the lower limbs, and the right picture is an enlarged view of a part of the accelerator and brake lever.

Fig. 2 Example of assisting aids for subjects with impairments in lower limbs

2.3 Characteristics of highways chosen for this experiment

In order to understand the traveling conditions of disabled people on highways, data analysis was conducted on curves, interflow and diverging zones, so that information was gained from previous interviews and observation of the driving conditions in which the driving load on the drivers is great. The selected curved zones are shown in Figure 1 as: Curve-A zone, Curve-B zone, Curve-C zone and Curve-D zone.

In this paper, each curve zone was divided into 3 sections (Fig. 3). Section 1 is from the starting point of a curve and the nose part of a diverging section. Section 2 is the area where a safety post is on the wall. Section 3 is the end of the curve and the nose part of the interflow. In addition, each zone of straight, split and interflow was also selected (Fig. 1).

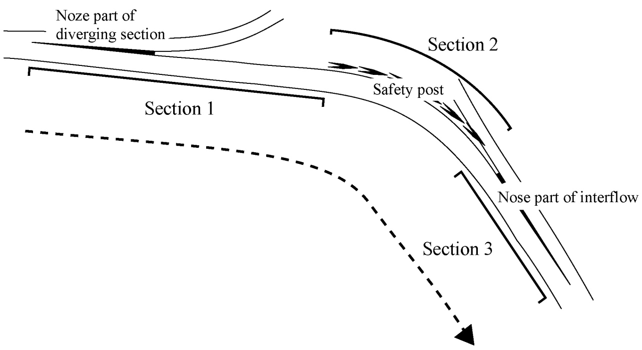


Fig. 3 Definition for the classification of each curve zone

3. RESULTS

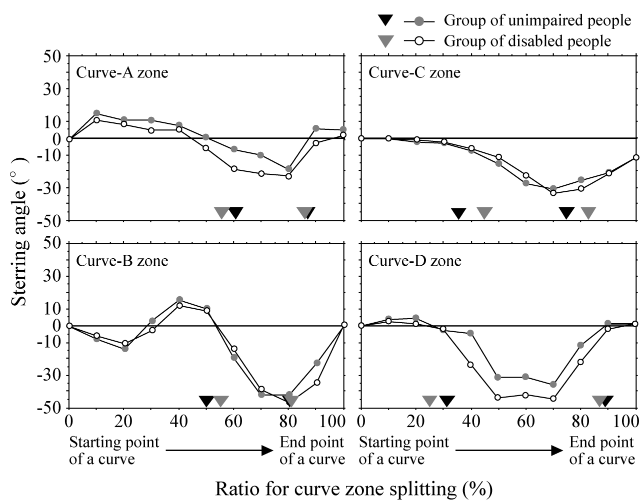
3.1 Driving load at curve zones based on the performance of steering control of drivers

The average angle for turning a steering wheel by the disabled subjects between Section 1 and 2 in the curve zone shows a specific result about road structure and driving techniques on curves. Figure 4 shows the steering angle when the starting point of a curve is set as 0° and the end part as 100%. Driving on curves is divided into two characteristics: single-curve and multiple-curve. Characteristics of a single-curve can be seen in the driving at the Curve-C zone and the Curve-D zone where steering wheels were turned in the same direction from start to finish of the curve.

The average steering angle and range at Curve-D zone were 9.7° (15.5) and 40.4° for the group of unimpaired people, and 16.0° (19.7) and 46.5° for the group of disabled people. The steering angle on curves showed significant differences ($t=3.30$, $p<0.008$). The angle for operating a steering wheel displays approximately 6° of difference. It was found that in the case of disabled people, the angle of the steering wheel was small just after they began driving on a curve and it increased as they drove round the curve.

The average steering angle of Curve-C zone for the group of unimpaired people was 12.9° (11.4) and the average range was 30.6°, and for the group of disabled people they were 12.6° (12.3) and 32.9° respectively. There were no significant differences between the two groups.

Curve-A zone and Curve-B zone were multiple-curves and the steering was operated in right-left directions. These curves indicated different changes of steering angles in comparison with that of the curves described earlier. In other words, the ranges of the steering by unimpaired and disabled people on Curve-A zone were 33.8° and 33.7° respectively, and the difference was 0.1°. However, the average angles were −2.6° (10.3) for the unimpaired and 3.1° (12.1) for the disabled group, and the difference was 5.7°. The time changes of steering angle showed significant differences between these two groups ($t=4.97$, $p<0.001$). This result was the difference in the steering angles between the first half and latter half of driving curves. The steering angle decreased as the vehicle reached the end of the curve with the unimpaired group, however, in comparison, the steering angle was smaller in the first half and greater in the latter half of the curve for the disabled group. At Curve-B zone, there were no significant differences between the two groups.

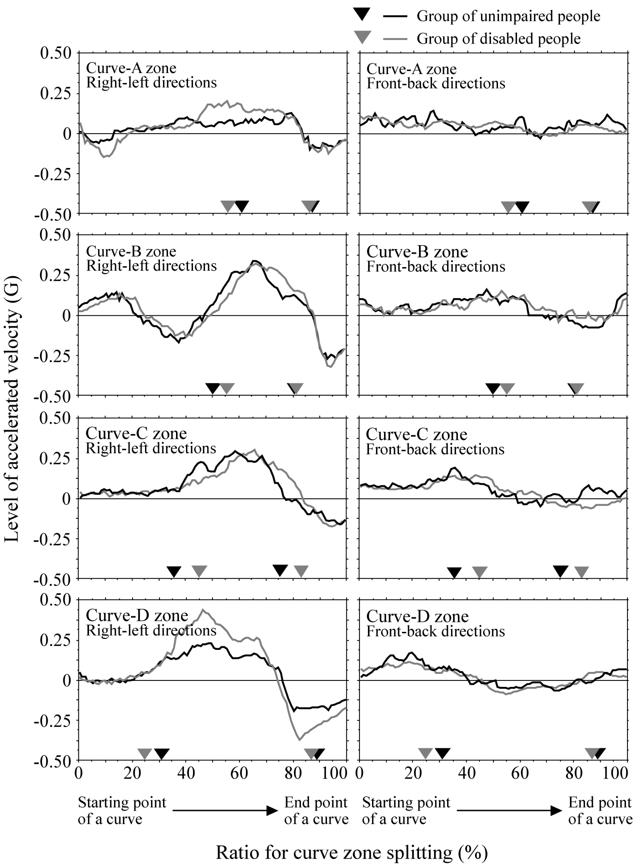


Note: The ▼ marks in the figure show the starting points of Sections 2 and 3.

Fig. 4 Comparison of the steering angle between the two groups

3.2 Changes of accelerated velocity and driving load on highways

In order to compare the accelerated velocity between the two groups of unimpaired and disabled people, the driving time on the selected zones for this analysis was divided into 100 time-units, and the accelerated velocity of a vehicle driving in right-left and front-back directions was compared. An average time was used for this data. Figure 5 shows the directions and size of the accelerated velocity of the two groups at four curve zones. The waveform noise of the velocity was smoothed, and the average velocity was calculated in time units.



Note: The ▼ marks in the figure show the starting points of Section 2 and 3.

Fig. 5 Comparison of the accelerated velocity between two groups

As to the accelerated velocity at the four curve zones, the results varied between the two groups. It became clear that some curve zones put more load on the disabled drivers, and they also experienced more difficulties in comparison with the unimpaired drivers.

Table 1 shows a comparison of average accelerated velocity and range of the two groups at the curve zones. As the table shows, the accelerated velocity was greater in the right-left direction for the disabled group and, except for Curve-B zone, the front-back direction was greater for the unimpaired group. The accelerated velocity of Curve-A and D zones shown in Figure 5 indicates significant differences between the two groups. In comparing the accelerated velocity and the range in the front-back direction between the two groups, the velocity of the unimpaired group was 1.3 and 1.4 times greater and the range was 1.4 and 1.2 times greater than those of the disabled group. The accelerated velocity and the range in the right-left directions were greater for the disabled group. Especially at Curve-A and D zones, the accelerated velocity was 1.4 and 1.5 times greater and the range was 1.5 and 1.9 times greater than for the unimpaired group. These results show the possibility that, at these zones, the disabled people were either conducting an improper reduction of speed or turning the steering wheel suddenly.

As a result of a t-test for the accelerated velocity of the two groups at the four curve zones, significant differences for the right-left direction were found at Curve-A zone ($t=2.00$, $p<0.05$) and Curve-D zone ($t=1.97$, $p<0.05$). As to the front-back direction, significant differences were found at Curve-A zone ($t=2.86$, $p<0.05$), Curve-C zone ($t=2.71$, $p<0.008$) and Curve-D zone ($t=3.02$, $p<0.003$). At Curve-B zone, the disabled people

Table 1 Comparison of the statistical values of accelerated velocity between the groups of unimpaired and disabled people

Directions of acceleration	Curve zones	Group of disabled people (N=10)		Group of unimpaired people (N=5)	
		Average accelerated velocity G (SD)	Range	Average accelerated velocity G (SD)	Range
Right-left	A	0.045 (0.099)	0.345	0.033 (0.059)	0.226
	B	0.053 (0.167)	0.661	0.049 (0.162)	0.626
	C	0.083 (0.122)	0.492	0.082 (0.126)	0.469
	D	0.064 (0.224)	0.810	0.044 (0.131)	0.427
Front-back	A	0.043 (0.031)	0.126	0.054 (0.036)	0.178
	B	0.051 (0.045)	0.201	0.046 (0.063)	0.245
	C	0.049 (0.064)	0.212	0.063 (0.054)	0.248
	D	0.023 (0.058)	0.200	0.032 (0.065)	0.237

kept to their driving state in the same way as the unimpaired people. A similar driving state could be estimated between the two groups at Curve-C zone, though a difference could be found in accelerating and decelerating of speed.

Figure 6 shows a comparison of accelerated velocity between the two groups at straight, diverging and interflow zones. In comparing the accelerated velocity among the three zones, all of the velocity for the disabled people was greater except when driving in a front-back direction at the interflow zone. The result of the t-test shows significant differences for all situations. The average accelerated velocity at the straight zones was 0.123G (0.028) in right-left directions and 0.106G (0.029) in a front-back direction for the group of disabled people, and 0.083G (0.019) and 0.083G (0.023) for the unimpaired group. The average accelerated velocity at interflow zones was 0.096G (0.013) in right-left directions and 0.099G (0.015) in front-back directions for the group of disabled people, and 0.073G (0.010) and 0.110G (0.027) for the group of unimpaired people. The average accelerated velocity at diverging zones was 0.114G (0.023) in right-left directions and 0.107G (0.023) in front-back directions for the group of disabled people, and 0.081G (0.011) and 0.076G (0.019) for the group of unimpaired people.

Next, the driving load was studied by examining the accelerated velocity at three sections, where safe driving is navigated. This evaluation of accelerated velocity was conducted by different methods from the indicators in Figure 5. An absolute figure was calculated after the measured waveform was equalized, and comparison was made by using the figure as an index of the size of the accelerated velocity. Furthermore, the driving time at curves was divided into 100 time-units and the average acceleration during each 1% was calculated. The borderlines of the curve zones for the groups of disabled and unimpaired people were identified, and the average accelerated velocity at each zone was calculated. Figure 7 shows a comparison of accelerated velocity for the two groups at the three different sections.

Regarding the accelerated velocity in a right-left

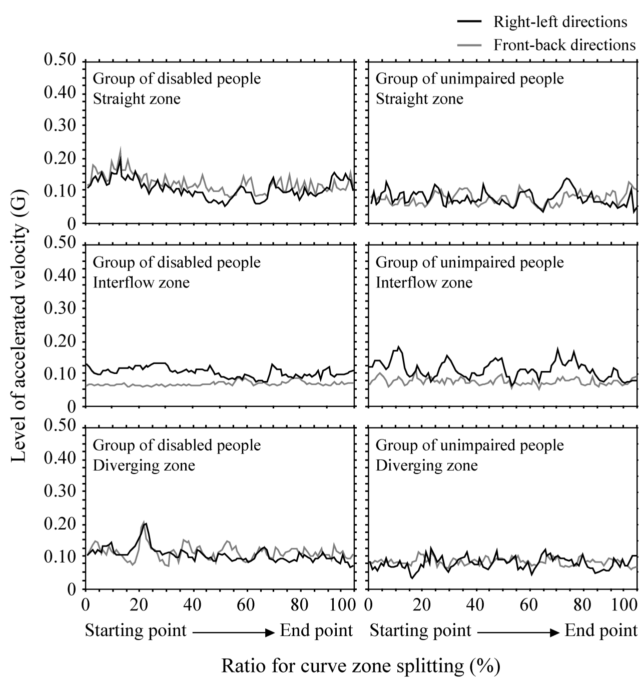


Fig. 6 Comparison of accelerated velocity of the two groups at straight, diverging and interflow zones

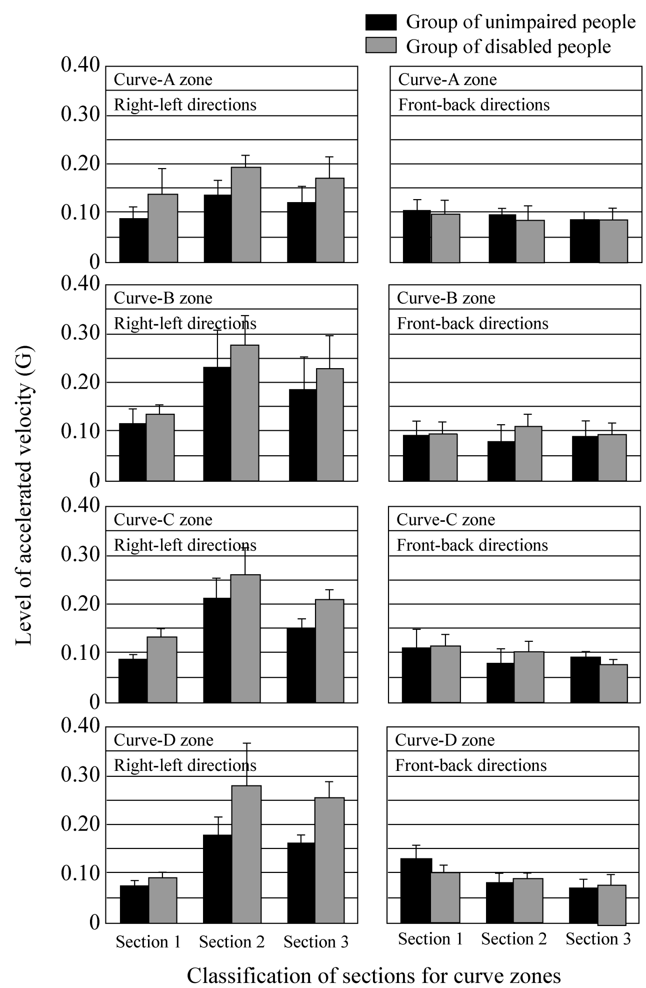
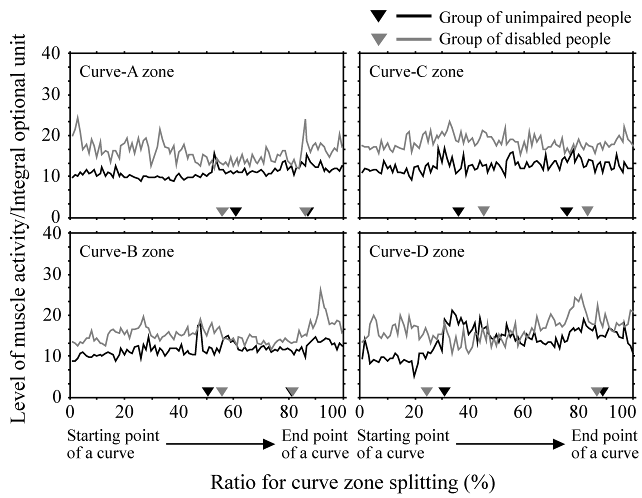


Fig. 7 Comparison of accelerated velocity of the two groups

direction at Sections 1, 2 and 3, the average accelerated velocity of the disabled people was high in all three sections. In addition, the velocity increased in the order of Section 1, Section 3 and Section 2. The biggest difference from the result obtained from the group of unimpaired people was at its most significant at Section 2 of Curve-D zone. This means that it is a typical zone that disabled people find difficult to deal with. At Section 2, the impact caused by the accelerated velocity in the right-left direction was the strongest. On this section, drivers feel tension in order to fix their posture, the upper half of the body leans as a backlash on Section 3 where the direction of acceleration changes, and then the upper limb is under strain from the effort to keep the posture and to control the vehicle. Thus, it is possible that more severe muscle tension is triggered and this will put more driving load onto the driver than under normal driving conditions.



Note: The ▼ marks in the figure show the starting points of Section 2 and 3.

Fig. 8 Comparison of the level of muscle activity among three sections

3.3 Evaluation of drivers' tension on highways from the point of view of muscle activity

In order to examine how the steering angle and acceleration velocity correspond to the activity of the trapezius muscle of the shoulders, the level of muscle activity was compared between the groups of disabled and unimpaired people by applying a method whereby the curve zones are divided into 100 sections as previously described.

A comparison of the average muscle activity at the four curve zones shows that myoelectric activity for the group of disabled people was higher than that of unimpaired people.

At Curve-A zone, the level of myoelectric activity was 21.9 (1.89) for the group of disabled people and 18.2 (0.97) for the unimpaired people. It was 23.7 (1.25) and 19.5 (1.14) at Curve-B zone. It was 23.7 (1.25) and 19.5 (1.14) at Curve-C zone and 22.4 (2.18) and 20.3 (2.48) at Curve-D zone. The result of a t-test showed statistically significant differences in all cases. Incidentally, the levels of muscle activity while the subjects were resting in a sitting position were 9.2 (2.16) for the disabled people and 9.7 (2.44) for the unimpaired people.

The best comparison of the level of myoelectric activity is often made by comparing the maximum activity of the trapezius muscle, but the technology for measuring the activity level of the disabled people is limited. Thus, in this experiment, RMS (Root Mean Square) of the electric potential of muscle activity was calculated, and the average-per-time unit was compared. Figure 8 shows a comparison of the level of muscle activity among three sections at each curve zone. The comparison of the curve zones and the level of muscle activity are an important index in order to understand how the disabled people respond to visual signs created according to the criteria of unimpaired people and what kind of condition they are driving in.

Figure 9 shows a comparison of the levels of myoelectric muscle activity between the groups of disabled and unimpaired people while driving on straight, interflow and diverging sections on highways. The result shows that the level of myoelectric activity for the group of disabled people was higher than for the group of unimpaired people.

Figure 10 shows a comparison of the levels of muscle activity between the groups of disabled people and

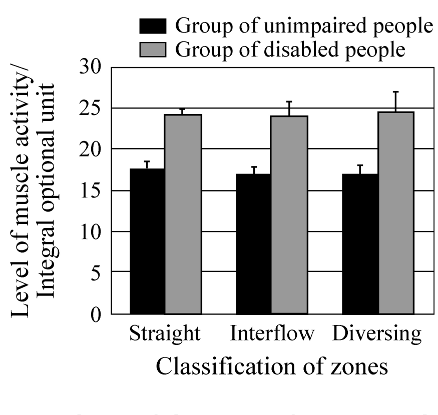


Fig. 9 Comparison of the level of myoelectric muscle activity between two groups

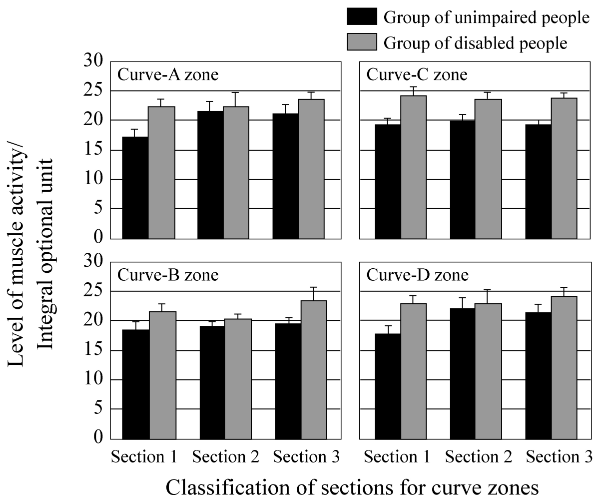


Fig. 10 Comparison of the levels of muscle activity between two groups

unimpaired people at the four curve zones. Similar to the result of the comparison of straight, interflow and diverging sections, the level of muscle activity for the group of disabled people was greater than for the group of unimpaired people in all sections. Furthermore, the level of myoelectric activity for the group of unimpaired people at the curve zones was higher than the myoelectric activity in the straight, diverging and interflow sections, but this tendency could not be found in the group of disabled people. A constantly high level of activity was found, which indicates high tension.

4. DISCUSSION

As Figure 4 shows, the difference of the steering angle between the groups of disabled and unimpaired people was significant at Curve-A and D. The angle was small when the vehicle enters the curve and it became larger later. In other words, sudden and rapid control of steering caused movement in the upper half of the driver's body and this put excess load on the driver. This kind of driving load is a burden for drivers and it becomes difficult to maintain posture and driving technique, especially for people with impairment to their lower limbs. In order to ease this situation, it is necessary to introduce a road structure and induction methods which disabled people can find easier to deal with, and the introduction of a warning signal which detects the driving status of a driver is also necessary. The introduction of a seat on which drivers can easily maintain a suitable posture is also needed.

When the temporal response for the turned angle of a steering wheel was similar in the two groups, it can be estimated that the situation was also manageable for the group of disabled people. If the detailed connection between the driving conditions and road structure is studied, this will be a help to reduce the driving load on disabled people. However, even if disabled people manage to handle the situation, the driving load for disabled people cannot be the same as for unimpaired people, though this should help to maintain the minimum driving safety. On the contrary, the driving conditions on highways which disabled people can not handle indicates that the situation certainly exists in which disabled people find it difficult to drive at high speed.

As Figure 5 shows, the accelerated velocity at Curve-A and D zones between the two groups of disabled and unimpaired people was significantly different in both right-left and front-back directions. It can be speculated that the driving load in these situations was heavier for the group of disabled people and it created a severe driving condition for them.

The accelerated velocity in a front-back direction shows either acceleration or slowing down of a vehicle, and this implies that the control of speed by the driver was different when driving at curved zones for both groups. Centrifugal forces on curves influenced the group of disabled people greatly. The body of a driver swings in a right-left direction when the vehicle enters or exits a curve. If the lower limbs of the driver cannot support the posture of the body, the body has to be supported by the upper limbs, thus creating a heavier driving load on the driver because the two actions, retaining body posture and driving the vehicle, have to be conducted at the same time. Especially when the steering wheel is turned back to its previous angle just before the end of a curve, the body of the vehicle swings a great deal. Disabled people cannot support their upper body as well as unimpaired people in order to handle the strong centrifugal force at curves. Thus, disabled people stretch their upper limbs and push their shoulders and their backs into the backrest of the driving seat in order to retain the posture of their upper body. However, at almost the end of a curve, turning the steering back contributes to losing balance for supporting the upper body.

As Figure 6 shows, the levels of accelerated velocity on straight, diverging and interflow sections were significantly different between the two groups. How the difference in the accelerated velocity reflects the driving load for the group of unimpaired people was studied from the activity of the trapezius muscle in the shoulders.

Figure 7 shows, similarly to differences of steering angles at Curb-A and Curb-D, the level of accelerated velocity in a front-back direction was high in the group of unimpaired people and this is an extremely interesting point. Acceleration in a front-back direction means an increase and decrease of speed. In both groups, greater acceleration of speed was found in Section 1 and the speed decreased as the vehicle moved to Sections 2 and 3. This means that the driver is traveling in response to road signs that indicate the driver should slow down, and this is stronger for the group of unimpaired people.

As Figures 8 and Figure 9 show, the level of myoelectric activity was higher in the group of disabled people and this implies that the driving load was constantly heavy for them. The tension in the trapezius muscle on the right shoulder relates to the actions of lifting one's elbow, fixing the upper body and driving a vehicle. This means that the active mass of the disabled people includes loads which are caused by actions other than driving.

As a result, the muscle tension of disabled people is constantly high when they are driving on highways, and a driving load is constantly put on the drivers (Fig. 10). Unlike the case of unimpaired people, when disabled people are driving, they receive a larger load on their body and they are constantly tense in order to deal with the situation.

The amount of muscle activity at the section of each curve became greater in an order corresponding to Sections 1, 3 and 2 for the group of unimpaired people, while the level of myoelectric activity became the greatest at Section 3 for the group of disabled people. This indicates that a driving load in response to the change of acceleration in a right-left direction was required.

5. CONCLUSION

In this study, it was found that the driving load for disabled people was heavier than that for unimpaired people, and it was also discovered that there are some difficult situations which exist for disabled people when they try to drive in the same way as unimpaired people. Driving environments are designed basically for use by unimpaired people, and building highways with small and sharp curves is inevitable. However, in this view, it is necessary to assure safe driving for disabled people and to prevent possible accidents. In order to support safe driving by disabled people, the following are required: (1) to investigate the driving load for disabled people based on their driving and traveling situations and to reduce their driving load as much as possible; (2) to predict danger and to develop traffic-warning systems equipped with functions for predicting dangerous situations.

As to the reduction of driving load, the installation of driving-aid devices to vehicles built basically for the movements of unimpaired people and the alternation of driving methods are not enough to support driving by disabled people. With an understanding of this situation, it is necessary to acknowledge the driving situation for disabled people scientifically and to understand their driving load. When disabled people are driving vehicles, one of their hands is mainly used for steering the wheel and another hand is used for controlling acceleration and braking. They cannot control the steering wheel with both hands; thus their posture is unstable when they are driving. Nine out of ten vehicles brought by disabled people for use in this experiment were also equipped with a system to control acceleration and braking by hand. In this view, for safe driving by disabled people, the following are required: (1) driver's seats which can stabilize the driver's posture even on curves; (2) development of a human interface system for disabled people; and (3) a support system for safety, such as access to information on road situations and warning systems when disabled people drive into the starting point of curves.

This prediction and providing of road-warning systems is a concept to support safe driving by disabled people by providing them with information about situations that they can find difficult to detect through the current sensors installed in their vehicles. So far, various kinds of support systems for unimpaired people have been planned, and are now getting ready for putting into practice.

Induction signs at the starting point of a curve are one method to provide information and to support safe driving. If induction systems to reduce the muscle tension of disabled people while driving their vehicles are developed and introduced, unimpaired people will also find it comfortable for driving. The road conditions created only for unimpaired people will only increase the driving load for disabled people.

As a future task, it is important to clarify dangerous areas from the viewpoint of disabled people. It is also necessary to evaluate conditions when people drive at high speeds, and this should happen not only by categorizing the groups of disabled and unimpaired people, but also by evaluating people individually or by comparing the conditions with more general roads.

REFERENCES

1. National Police Agency. Driver's license statistics. (2004).
2. National Rehabilitation Center for Persons with Disabilities. Physically handicapped people/senior citizens and driving: Historic process and present conditions. Chuohoki Publishers, Tokyo. (1994).
3. Hisari, Y., Mihoshi, A., Kitagawa, M., Hashimoto, N., Ehara, T. Fundamental examination of highways for senior citizens and handicapped people. "JSCE 57th annual meeting" IV-024: pp.47-48. (2002).
4. National Rehabilitation Center for Persons with Disabilities. Driving guidance handbook for physically handicapped people. Chuohoki Publishers, Tokyo. (1990).
5. Dols, J. F., Garcia, M., Sotos, J. J. Procedure for improving the ergonomic design of driving positions adapted for handicapped people. "Boletín Factores Humanos" 12-13: pp.7-17. (1996).
6. Kroemer, K., Grandjean, E. Fitting the task to the human, 5th edition. Taylor & Francis, London. (1997).
7. Wikström, B.-O. Effects from twisted postures and whole-body vibration during driving. "International Journal of Industrial Ergonomics" 12 (1-2): pp.61-75. (1993).
8. Hostens, I., Ramon, H. Assessment of muscle fatigue in low level monotonous task performance during car driving. "Journal of Electromyography and Kinesiology" 15 (3): pp.266-274. (2005).
9. Salvucci, D. D., Liu, A. The time course of a lane change: Driver control and eye-movement behavior. "Transportation Research Part F" 5 (2): pp.123-132. (2002).
10. Imsland, L., Johansen, T. A., Fossen, T. I., Grip, H. F., Kalkkuhl, J. C., Suissa, A. Vehicle velocity estimation using nonlinear observers. "Automatica" 42 (12): pp.2091-2103. (2006).
11. Kitahama, K., Sakai, H. Measurement method of normalized cornering stiffness. "JSAE Review" 21 (2): pp.213-217. (2000).

ACKNOWLEDGEMENTS

We would like to extend special thanks to Hanshin Toll Road Service Association and Hanshin Expressway Management Technology Center, for their help in this experiment. We would also like to extend special thanks to the people who participated in this experiment. Contact to the author: hiroshi.ikeda@union-services.com