A Proposal for Optimum Gripping Position and Operating Method Focusing on the Upper Limb Load and the Control Force

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Abstract. Many automotive industries have developed the Electric Power Steering which helps drivers steer. Before the development, gripping upper side of steering wheel was common because it is easy to exert the force on it. However, the spread of the EPS enables drivers to operate steering wheel easily if they grip anywhere. In addition, the American Automobile Association recommends to grip under side of steering wheel and to operate with Pull Push-steering from the viewpoint of driving fatigue and avoiding the risk of injury caused by air bag activation. This study thus proposes the position of optimum gripping and the method of operation by focusing on the control force applied to the steering wheel and upper limb load of the driver. First, the driving simulator was made up to obtain the data control force applied to steering wheel, force direction and steering angle. Secondly, two experiments were carried out under the three conditions; to grip upper side with cross steering, under side with cross-steering and under side with Pull Push steering focused on the control force applied to the steering wheel and upper limb load of the driver. These experiments showed the way to grip under side position is better than upper side position.

Keywords: steering wheel, upper limb load, control force, gripping position, operating method

1. INTRODUCTION

Approximately 250 years have passed since Cugnot invented the steam dray. It was called the first car in the world, and the automotive industry continues to develop today. Although various automotive technologies have been developed to enhance our lives, the number of casualties caused by traffic accidents cannot be said to have lessened. In fact, an increase in moving violations in recent years shows that a lack of attention among drivers has led to a significant increase in the number of traffic accidents. These include a failure to perform safety checks, inattentive driving, rolling stops, and ignoring signals. It is recommended that drivers take a break every two hours because human beings are thought to have reduced attention when they feel generally tired. In addition to the concept of fatigue, the American Automobile Association (AAA) has recommended that drivers steer with their grip under half of the steering wheel and use “push–pull” steering to avoid the risk of injury, such as fractures and blindness, caused by the operation of airbags. Until now, several studies have clarified the operability of steering wheels and the behavioral characteristics of steering operation. (Berti l, 2011; Imamura, Itoh, Zhang and Miyake, 2007; Katoh, Shibata, Bando, and Ikeda, 2013; Otsuka, Tachiwana and Doi, 2013) However, there are no studies which have evaluated the steering operation considering the grip position.

In this study, we suggest the optimum grip position and operation method focusing on the control force applied to the steering wheel and the upper limb load of the driver. First, we fabricated a driving simulator with force and motion sensors to obtain the data such as the control force applied to steering wheel, force direction, and steering angle. Second, two experiments were conducted under four conditions: grip the upper side with cross steering, grip the underside with cross-steering, grip the upper side with push–pull steering, and grip the underside with push–pull steering while focusing on the control force applied to the steering wheel and upper limb load of the driver.

2. DEVEROPEMENT OF THE EXPERIMENTAL DEVICE

2.1 Driving Simulator

In this study, two experiments were conducted using the driving simulator designed and fabricated by us, as shown in figure 1. These experiments clarified the control force and upper limb load during the driving operation. This section shows the equipment that comprised the driving simulator and experimental devices.

a. Six-axis force sensor

A Six-axis force sensor (WEF-6A500-10-RC5-A, WACOH-TECH Inc.) can measure force in the X-, Y-, and Z-axis directions and torque about the X-, Y-, and Z-axes. In this study, the sensor was attached to the fixed part of the steering wheel and measured the control force applied to the steering wheel.

b. Nine-axis motion sensor

A motion sensor (IMU-Z2, ZMP INC.) is a device for detecting the three-dimensional position by combining acceleration, gyro, and geomagnetic sensors. In this study, the sensor was attached to the center of the steering wheel and measured the steering angle.

c. Hardware and software of the driving simulator

The driving simulator employed in the experiment used a PlayStation 3(CECH-2100, Sony Interactive Entertainment Inc.) and Gran Turismo 6. It included a decomposed steering controller (Thrustmaster T300RS, Guillemot Corp.) and incorporated an actual vehicle steering wheel and 6-axis force sensors.

d. Surface electromyogram

An electromyogram (EMG) can visualize the muscle potential generated due to human muscle activity. It can evaluate a muscle load by calculating %MVC what the muscle exerts when working, against the maximum muscle load exerted. In this study, we used an EMG measurement system(SX230-1000) and TRIAS which is an EMG analysis system manufactured by DKH Ltd.

2.2 Preparation of the Experiment

The driving simulator could measure force and torq ue in the X-, Y-, and Z-axes in world coordinates becau se the 6-axes force sensor rotated along with the steerin g wheel. Therefore, we measure the steering angle of a time series using an acceleration sensor in synchronism with the data sampling period of the force sensor (10m s). We then converted the local coordinate system to the world coordinate system by combining the operating forc e data. The calculation formula is (1) ~ (5).

$$RF_D = \left(\arctan(F_x, F_y) * \frac{180}{\pi}\right) - \theta_A \quad \cdots(1)$$

$$RF_M = \sqrt{{F_x}^2 + {F_y}^2} \quad \cdots(2)$$

$$GF_x = \cos(RF_D) * RF_M \quad \cdots(3)$$

$$GF_y = \sin(RF_D) * RF_M \quad \cdots(4)$$

$$GF_z = F_z \quad \cdots(5)$$

（RF_D ：The resultant force direction, θ_A ：The steering angle, RF_M ：The resultant force magnitude, GF_x, GF_y, GF_z ：The control force of the axial direction in the global coordinate system）

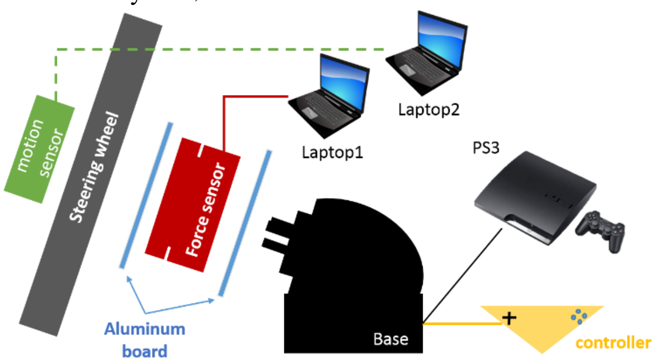


Figure 1: The configuration of the driving simulator

3. EXPERIMENT Ⅰ

3.1 Experimental Tasks

In this experiment, the control forces applied to the steering wheel in the X-, Y-, and Z-axis directions were measured using the driving simulator in case the grip position and operation method were different. The experimental task was to perform a left turn by operating the steering wheel counterclockwise for 5 s followed by clockwise for 5 s. The experimental conditions were “upper cross” steering, “upper push–pull” steering, “under cross” steering, and “under push–pull” steering with a combination of two levels of the grip position (upper, under) and two levels of the operating method (cross steering, push–pull steering). We conducted three trials for each condition. Also, as described in the previous section, the control force data in the X-, Y-, and Z-axis directions obtained in this experiment were in the sensor local-coordinate system. Therefore, they were converted to the world coordinate system using the previous formula (1) ~ (5).

The force required for the steering operation was a tangential force on the steering wheel in the XY plane. Therefore, in this experiment, the magnitude of the resultant force in the XY plane was used us an index of evaluation. Also, the Z-axis force—i.e., pushing and pulling forces on the steering wheel—was considered to be unrelated to the direction. Therefore, in this experiment, the Z-axis direction force was used as an index of evaluation of the waste of force.

3.2 Experimental Procedure

Five graduate and undergraduate male students were used as subjects for this experiment. All subjects were right handed, and a year had passed since they acquired their driver's licenses. The mean and standard deviation for the age, height, and body weight of the subjects were21.6 ± 0.9 years old, 176.2 ± 3.6 cm and 65.6 ± 9.1 kg, respectively. After they settled in their usual driving postures, we adjusted their elbow joint angles to be approximately 110° (Fig.2). Furthermore, to eliminate any order effect, the order of the conditions (Fig.3) was randomized for each subject.

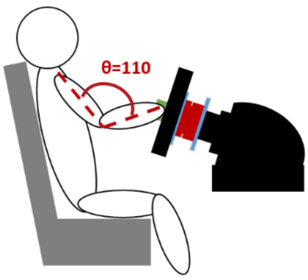


Figure 2: Basic Posture

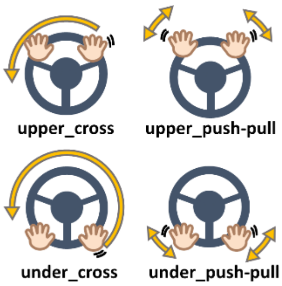


Figure 3: Experimental conditions

3.3 Result

Graphs of the resultant force in the XY plane and the Z-axis direction force are shown in Fig. 4. And the result of the analysis of variance(ANOVA) is shown in Fig.5. First, by looking at the average value of the resultant force in the XY plane, it can be seen that the subjects' control force was minimal in the case of upper cross steering and under push pull steering. Also, there was no consistency in the size of the control force caused by differences in the experimental conditions. Looking at the results of the ANOVA, no significant differences were observed in the magnitudes of the resultant force in the XY plane due to the experimental conditions. Second, if you look at the average value of force in the Z axis direction, it was found that the wheel could be operated with a smaller control force in the conditions of upper push pull steering and under push pull steering than in the other conditions. In the ANOVA results, a significant difference was observed in the main effect of the operation method. Therefore, it was found that subjects were able to operate the steering wheel with a small control force using these two methods.

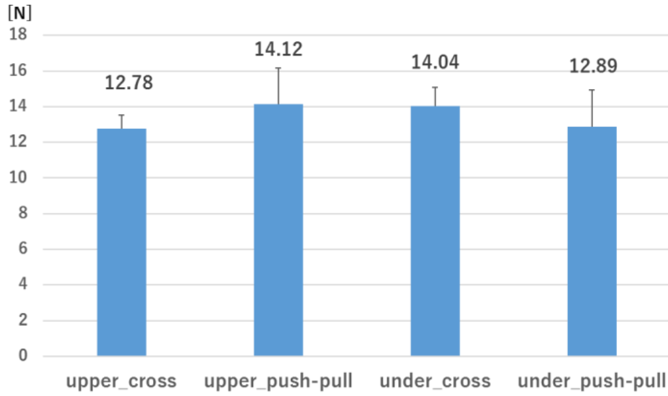


Figure 4: (a)The XY resultant force

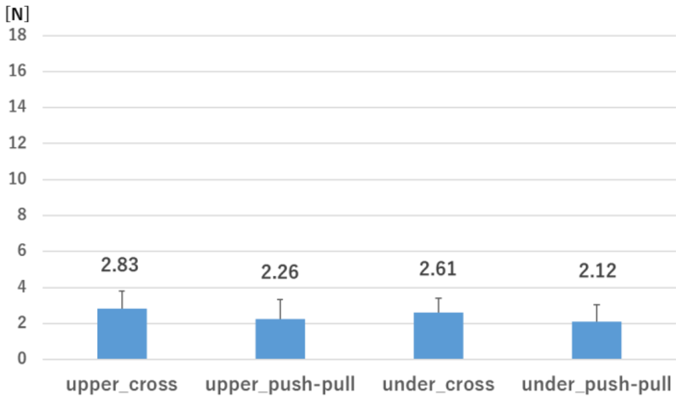


Figure 4: (b)The Z-axis direction force

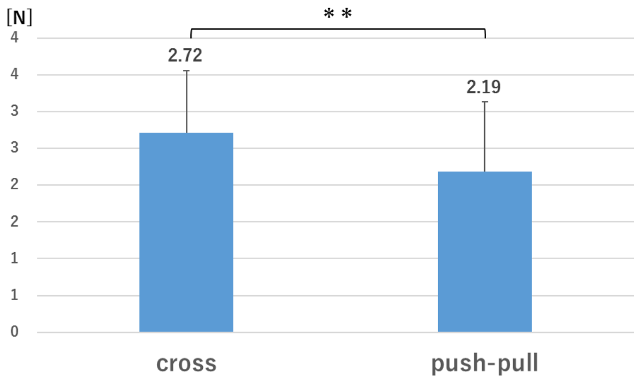


Figure 5: The result of the ANOVA

3.4 Discussion

In this experiment, significant differences in the Z-axis direction force due to differences in the grip position were not observed; however, it was observed in the operation methods. First, we considered the reason why a significant difference was not observed due to a difference in the grip positions. The cross steering operation became basically the same operation except that the beginning of the gripping position was different. Also, the push–pull steering operation basically turned into the same operation except that it was performed either on the upper side or underside. Therefore, it was believed to be the reason why a significant difference was not observed. Second, we considered the reason why a significant difference was observed due to a difference in the operation method. In cross steering, the pushing and pulling force generated when operating the steering wheel by flexion and horizontal adduction of the shoulder joint was considered a waste of force. Furthermore, in push–pull steering, the pushing and pulling forces were considered a waste of force. It was generated by the operation of the push–pull steering, which was a repetition of gripping the left part of the steering with the left hand on the lower side and gripping the right part of the steering with the right hand on the upper side. These results found that the push–pull steering condition with an underside grip is the best way from the viewpoint of control force.

However, if the condition wherein the underside is gripped increases the upper limb load, it cannot be considered to be the best way even though it is better from the control force viewpoint. Consequently, we conducted another experiment on upper limb loads under the same conditions.

4. EXPERIMENT Ⅱ

4.1 Experimental Tasks

In this experiment, the upper limb load was measu red by the surface EMG for a case wherein the grip po sition and operation method were different for the specifi ed course: two left turns and two right turns. Eight mus cles were chosen as test muscles: trapezius (top), anterio r deltoid, infraspinatus, pectoralis major (clavicle part), tr iceps long head, biceps, extensor carpi radialis, and exte nsor carpi ulnaris. These correlated that had a strong rol e in the steering operation and were shown in the releva nt papers to cause body effects such as a stiff neck.(Miz uno, Hayama, Kawahara, Lou, Liu and Ji, 2012; Nishika wa, Furukawa, Kawate, Miyazaki, Nouzawa and Tsuji, 2 015; Takahashi, Sugano and Okazaki, 2013) In this expe riment, the compared upper limb load during left and rig ht turns was considered as the difference in upper limb load exerted during the left and right turns. The position s of the test muscles are shown in Fig.6.(Aldo, 1997, Ki zuka, Masuda, Kiryu and Sadoyama, 2006; Criswell, 201 1) The experiment was conducted using the following pr ocedure: After assuming the driving position, 5s of relax ation, 5s operation preparation, running the specified cou rse, 5s of posture maintenance, and 5s of relaxation. The experimental conditions were the same as that in Experi ment I and for three trials in each condition.

4.2 Experimental Procedure

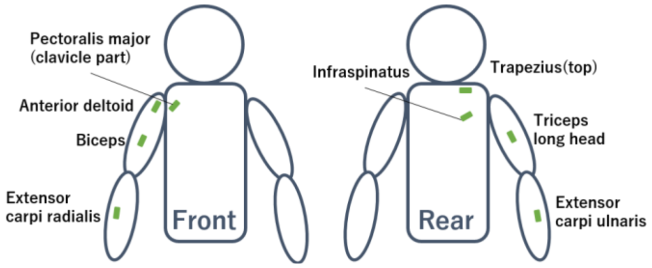


Figure 6: The position of each test muscles

Five graduate and undergraduate male students were used as subjects for this experiment. All were right handed and a year had passed since they acquired their driver's licenses. The mean and standard deviation of the age, height, and body weight of the subjects were 21.6 ± 0.9 years old, 176.2 ± 3.6 cm and 65.6 ± 9.1 kg, respectively. After assuming their usual driving posture, we readjusted their elbow joint angles to be approximately 110°. Furthermore, to eliminate any order effect, the order of the conditions was randomized for each subject. Also, in this experiment, we set the running speed to 40 km/h without accelerator operation to avoid the dual task of steering and accelerator operation.

4.3 Result

The graph of the average %MVC of each of the test muscles in the left and right turn section is shown in Fig. 7. If we look at the average value of the %MVC for the trapezius (top), it can be seen that the %MVC was less when gripping the underside of the steering wheel. The ANOVA results showed significant differences due to the experimental conditions in the main effect of the grip position. If we look at the average value of the %MVC for the anterior deltoid, it can be seen that the %MVC was less when gripping the underside of the steering wheel and operating with push–pull steering. The ANOVA results showed significant differences in the main effect of the grip positions and the operation methods due to the experimental conditions. If we look at the average value of the %MVC for the pectoralis major (clavicle part), no regularity or characteristics can be seen; however, the ANOVA results show significant differences due to the experimental conditions in the main effect of the grip positions and operation methods. If we look at the average value of the %MVC for the triceps long head, it can be seen that the %MVC was less when gripping the upper side of the steering wheel and operating with cross steering; the ANOVA results show significant differences due to the experimental conditions in the main effect of the grip positions and operation methods. If we look at the average value of the %MVC for the biceps, it can be seen that the %MVC was less when gripping the upper side of the steering wheel and operating with cross steering; the ANOVA results show significant differences due to the experimental conditions in the main effect of the grip positions and operation methods. If we look at the average value of the %MVC for the extensor carpi radialis, it can be seen that the %MVC was less when gripping the upper side of the steering wheel and operating with cross steering; the ANOVA results show significant differences due to the experimental conditions in the main effect of the grip positions and operation methods. If we look at the average value of the %MVC for the extensor carpi ulnaris, it can be seen that the %MVC was less when operating with cross steering; the ANOVA results show significant differences due to the experimental conditions in the main effect of the operation methods.

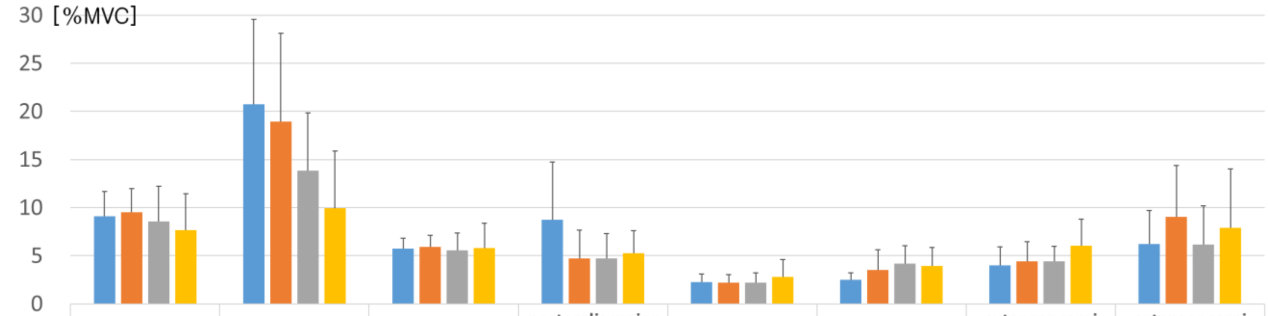
4.4 Discussion

4.4.1 Influence of the difference in grip position on the upper limb load

First, we considered the influence of a difference in the grip position on the upper limb load. For the left and right turn section, the upper limb loads on the trapezius (top), anterior deltoid, and pectoralis major (clavicle part) reduced when gripping the underside of the steering wheel. Meanwhile, the triceps long head, biceps, extensor carpi radialis, and extensor carpi ulnaris decreased when gripping the upper side of the steering wheel. At a glance, it was thought that gripping the upper side of the steering wheel was a better way because the loads increased in four muscles while decreasing in three muscles. However, looking at the conditions of gripping the upper side and underside, the total %MVC was found to be 117.59 and 98.99, respectively. (Fig.8) The reason for this was that in the conditions of gripping the upper side of the steering wheel required the elevation and flexion of the shoulder and shoulder joint. Therefore, it was considered that the upper limb loads on the trapezius (top), anterior deltoid, and pectoralis major muscle clavicle part were increased to maintain the posture. Also, it was considered that the triceps long head, biceps, extensor carpi radialis, and extensor carpi ulnaris were used to finely control the rotation of the steering wheel. The amount of %MVC was small for differences in grip position because these muscles varied the limb position of the forearm with the grip position, but the operation did not change much. Therefore, it was found that a steering wheel can be operated with a small upper limb load when gripping the underside of the steering wheel.

4.4.2 Influence of the difference in operating method on the upper limb load

Second, we considered the influence of a difference in the operating method on the upper limb load. For the left and right turn section, the upper limb load on the anterior deltoid and pectoralis major (clavicle part) decreased when operating with push-pull steering; also, the upper limb load on the triceps long head, biceps, extensor carpi radialis, and extensor carpi ulnaris decreased when operating with cross steering. Similar to the previous section, at a glance, it was considered that operating with cross steering was a better way because the upper limb load increased in four muscles while decreasing in two muscles. However, looking at the conditions of cross steering and push–pull steering, the total %MVC was found to be 109.02 and 107.56, respectively. (Fig.9) This is because the condition of



	trapezius (top)	anterior deltoid	infraspinatus	pectoralis major (clavicle part)	triceps long head	biceps	extensor carpi radialis	extensor carpi ulnaris
upper_cross	9.13	20.76	5.73	8.77	2.28	2.51	3.98	6.21
upper_push-pull	9.50	18.96	5.92	4.72	2.21	3.49	4.40	9.02
under_cross	8.57	13.83	5.57	4.69	2.21	4.20	4.39	6.19
under_push-pull	7.63	9.97	5.81	5.28	2.77	3.93	6.03	7.90

upper_cross upper_push-pull under_cross under_push-pull

Figure 7: The average %MVC of each test muscles

cross steering required flexion and horizontal adduction of the shoulder joint. Therefore, it was found that a steering wheel can be operated with a small upper limb load when using push–pull steering. Furthermore, in this experiment, the maximum steering angle was approximately 45°. If the steering angle was larger, it is thought that the upper limb load would be larger.

4.4.3 Conclusion of Experiment Ⅱ

In sections 4.4.1 and 4.4.2, we considered the influence of the difference in the grip position and operating method on the upper limb load. The results of these considerations are that the loads on the trapezius (top), anterior deltoid, and pectoralis major (clavicle part), which affected the elevation, flexion, and horizontal flexion of the shoulder joint, were small in the condition of under push–pull steering. Therefore, it was found that under push–pull steering was the best way to operate a steering wheel from the viewpoint of upper limb load.

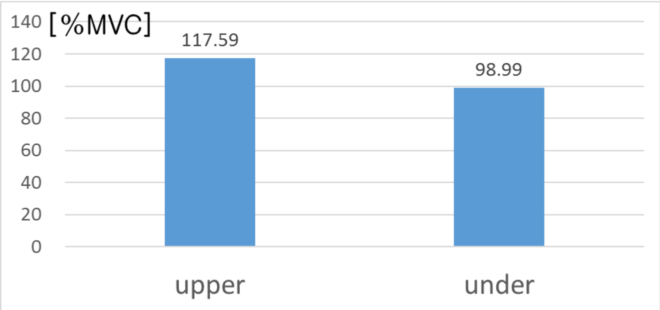


Figure 8: The Total %MVC of each gripping positions

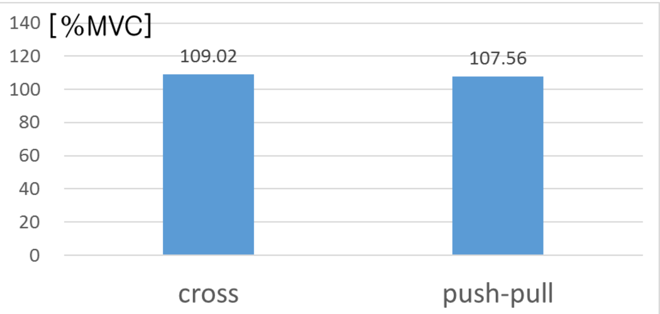


Figure 9: The Total %MVC of each operating methods

5. CONCLUSION

In this study, we clarify the driving method that can be operated with a small load under the condition "under_push-pull" steering. This was done by two types of experiments using a driving simulator that was fabricated by us. First, in the control force experiment, we imposed a left turn task on the subjects and compared the magnitude of the resultant force in XY plane and the Z-axis direction force for all four conditions, which included a combination of two levels of the grip position (upper, under) and two levels of operation method (cross steering and push–pull steering). As a result, it was found that the condition wherein a subject grips the underside of a steering wheel with push–pull steering is a better way from the viewpoint of control force. Second, the experiment on upper limb loads was carried out under the same four conditions. As the result, it was found that under push–pull steering was the best way to operating a steering wheel from the viewpoint of upper limb load.

However, there are various road environments. Hence, it is thought that the driving load will change for different driving modes such as driving in the city or on the highway. Therefore, adding the various environmental conditions in the experiment will be necessary.

REFERENCES

Aldo O. Perotto (1997) *Anatomical Guide for the Electromyographer: The Limbs and Trunk (in Japanese)*, 34-37, 66-67, 74-75, 80-81, 86-87, 90-91, 234-235

Bertil, J. (2011) Hand Position on Steering Wheel During Driving, *Traffic Injury Prevention*, 12:187–190

Criswell, E. (2011) *Cram's Introduction to Surface Electromyography, Second Edition*, Jones & Bartlett Learning, 103-114

Imamura, T., Itoh, K., Zhang, Z. and Miyake, T. (2007) Measurement of Car Driver' s Behavior based on Holding and Driving Style of a Steering Wheel, *Proceedings of the 2007 JSME Conference on Robotics and Mechatronics*, Akita, Japan, 1A2-E07 (in Japanese)

Katoh, A., Shibata, T., Bando, T. and Ikeda, K. (2013) A study on investigating the difference between expert and non-expert drivers using an easy-to-use driving simulator, *IEICE Technical Reports*, **113**(111), 95-100 (in Japanese)

Kizuka, T., Masuda, T., Kiryu, T. and Sadoyama, T. (2006) *Biomechanism Library Practical Usage of Surface Electromyogram*, Tokyo Denki University Press, 15-17

Mizuno, T., Hayama, R., Kawahara, S., Lou, L., Liu, Y. and Ji, X. (2012) Research on Relationship between Steering Maneuver and Musclus Activity, *Jtekt Enjineering Jounal*, 1010, 13-18 (in Japanese)

Nishikawa, K., Furukawa, K., Kawate, I., Miyazaki, T., Nouzawa, T. and Tsuji, T. (2015) Analysis of steering wheel operations based on human arm mechanical properties, *Transactions of the JSME*, **81**(831) (in Japanese)

Otsuka, Y., Tachiwana, S. and Doi, S. (2013) Improvement of Handling Feeling Based on Grasping Characteristic of Driver, *Transaction of the JSME*, **79**(806), 15-25 (in Japanese)

Takahashi, H., Sugano, T. and Okazaki, T. (2013) A Study of Lane Keeping Assistance by Steering Control Based on Muscular Activity, *Mazda Technical Review*, 31, 131-136 (in Japanese)