Research on Relationship between Steering Maneuver and Muscles Activity

T. MIZUNO R. HAYAMA S. KAWAHARA L. LOU Y. LIU X. JI

To operate driver assistance systems (DAS) at optimum efficiency, establishment of a system evaluation method including behavior of the driver is necessary. In this study, muscle behavior during steering maneuvers has been investigated in order to create an estimation method of a driver's physical workload and an evaluation method for DAS. This paper reports on the investigation results of muscle behavior while stabilizing the steering wheel. Multiple muscles were simultaneously activated corresponding to each steering direction. When CCW direction torque was generated by the driver, it was observed that the anterior deltoid on right shoulder was activated first. And then, infraspinatus was activated and finally the middle deltoid and pectoralis clavicular muscles were activated.

Key Words: *steering maneuver, electromyography (EMG), driver's physical workload*

1. Introduction

Many driver assistance systems (DAS) adopting electronic control technology are being put to practical use in order to improve safety and energy efficiency. DAS also contribute to the improvement of vehicle stability and maneuverability. In particular, electric power steering systems are expected to advance in the future as important role of DAS. Already, due to demands such as consideration for the environment and maneuverability, a function to assist steering is adopted in many vehicles. R&D is being carried out to create new DAS and improve energy efficiency through the application of this function.

DAS performance impacts on the overall behavior of the entire system, including maneuvers made by the driver. A performance evaluation of the overall system including the driver's maneuver is necessary to alleviate driver's physical workload and further reduce traffic accidents.

In quantitative evaluations on steering performance, the driver inputs of steering angle and torque are measured, as well as vehicle behavior such as yaw rate and lateral acceleration. These measurements are evaluated based on correlation with results of subjective evaluations. In recent years, evaluation methods using the physiological indicators of drivers are also being examined. For example, trials have been performed to evaluate steering performance by quantitatively measuring driver shoulder and upper limb muscle activity with electromyography (EMG)[1)–12)].

The authors have investigated muscle activity in steering maneuvers to establish a steering performance evaluation method and a technique to estimate steering workload of the driver. With consideration to kinematics and movement anatomical science during driver steering, 10 muscles able to be measured with EMG were selected. Moreover, the roles of muscles and features of their activation when the driver changes the steering wheel angle have been shown in previous study[13)].

This paper reports the results of an investigation of muscle activity during the subject stabilizes the steering wheel (hereinafter "Passive Steering"). First, **Section 2** describes the muscle selection process and gives an overview of its results. **Section 3** explains the method of tests performed to investigate the role and characteristics of the selected muscles. **Section 4** discusses the order of muscle activity at steering. Finally, **Section 5** provides an overall summary.

2. Selecting Muscles for Measurement

Selecting muscles is required in order to investigate mascle activities involved with driver's steering maneuvers using EMG. There is a publication[4)] which reports that the anterior deltoid, clavicular portion of pectoralis major, sternal portion of pectoralis major, posterior deltoid, middle deltoid, long head of the triceps, lateral head of the triceps, and biceps are activated. And also this publication reports that the shoulder muscles are

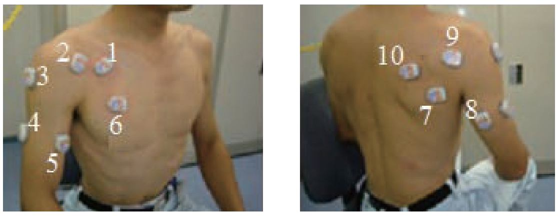
**1 This paper was prepared based on the FAST-Zero'11 Proceedings (20117373) hosted by JSAE in 2011.*

primarily active in the steering maneuver. In this study, measured muscle selected with referral to this publication.

Steering maneuvers, from the perspective of kinematics, include not only flexion and extension of the upper limb, but also abduction, adduction, supination and pronation. Based on knowledge of movement anatomical science, teres major and infraspinatus were selected as measured muscle. **Figure 1** shows the selected muscles and their positions as well as the related maneuvers.

3. Test Method

A basic test was performed using a Driving Simulator (DS) in order to investigate muscle activities in steering maneuver. This study aims to clarify the basic properties of the steering muscle activation order and examines steering by the driver to stabilize steering wheel angle against disturbance. Passive steering conditions are similar to steering maneuvers when driving in a straight line, which accounts for the majority of time spent driving a vehicle. Therefore this conditions are important in the establishment of a method to estimate steering workload.



No	Muscles	Upper limb movements around the shoulder joint					
		Flexion	Extension	Abduction	Adduction	Supination	Pronation
1	Clavicular portion of pectoralis major	★			☆		★
2	Anterior deltoid	★					★
3	Middle deltoid			★			
4	Lateral head of the triceps		☆				
5	Biceps	★					
6	Sternal portion of pectoralis major				☆		☆
7	Teres major		★		★		★
8	Long head of the triceps		★		☆		
9	Posterior deltoid		★			★	
10	Infraspinatus		☆		★	☆	

Fig. 1 Relation between studied muscles and movement of upper limb and upper arm.
(★Related closely, ☆Related slightly, Blank: No relation)

3. 1 Test Conditions

Test subjects have been required to sit on a driver's seat on the driving simulator shown in **Fig. 2**. Here, subjects stabilized the steering wheel against the triangular waveform steering reaction torque with an amplitude of 5 Nm and frequency of 0.025 Hz, as shown in **Fig. 3**. In this DS, a steering column was mounted in front of a driver seat imitated a passenger vehicle. Based on the driver's operations, it was possible to generate steering reaction torque using a reaction actuator. This DS has good capability for evaluations of steering systems including vehicle behavior. In this test, only a function of steering torque control was used.

The amplitude of 5 Nm was set to be equivalent to the torque borne by the driver when steering a vehicle with a function of assisted steering. Moreover, the frequency was determined in quasi-stable range in order to investigate activation order of muscle activity.

Figure 4 shows the basic posture of the subjects. Subjects were asked to position themselves so that the angle between their forearm and upper arm was approximately 110 degrees. A grasping position of right hand on the steering wheel was set at 3 o'clock position. The left hand was released from the steering wheel. The view of the DS test is shown in **Fig. 5**.

The steering wheel angle and torque were measured. Also, EMG signals related to the abovementioned upper limb movement were measured. These measurement results were recorded in a data logger at a sampling frequency of 1 kHz. The muscles listed in **Fig. 1** were measured. EMG signals were transmitted from a wireless sensor unit to a logger by radio wave. Since the sensors were small enough and lightweight, the subject could maneuver ordinarily and natural operation maneuvers were realized.

Fig. 2 Driving simulator

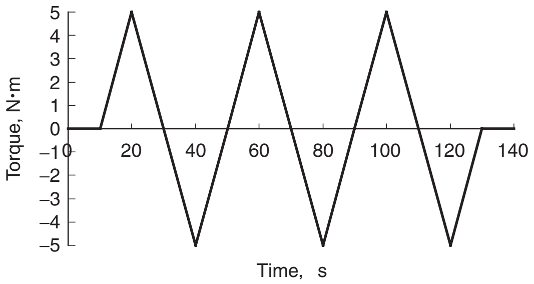


Fig. 3 Steering wheel torque from DS

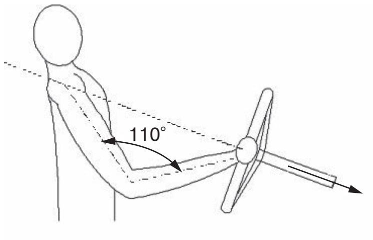


Fig. 4 Basic posture

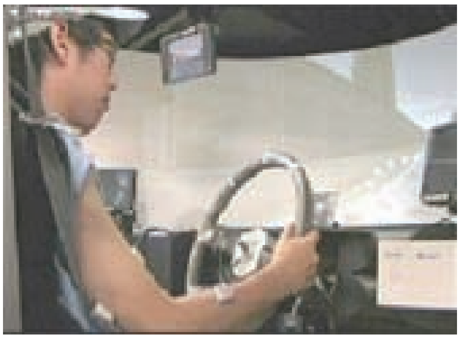


Fig. 5 View of DS test

Table 1 Grouping of subject

Group	Description	Number of subjects
A	Experienced	7
B	General	7
C	Inexperienced	6

3. 2 Test Subjects

20 subjects aged between 25 and 50 participated in the test. The subjects was selected based on guidelines shown in **Table 1** with consideration to the influence of their driving skill on the examination.

Group A consists of subjects who had received driver training as steering evaluators. Group B consists of subjects who drive on a daily basis. Group C consists of subjects who do not drive daily and have insufficient driving experience. 7, 7 and 6 subjects were chosen and assigned to Groups A through C respectively.

4. Test Results

Out of the passive test results, **Fig. 6** (A) through (C) show the results of one subject from each group. The X axis of the graph shows the time, while the Y axis shows (from the top) steering torque, the EMG signals of biceps, anterior deltoid, middle deltoid, clavicular portion of pectoralis major, infraspinatus, lateral head of the triceps, long head of the triceps, posterior deltoid, sternal portion of pectoralis major and teres major. The positive value of steering torque is the subject's input torque in the CW direction opposing the torque generated by the DS in the CCW direction. EMG signals have been processed with a 15 to 500 Hz band path filter and the root mean square has been applied for 100 samples. (Here, the steady vibration of the sternal portion of pectoralis major indicates heart muscle activity).

4. 1 Torque Direction and Muscle Activation

In the CW input by the subject (approx. 15 to 25 s, 45 to 60 s, 85 to 105 s of **Fig. 6**), the long head of the triceps, lateral head of the triceps, posterior deltoid and teres major were largely activated. Meanwhile, in the CCW input by the subject (approx. 25 to 45 s, 65 to 85 s, 105 to 115 s of **Fig. 6**) the clavicular portion of pectoralis major, anterior deltoid, middle deltoid, infraspinatus and teres major were largely activated.

Table 2 is a summary of these results. Results for the subjects not shown in **Table 2** also had the same trend. Furthermore, no differences were recognized between the groups, with muscle activation being the same regardless of driving skill.

Moreover, regardless of the direction of the torque the steering was opposing, multiple muscles were observed as being activated at the same time. Therefore it was observed that passive steering maneuvers cannot be achieved with single muscle activity.

There was a trend of the lateral head of the triceps (**Fig. 6** (A)) and posterior deltoid (**Fig. 6** (C)) being active when torque was outputted in both directions.

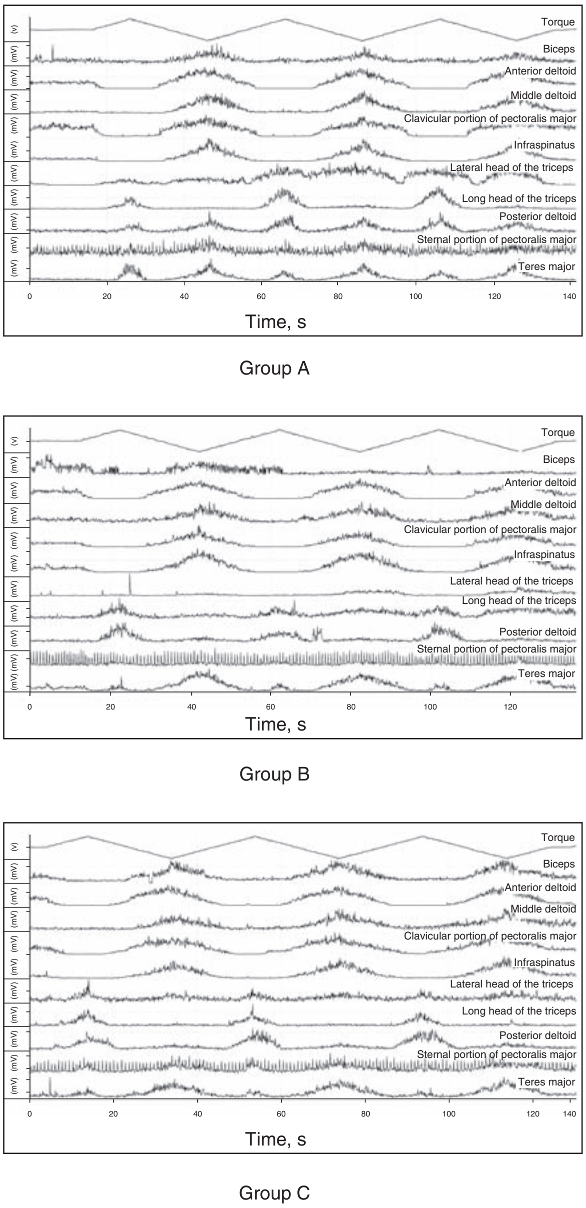


Fig. 6 Example of EMG signals in passive steering maneuver

Table 2 Grouping of muscles

Torque	Muscle
CW torque	Long head of the triceps
	Lateral head of the triceps
	Posterior deltoid
CCW torque	Anterior deltoid
	Middle deltoid
	Clavicular portion of pectoralis major
	Infraspinatus
CW & CCW torque	Teres major

4. 2 Co-contraction Activity

Next, characteristics of muscle activity when switching from a CCW maneuver to a CW maneuver were examined. For example, when CCW steering torque decreases from around the 30 s mark in **Fig. 6**, the activity of the infraspinatus decreases at the same time as activity of the long head of the triceps increases in order to generate CW steering torque. At this time, there is an overlap during which both muscles are simultaneously active. **Figure 7** gives another example of the EMG signals of subjects belonging to Group A at this overlap. These results show that the two muscles are in a co-contraction relationship and it is believed that the simultaneous activity of both muscles is not effective on the steering wheel as steering workload. This simultaneous activity is believed to be a wasted maneuver and one of the factors lowering driver steering efficiency.

4. 3 Activation Order

An evaluation was made of the activation order for the multiple muscles active in the CW and CCW steering shown in **Table 2** in order to study the relationship between these muscles. **Figure 8** gives one example of such a relationship. The X axis of the graph shows time and the Y axis shows EMG signals.

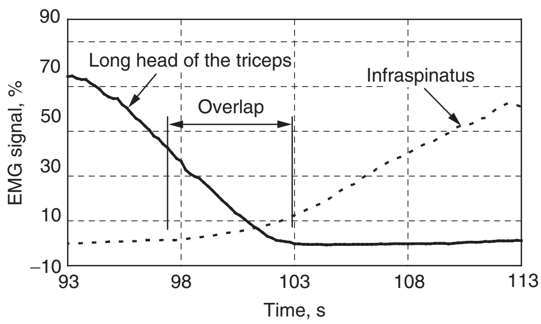


Fig. 7 Example of co-contraction

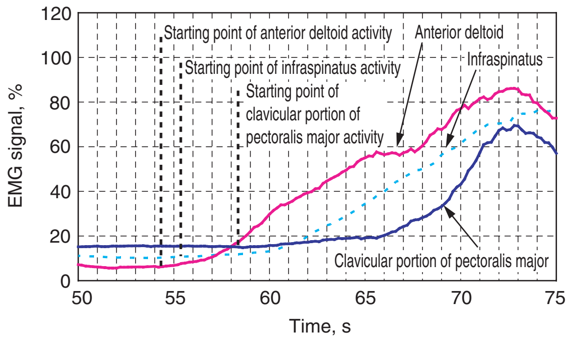


Fig. 8 Examples of activation starting time

4. 3. 1 Muscle Activation Order at CW Maneuver

The muscle activation order in a CW maneuver was evaluated. Using the point where the EMG signal of the lateral head of the triceps increased as a reference, a reading was made to ascertain the delay before other EMG signals began to increase. **Figure 9** shows the results of this reading. The X axis shows which muscles are active in a CW maneuver, and the Y axis shows the delay in each muscle activity starting to increase. The bar graph shows the delay of each subject, and the line graph shows the average delay of subjects from each group. These results demonstrate that, in the case of CW maneuvers, there are no obvious trends regarding muscle activation. Moreover, no significant difference was observed between subject groups.

4. 3. 2 Muscle Activation Order at CCW Maneuver

Next, the muscle activation order in a CCW maneuver was evaluated. Using the point where the EMG signal of the anterior deltoid increases as a reference, a reading was made to ascertain the delay before other EMG signals began to increase. **Figure 10** shows the results of this reading. Each axis and graph is the same as the evaluation results of CW maneuvers.

The results of this evaluation showed that, unlike CW maneuvers, there were drivers which had differing muscle activation orders, however, it was observed that under these conditions muscles were activated in the order shown in **Table 3**. In addition, because this same trend was common to the different subject groups, the test showed that the same muscle control was performed regardless of driving skill. Furthermore, the anterior deltoid, infraspinatus, middle deltoid and clavicular portion of pectoralis major are activated by movement of the shoulder joint, while the biceps are activated by the elbow joint. Hence, it can be claimed that subjects first tried stabilizing steering against the changing steering wheel torque by increasing the rigidity of their should joints. Then subjects compensated for any insufficiencies with activation of their elbow joints.

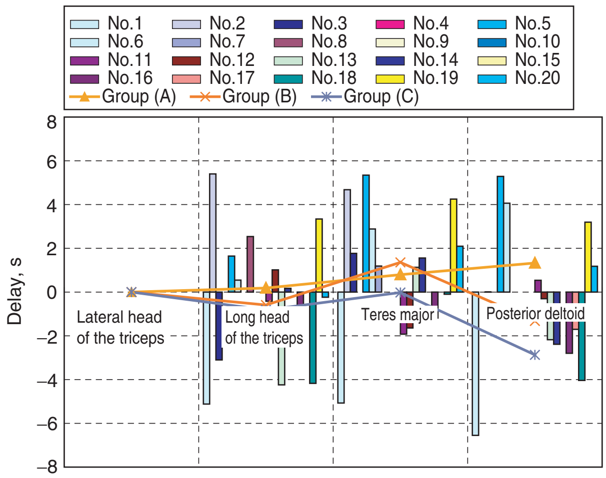


Fig. 9 Activation order in CW maneuver

5. Summary

This paper investigated the roles and characteristics of muscle behavior for stabilizing the steering wheel with a passive steering maneuver, in order to establish an evaluation index of the driver's workload on steering maneuver. With the research, the following conclusions can be drawn:

1) Different muscles are activated depending on the steering torque direction. For either direction of torque, multiple muscles are active simultaneously as opposed to individual muscle activity. Complex muscle control is performed by the subject.
2) When the direction of torque changes, the activated muscles change. This change does not happen instantaneously. There is an overlap where either muscle is active. This co-contraction activity in the overlap does not generate effective torque on the steering wheel and may be a factor in lowering driver steering efficiency.
3) In order to stabilize the steering wheel against torque forcibly applied in the CCW direction, the driver generates torque in the CW direction. At this time, the long head of the triceps, the lateral head of the triceps

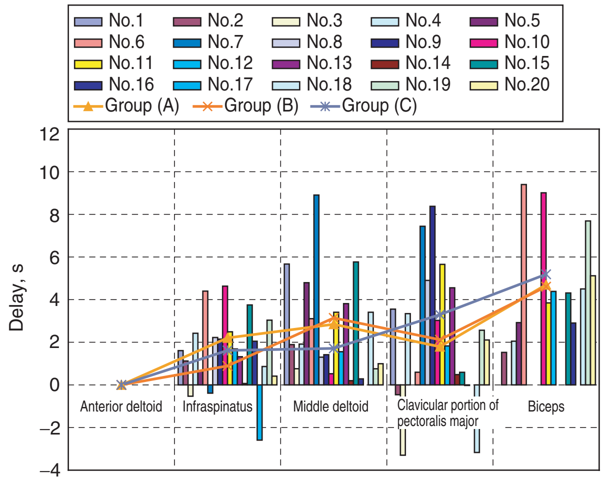


Fig. 10 Activation order in CCW maneuver

Table 3 Activation order

Activation order	Muscles
1	Anterior deltoid
2	Infraspinatus
3	Middle deltoid Clavicular portion of pectoralis major

and the posterior deltoid are activated. In this study, there was great variation in the muscle activation order between subjects, therefore no obvious common characteristics were observed.

4) In order to stabilize the steering wheel against torque forcibly applied in the CW direction, the driver generates torque in the CCW direction. At this time, the anterior deltoid is activated first, followed by the infraspinatus, the middle deltoid and finally the clavicular portion of pectoralis major. This shows that, at first the driver tries to stabilize the steering wheel by improving the rigidity of their shoulder joint, and then improves the rigidity of their elbow joint against any extra torque generated.

Biometrics such as EMG is useful in estimating the driver's physical workload. But there are also expectations that it may play a role in the active safety technology field relating to steering such as accident prevention and detection of driver's intention.

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T. MIZUNO*


R. HAYAMA**


S. KAWAHARA***


L. LOU****


Y. LIU*****


X. JI*****

* *Advanced Fundamental Research Dept., Research & Development Headquarters*

** *Electronic Systems R&D Dept., Research & Development Headquarters, Doctor of Informatics*

*** *Mechanical Systems R&D Dept., Research & Development Headquarters*

**** *Advanced Fundamental Research Dept., Research & Development Headquarters, Doctor of Agricultural Engineering*

***** *Department of Automotive Engineering, Tsinghua University*