SCIENCE CHINA
Technological Sciences

December 2012 Vol.55 No.12: 3445–3454
doi: 10.1007/s11431-012-5045-9

Function of shoulder muscles of driver in vehicle steering maneuver

LIU YaHui[1*], JI XueWu[1], RYOUHEI Hayama[2], TAKAHIRO Mizuno[2] & LOU LiMing[2]

[1] *State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China;*
[2] *Research and Development Center, JTEKT Co., Ltd., Nara 634-8555, Japan*

Received June 18, 2012; accepted August 14, 2012; published online September 28, 2012

In order to study the function of muscles of driver shoulder during vehicle steering, identification of relations between electromyograph (EMG) activity of 10 shoulder muscles and steering force was performed. The procedure was to perform controlled steering maneuver by right hand in a driving simulator, and based on analyzing the EMG data with steering force in the steering wheel plane, the function was identified. It was found that muscle function depends strongly on both steering rotation and steering torque directions. In clockwise steering, the long head of triceps brachii was the prime mover and an important contributor to clockwise moment, while the sternocostal portion of the pectoralis major, the lateral head of triceps brachii, biceps brachii and teres major were the important stabilizers or fixators. In contrast, in counterclockwise steering, the anterior, middle and posterior deltoid, the clavicular portion of the pectoralis major and infraspinatus were the prime movers and also the important contributors to counterclockwise moment, while the sternocostal portion of the pectoralis major, the lateral head of triceps brachii, biceps brachii and teres major were the important stabilizers or fixators. We conclude that the prime movers are primarily a consequence of steering direction, while the stabilizers or fixators are primarily constant. These results can be used to improve the neuromuscular model and estimate the steering comfort of driver.

electromyograph, muscle function, steering maneuver

Citation: Liu Y H, Ji X W, Ryouhei H, et al. Function of shoulder muscles of driver in vehicle steering maneuver. Sci China Tech Sci, 2012, 55: 3445–3454, doi: 10.1007/s11431-012-5045-9

1 Introduction

Very little is known about the function of muscles of shoulder during vehicle steering; in other words, the functions of those muscles are not very clear, although some investigations into muscle characters during vehicle steering have been published since 1975 or so. The function of muscles of upper limb in vehicle steering has been investigated with use of the electromyographic investigations [1–3]. Although the results showed the prime movers during contralateral steering and the important stabilizers during steering, one question still exists: which muscle(s) is (are) the prime mover(s) during ipsilateral steering? The muscular behaviors in a steering task have been studied continuously since 2003 [4–11]. Some of these studies [7, 8] described the properties of driver arm and some muscles during steering task, including the measurement method of steering torque by means of the electromyograph (EMG) of driver. Others [4–6, 9–11] mainly concerned the neuromuscular dynamics for building driver model to study the control principles of steering. However, none of these articles [4–11] actually concerned any attempts to investigate the function of muscles of driver shoulder in vehicle steering, except the investigations in 1970s [1–3].

Some evaluation methods of steering or other character-

*Corresponding author (email: liuyahui@tsinghua.edu.cn)

istics of vehicle have been studied in recent years based on certain muscles behaviors by means of the EMG signals [12–16]. Most of these investigations mainly concerned the muscular activity to analyze driver efforts to evaluate the drivability, and only one article concerned the steering characteristic [15]. However, none of them concerned the investigation of the muscles function in vehicle steering.

The relations between the activity of 10 shoulder muscles and steering force were studied based on some controlled steering maneuvers by right hand in a driving simulator with the help of the EMG signals, and the muscles function of driver shoulder during vehicle steering was preliminarily investigated in this paper. In Section 2, the methods were elaborated. The results and discussion were presented in Section 3, and the concluding remarks were summarized in Section 4.

2 Methods

Nineteen male subjects participated and gave their informed consent to the procedure, which was approved by the local ethical committee. These subjects were divided into three groups of drivers with different driving levels, including skilled driver, normal driver and inexperienced driver (Table 1). Six subjects in the skilled driver group had held driving licenses for 8–25 a and they were the professional vehicle testers. The mean height of them was 172.2 (ranging from 165 to177) cm, body weight 67.3 (61–90) kg and age 34.3 (27–43). Seven subjects in the normal driver group had held driving licenses for 3–22 a and the average weekly driving distance amounted to 100–500 km. The mean height of them was 167.3 (ranging from 160–180) cm, body weight 65 (55–84) kg and age 32.3 (26–42). Six subjects in the inexperienced driver group had held driving licenses for 1–27 a. They were paper drivers or the average weekly driving distance was less than 100 km. The mean height of them was 167.7 (ranging from 161 to 175) cm, body weight 66.3 (58–83) kg and age 33 (25–49).

2.1 Procedure

There were two experiments that were performed for each subject. In each experiment, the subject was seated in the driver seat, and held the steering wheel with right hand at the 3 o'clock position as the neutral or basic posture in a driving simulator (Figure 1), the same as the driving posture but without fastening the seat belt. The left hand was released from the steering wheel in the experiments. The seat and steering wheel were adjusted so that the arm was slightly bent at the elbow (approximately 110 deg between the forearm and upper arm) and the line along the steering axis (steering column) was approximately parallel to the line through the shoulder and wrist joints in the basic pos-

Table 1 Subject characteristics

Subject [a]	Age	Driving years	Height (cm)	Percentile [b] (height)	Weight (kg)	Percentile [b] (weight)
S1	27	8	165	21	61	33
S2	29	10	168	36	68	59
S3	43	25	173	70	60	31
S4	35	15	175	78	63	41
S5	41	22	175	78	90	96
S6	31	12	177	84	62	37
N1	26	3	160	3	57	18
N2	27	5	162	8	62	37
N3	33	12	165	21	61	33
N4	31	12	166	27	56	15
N5	27	4	168	36	55	12
N6	42	14	170	45	80	87
N7	40	22	180	93	84	92
I1	28	1	161	6	60	31
I2	33	11	166	27	58	20
I3	49	27	166	27	70	68
I4	25	7	168	36	83	92
I5	33	1	170	45	63	41
I6	30	1	175	78	64	46
Mean skilled driver (±SD)	34.3(6.5)	15.3(6.8)	172.2(4.7)	61.2(26.1)	67.3(11.4)	49.5(24.9)
Mean normal driver (±SD)	32.3(6.5)	10.3(6.8)	167.3(6.5)	33.3(30.2)	65(11.9)	42(33.8)
Mean inexperienced driver (±SD)	33(8.4)	8(10.2)	167.7(4.7)	36.5(24.1)	66.3(9.1)	49.7(26.3)

a) The letter in the subject designation indicates the group of the subject, and the number indicates the serial numbering of the subject in one group.
b) Percentile values based on height and weight are based on Human Characteristics Database of NITE (National Institute of Technology and Evaluation) in Japan (2003).

Figure 1 Subject in the basic posture sitting in the driving simulator and grasping the steering wheel with right hand at the 3 o'clock position.

ture. The basic posture came from lots of investigations in which most of subjects in present investigation would feel comfortable in this posture. The basic posture approximately conformed to their driving customs.

2.1.1 *Passive steering task*

The subject was instructed to stabilize the steering wheel in its neutral position under the disturbed torque produced by a motor. The magnitude and frequency of the disturbed torque were defined as 5 N m and 0.025 Hz (Figure 2), respectively. The magnitude was determined by referring to the value of torque in the actual driving condition with a conventional power-assisted steering system. The frequency was determined in quasi-stable range in order to detect distinct and useful results. The subject continuously stabilized the steering wheel (keeping it in its neutral position) for at least one circle, including 3 varying torque periods.

2.1.2 *Active steering task*

The subject was instructed to perform a sine steering like the slalom steering test (Figure 3). The magnitude and frequency of this sine steering were approximately 60 deg (while steering torque was about 5 N m) and 0.25 Hz respectively, which were similar to the slalom steering test of vehicle under the velocity of 60 km/h. The subject continually performed this sine steering for at least 5 circles.

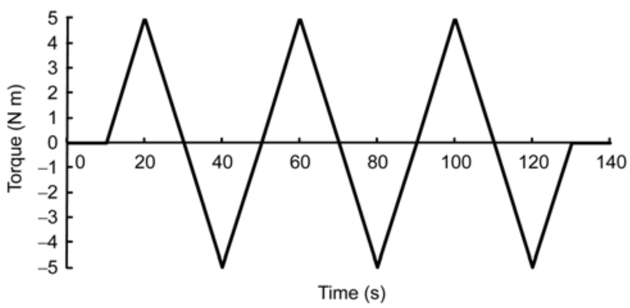


Figure 2 The disturbed torque produced by a motor in the driving simulator. One circle consists of 3 periods of varying torque.

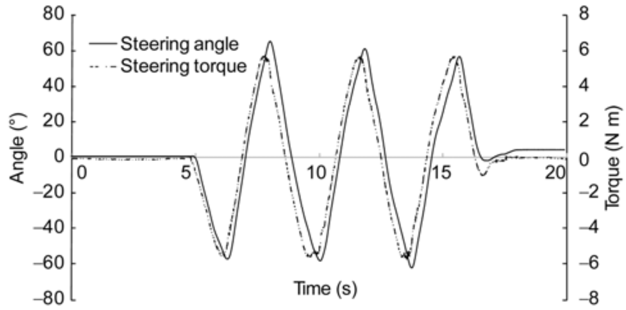


Figure 3 The active steering task. One circle consists of 3 periods of sine steering at least.

2.2 EMG and force/angle recording

The EMG signals were recorded from 10 shoulder muscles at the right side of subject (Table 2 and Figure 4). Wireless surface EMG devices (ZB-150H, Nihon Kohden Corporation, Japan) were applied. These surface electrodes were placed according to Perotto et al. [17]. The EMG signals were recorded by the telemetric equipment (WEB-1000,

Table 2 Functional groups of studied muscles in the investigation according to upper arm movements round the shoulder joint

Flexion	Extension
Clavicular portion of pectoralis major (PMA-C) Anterior deltoid (DELT-A) Biceps brachii (BB)	Teres major (TM) Posterior deltoid (DELT-P) Long head of triceps brachii (TB-L) Lateral head of triceps brachii (TB-LA)
Abduction	**Adduction**
Middle deltoid (DELT-M)	Infraspinatus (ISP) Teres major (TM) Sternocostal portion of pectoralis major (PMA-S)
Supination	**Pronation**
Posterior deltoid (DELT-P)	Anterior deltoid (DELT-A) Clavicular portion of pectoralis major (PMA-C) Teres major (TM)

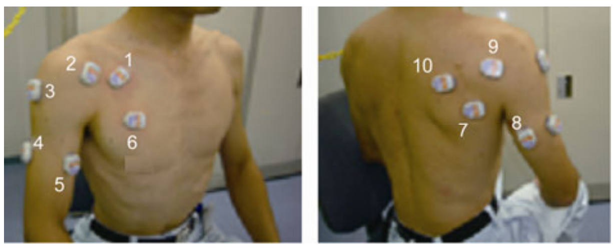


Figure 4 Studied muscles and the electrode placements. 1. PMA-C; 2. DELT-A; 3. DELT-M; 4. TB-LA; 5. BB; 6. PMA-S; 7. TM; 8. TB-L; 9. DELT-P; 10. ISP.

Nihon Kohden Corporation, Japan).

The forces exerted by the hand (Figure 5) were detected by a 3-axis force transducer (9017B, KISTLER), and the steering angle and torque were detected by a steering force/angle transducer (SFA-H, Kyowa, Japan). These forces, steering angle and torque were amplified by the telemetric equipment (WEB-1000, Nihon Kohden Corporation, Japan). The signals were sampled (WEB-1000, Nihon Kohden Corporation, Japan) with 1000, 5, 5 and 5 Hz for the surface EMG, forces, steering angle and torque signals, respectively. The EMG signals were digitally band-pass filtered (from 15 to 500 Hz). The root-mean-square value of the EMG signal that is defined as REMG was calculated for each recording segment (0.2 s). The REMG for a segment was to be compared to the force and torque recorded at the end of that segment in this study, assuming the force level here is caused by muscle activity in the preceding 0.2 s.

F_x in Figure 5 was the radial force component from the grasping position to the center of the steering wheel, hence, related to the stability of the driver body and the steering wheel, but not related to any moment round the steering column (steering torque M_z). F_y was the tangential force component from the grasping position upward, hence related to the moment M_z.

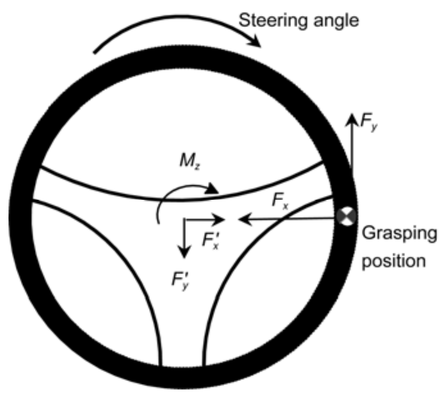


Figure 5 Forces and torque exerted by the hand in the steering wheel plane in the basic posture.

2.3 Relation between EMG and external forces

In order to investigate the relation, an expression giving linear relation between the REMG and the radial or tangential force was used, assuming that the forces in the steering wheel plane were counteracted by the muscle force.

$$\text{REMG} = \text{REMG}_0 + aF_{x,+} + bF_{x,-}$$

or

$$\text{REMG} = \text{REMG}_0 + cF_{y,+} + dF_{y,-}, \quad (1)$$

where

$$F_{x,+} = (|F_x| + F_x)/2 \quad (\text{positive } F_x),$$

$$F_{x,-} = (|F_x| - F_x)/2 \quad (\text{negative } F_x),$$

$$F_{y,+} = (|F_y| + F_y)/2 \quad (\text{positive } F_y),$$

$$F_{y,-} = (|F_y| - F_y)/2 \quad (\text{negative } F_y).$$

REMG_0 is the extrapolated REMG at zero force. REMG_0, a, b, c and d are estimated by multiple linear regression. An example of the regression is shown in Figure 6. In this process, the REMG was normalized to the maximum REMG value of each experiment task.

2.4 Cross-correlation analysis of EMG

The cross-correlation between the REMG signals was indicated by the correlation coefficients, which was given by

$$r_{i,j} = \frac{\sum (x_i(n) - \bar{x}_i)(x_j(n) - \bar{x}_j)}{\sqrt{\sum (x_j(n) - \bar{x}_j)^2 \sum (x_i(n) - \bar{x}_i)^2}}, \quad (2)$$

where i and j denote two muscles, $x_i(n)$ and $x_j(n)$ are the REMG values of muscles i and j, $\bar{x}_i$ and $\bar{x}_j$ are the average values of REMG of muscles i and j.

3 Results and discussion

3.1 Results

The original experiment results are shown in Figure 7. For most of the studied muscles, their activities varied with the variation of steering torque and forces in both the passive and active steering experiments. The muscle activation levels of two experiment tasks described by EMG/force slope for a given force based on eq. (1) are shown in Figures 8 and 9. For all muscles, the activation trends with different

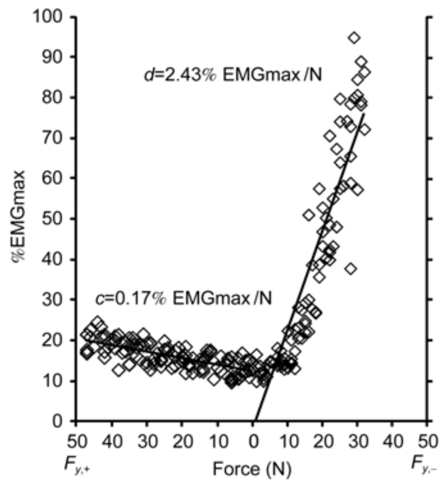


Figure 6 Determination of EMG/force slope for long head of triceps brachii for subject S6. Only the tangential forces ($F_{y,+}$ and $F_{y,-}$) are shown.

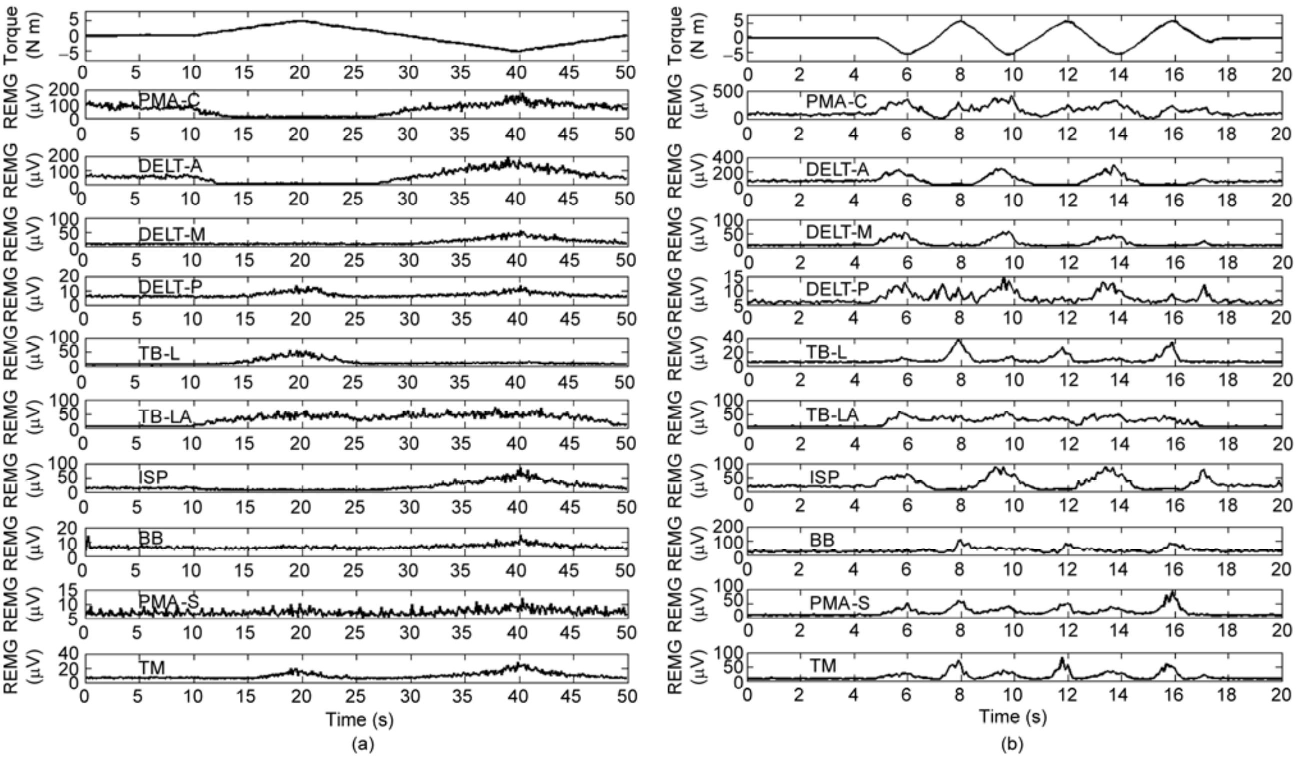


Figure 7 Typical results of REMG in the passive and active steering tasks. (a) Results of passive steering task; (b) Results of active steering task.

forces for the subjects in the same group were qualitatively similar in the same experiment task. In the skilled driver group, one subject (the diamond mark) had different patterns of DELT-P, TB-L and TB-LA, and two subjects (the triangle and multiplication marks) had different patterns of PMA-S and TM in the passive steering task. One subject (the diamond mark) had different patterns of PMA-C, BB and PMA-S, and another one (the square mark) had a different pattern of DELT-P in the active steering task. In the normal driver group, two subjects (the diamond and star marks) had a different pattern of DELT-P and one subject (the round mark) had a different pattern of TM in the passive steering task. One subject (the diamond mark) had a different pattern of BB, and another one (the multiplication mark) had a different pattern of TM in the active steering task. In the inexperienced driver group, two subjects (the diamond and square marks) had different patterns of DELT-P, TB-LA and PMA-S in the passive steering task. One subject (multiplication mark) had a different pattern of PMA-S in the active steering task.

For most muscles a well-defined force with the highest sensitivity was found, as shown in Table 3 and 4, as well as a force with the lowest sensitivity. It can be seen that the forces with the highest or lowest sensitivity for most of the muscles of the three group subjects were nearly identical in the same steering task. However, the skilled driver group had a different sensitivity force of TM in the passive steering task, the normal driver group had the different lowest sensitivity force of PMA-C in the active steering task, and the three groups had different sensitivity forces of BB in the active steering task.

Based on the cross-correlation analysis, the correlation of these muscles was obtained. Then, these muscles could be classified into different groups in terms of the steering torque. The statistic result of muscle classification according to the steering torque of all subjects is shown in Figure 10. For all muscles, the groups classified by cross-correlation analysis of all subjects were qualitatively similar to the classification results based on the REMG/force slopes shown in Figures 8 and 9.

3.2 Discussion

The muscles of shoulder are the primary power supply of steering torque [7] although the steering maneuver is a complex movement of upper limb, including motions around shoulder, elbow and wrist joints. The muscles investigated in this study therefore were restricted to the shoulder muscles, which mostly relate to the motion around the shoulder joint. In this study, the muscle activity characteristics in steering maneuver were investigated based on the radial and tangential forces applied on the steering wheel, which was different from the studies of Jonssonand Cole. The reason is that one certain muscle would present different functions corresponding to the composite movement during steering. For example, anterior deltoid would act as a remarkable agonist in adduction or a remarkable antagonist in abduction, but in order to perform a steering maneuver,

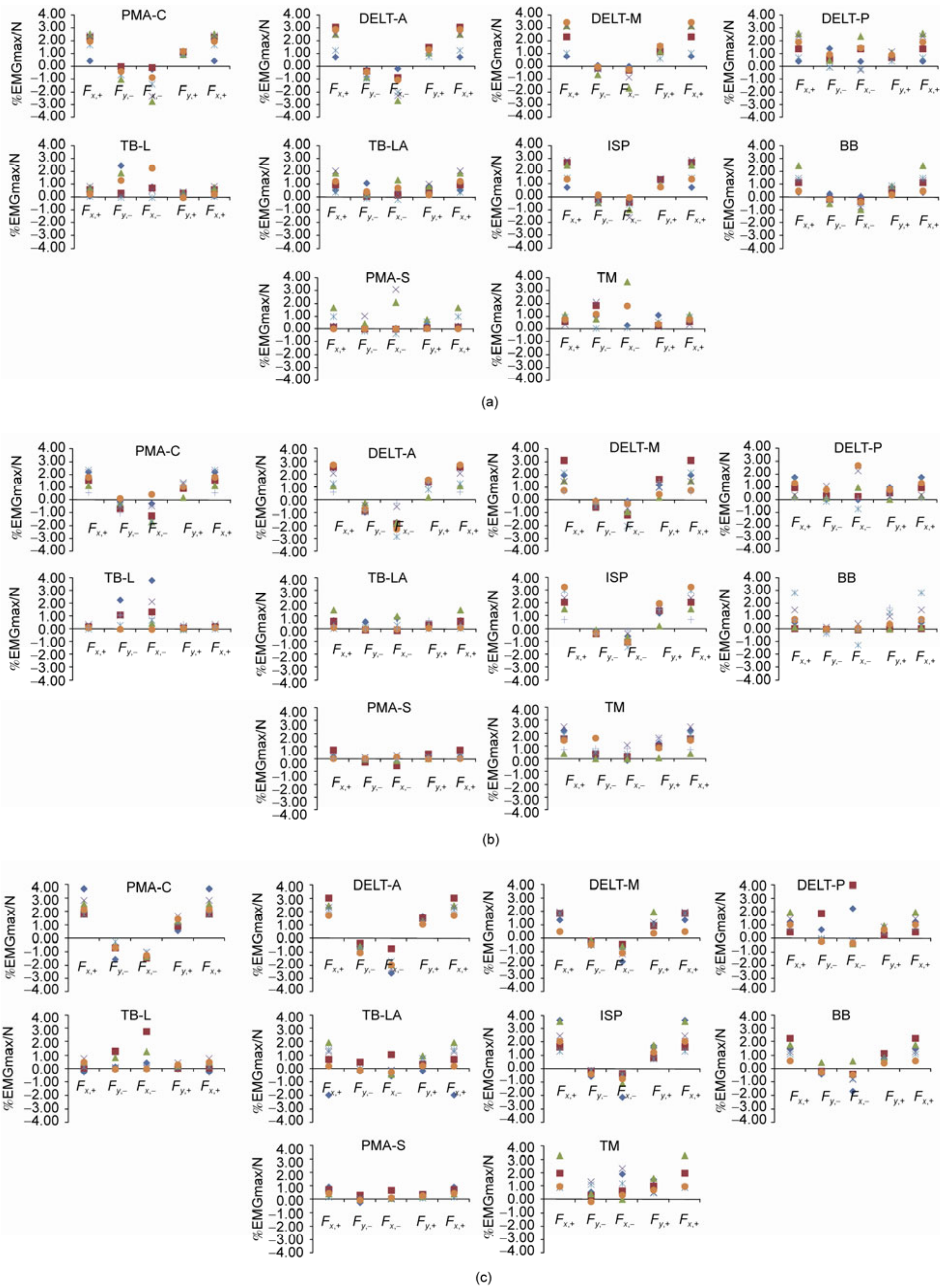


Figure 8 REMGs and forces of the studied muscles in the passive steering task. The *y*-axis is the EMG level for a given force. The same marks correspond to one subject in certain group. (a) Skilled driver group; (b) normal driver group; (c) inexperienced driver group.

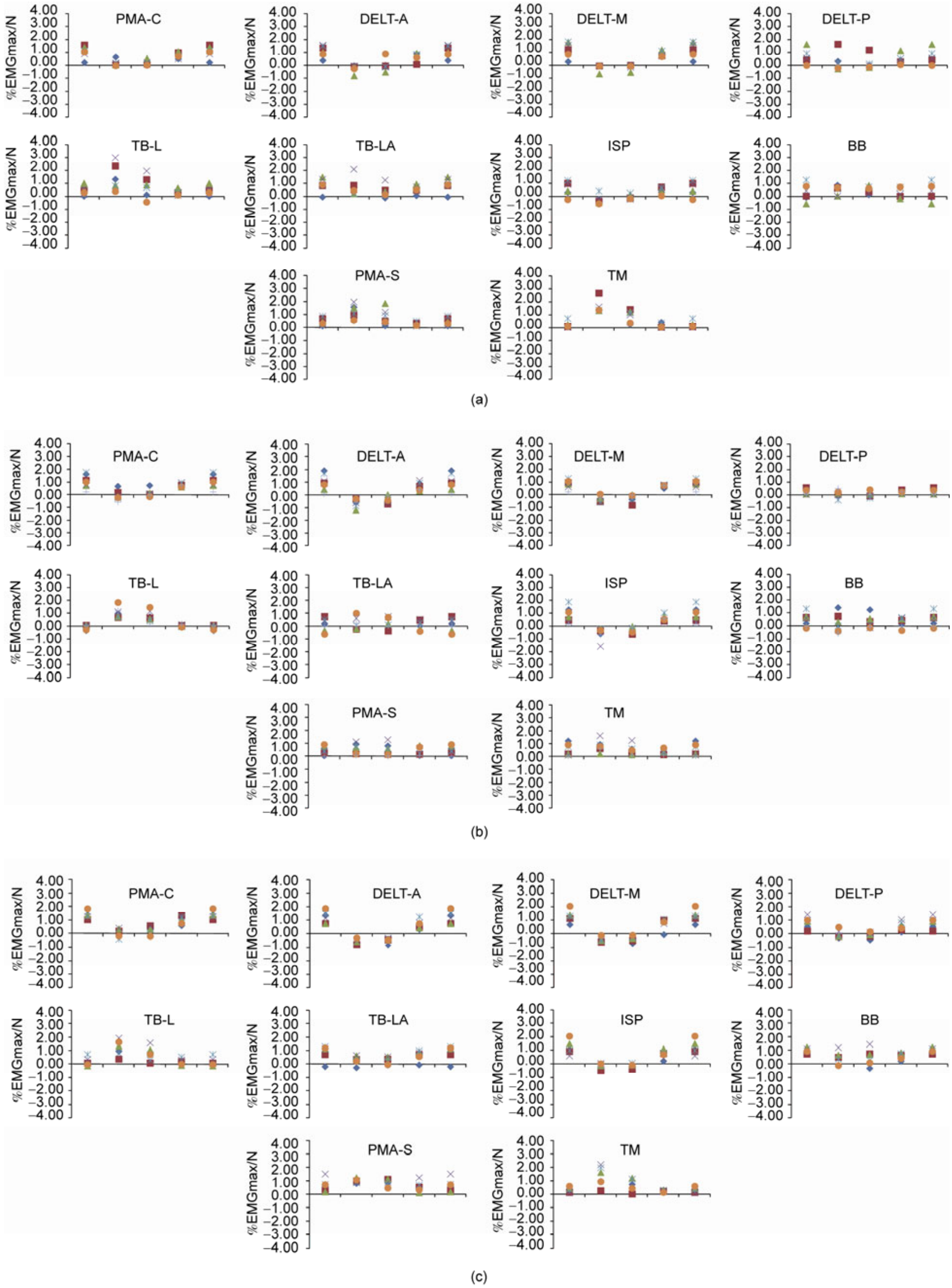


Figure 9 REMGs and forces of the studied muscles in the active steering task. The *y*-axis is the EMG level for a given force. The same marks correspond to one subject in certain group (as same as Figure 8). (a) Skilled driver group; (b) normal driver group; (c) inexperienced driver group.

Table 3 Passive steering task results of recorded muscles[a)]: The force with the highest sensitivity of REMG values in passive steering task, as well as the force with the lowest sensitivity of the REMG values

Muscle	Force with the highest sensitivity			Force with the lowest sensitivity		
	S	N	I	S	N	I
PMA-C	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$
DELT-A	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$
DEIT-M	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$
DELT-P	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$
TB-L	$F_{x,-}$	$F_{x,-}$	$F_{x,-}$	$F_{y,+}$	$F_{y,+}$	$F_{y,+}$
TB-LA	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$
ISP	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$
BB	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$
PMA-S	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$
TM	$F_{x,-}$	$F_{x,+}$	$F_{x,+}$	$F_{y,+}$	$F_{y,-}$	$F_{y,-}$

a) The subjects with different patterns omitted.

Table 4 Active steering task results of recorded muscles[a)]: the force with the highest sensitivity of REMG values in active steering task, as well as the force with the lowest sensitivity of the REMG values

Muscle	Force with the highest sensitivity			Force with the lowest sensitivity		
	S	N	I	S	N	I
PMA-C	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{y,-}$	$F_{x,-}$	$F_{y,-}$
DELT-A	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{x,-}$	$F_{x,-}$	$F_{x,-}$
DEIT-M	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{x,-}$	$F_{x,-}$	$F_{x,-}$
DELT-P	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{x,-}$	$F_{x,-}$	$F_{x,-}$
TB-L	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$	$F_{y,+}$	$F_{y,+}$	$F_{y,+}$
TB-LA	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{x,-}$	$F_{x,-}$	$F_{x,-}$
ISP	$F_{x,+}$	$F_{x,+}$	$F_{x,+}$	$F_{x,-}$	$F_{x,-}$	$F_{x,-}$
BB	$F_{y,-}$	$F_{x,+}$	$F_{x,+}$	$F_{y,+}$	$F_{x,-}$	$F_{y,-}$
PMA-S	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$	$F_{y,+}$	$F_{y,+}$	$F_{y,+}$
TM	$F_{y,-}$	$F_{y,-}$	$F_{y,-}$	$F_{y,+}$	$F_{y,+}$	$F_{y,+}$

a) The subjects with different patterns omitted.

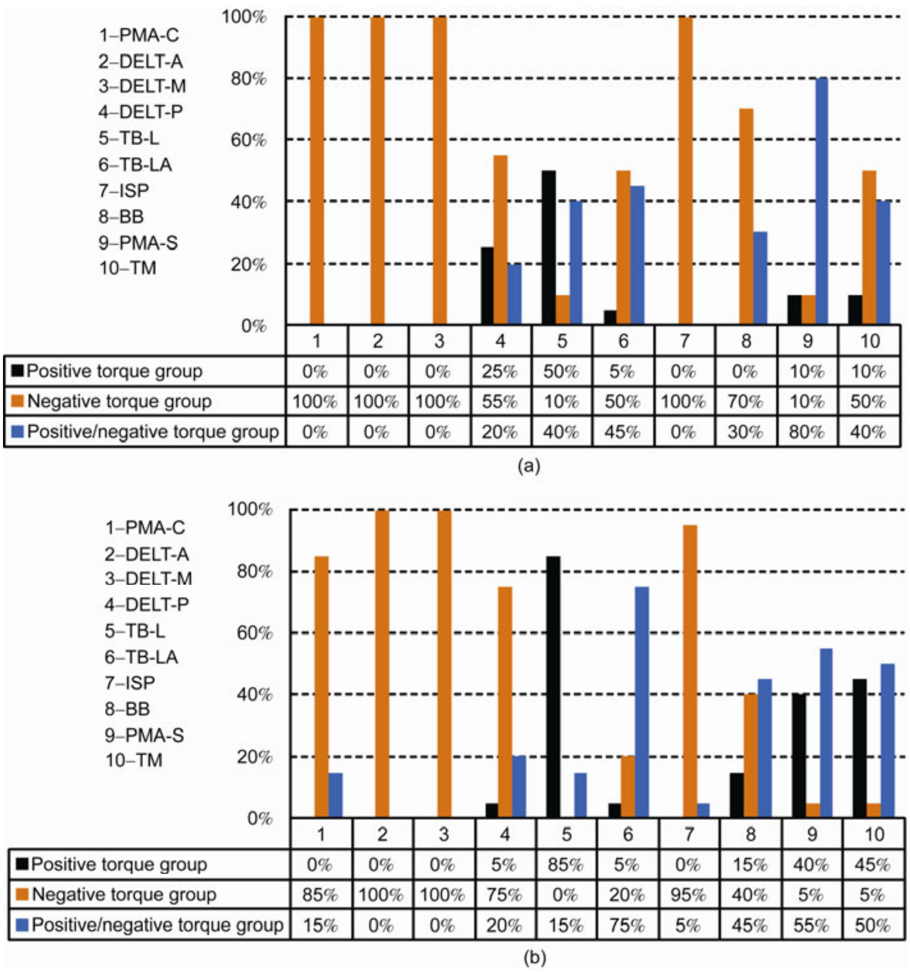
the motion around the shoulder joint was composed of abduction (or adduction), extension (or flexion) and supination (or pronation). The radial and tangential forces applied on the steering wheel therefore were used in this study, which could explain the composite function of muscle. The radial force could stabilize the driver upper body position against the tendency of lateral movement during steering, and the tangential force could produce the moment that steers the vehicle.

In this study, the similarity of the activation patterns among three group subjects was found for most of the studied muscles in certain experiment. The variation of REMG could be explained by the variations of the radial and tangential forces applied on the steering wheel by the driver, as given by expression (1). In other words, the REMG signals could be used to estimate the radial and tangential forces acting on the steering wheel. Moreover, this study indicated that the difference of driving experience would rarely influence the muscle behaviors when the individual variation of muscle activation was removed by the normalization.

Little difference of muscle function was found between the passive and active steering experiments. Comparatively, the muscles were more active in producing the radial force in the passive steering, but less active in producing the tangential force. For anterior deltoid, its activity was much more sensitive to the radial force, as compared with the tangential force in the passive steering, but this phenomenon was not distinct in the active steering. A probable explanation is that the subject should stabilize the steering wheel against the unknown disturbed force in the passive steering, and the radial force is more helpful to stabilize the steering wheel in this condition, thus the muscles present a distinguished activity to produce the radial force to stabilize the steering wheel. Nevertheless, the subject should be appreciated in rotating the steering wheel in the active steering, thus the muscles present more distinguished activity to produce the tangential force that is unlike in the passive steering.

4 Concluding remarks

This study investigated the functions of 10 muscles of driver shoulder during steering maneuver through the analyses of 19 subjects of different driving levels. In the active steering task, the results showed that when steering clock-



	1	2	3	4	5	6	7	8	9	10
Positive torque group	0%	0%	0%	25%	50%	5%	0%	0%	10%	10%
Negative torque group	100%	100%	100%	55%	10%	50%	100%	70%	10%	50%
Positive/negative torque group	0%	0%	0%	20%	40%	45%	0%	30%	80%	40%

(a)

	1	2	3	4	5	6	7	8	9	10
Positive torque group	0%	0%	0%	5%	85%	5%	0%	15%	40%	45%
Negative torque group	85%	100%	100%	75%	0%	20%	95%	40%	5%	5%
Positive/negative torque group	15%	0%	0%	20%	15%	75%	5%	45%	55%	50%

(b)

Figure 10 Statistic results of muscle classification through correlations of all subjects in the experiment tasks, classified by steering torque. The *y*-axis is the ratio of certain group of 19 subjects. (a) Passive steering task; (b) active steering task.

wise, the long head of triceps brachii was the prime mover and the important contributor to clockwise moment, while the sternocostal portion of the pectoralis major, the lateral head of triceps brachii, biceps brachii and teres major were the important stabilizers or fixators. In contrast, when steering counterclockwise, the anterior, middle and posterior deltoid, the clavicular portion of the pectoralis major and infraspinatus were the prime movers, and also the important contributors to counterclockwise moment, while the sternocostal portion of the pectoralis major, the lateral head of triceps brachii, biceps brachii and teres major were the important stabilizers or fixators. There was a little difference among the three groups, for example, the sternocostal portion of the pectoralis major acted as a stabilizer in normal driver, but as a mover in skilled or inexperienced driver sometimes. This difference would be further studied in the future.

In the passive steering task, when stabilizing the steering wheel against the clockwise-disturbed torque, the anterior, middle and posterior deltoid, the clavicular portion of the pectoralis major, and infraspinatus were the prime movers. In contrast, when stabilizing the steering wheel against the counterclockwise-disturbed torque, the long head of triceps brachii was the prime mover. The sternocostal portion of the pectoralis major, the lateral head of triceps brachii, biceps brachii and teres major were the important stabilizers or fixators in both passive steering tasks.

The investigation results have multiple applications such as improving neuromuscular model for driver modeling and estimating the steering comfort, which could help develop a more friendly steering system.

This work was supported by the National Natural Science Foundation of China (Grant No. 51005133), the National High Technology Research and Development Program of China (Grant No. 2011AA11A244), and Special Financial Grant of the National Science Foundation for Post-doctoral Scientists of China (Grant No. 201104098).

1 Jonsson S, Jonsson B. Function of the muscles of the upper limb in car driving. Ergonomics, 1975, 18(4): 375–388
2 Jonsson S, Jonsson B. Function of the muscles of the upper limb in car driving-IV: The pectoralis major, serratus anterior and latissimus

dorsi muscles. Ergonomics, 1975, 18(6): 643–649

3 Jonsson S, Jonsson B. Function of the muscles of the upper limb in car driving-V: The supraspinatus, infraspinatus, teres minor and teres major muscles. Ergonomics, 1976, 19(6): 711–717

4 Pick A J, Cole D J. Neuromuscular dynamics and the vehicle steering task. In: proceedings of the 18th IAVSD Symposium on the Dynamics of Vehicles on Roads and Tracks, Japan. Veh Syst Dyn, 2003, 41(Suppl.): 182–191

5 Keen S D, Cole D J. Steering control using model predictive control and multiple internal models. The 8th International Symposium on Advanced Vehicle Control, Taipei, China, 2006. AVEC060095

6 Pick A J, Cole D J. Neuromuscular dynamics in the driver-vehicle system. Veh Syst Dyn, 2006, 44(Suppl.): 624–631

7 Pick A J, Cole D J. Measurement of driver steering torque using electromyography. ASME J Dyn Syst Measur Contr, 2006, 126: 960–968

8 Pick A J, Cole D J. Dynamic properties of a driver's arms holding a steering wheel. Proceedings of the Institution of Mechanical Engineers, Part D-J Autom Eng, 2007, 221: 1475–1486

9 Pick A J, Cole D J. Driver steering and muscle activity during a lane-change manoeuvre. Veh Syst Dyn, 2007, 45(9): 781–805

10 Pick A J, Cole D J. A mathematical model of driver steering control including neuromuscular dynamics. ASME J Dyn Syst Measur Contr, 2008, 130(3): 1–9

11 Cole D J. Steering feedback-Mathematical simulation of effects on driver and vehicle. ATZ Auto Technol, 2008, 8: 2–6

12 Kuramori A, Kouguchi N, Kamijo M, et al. Evaluation of vehicle drivability by using muscle activity of drivers. 6th JSEK Conference, 2003

13 Kuramori A, Kouguchi N, Ishikawa K, et al. Evaluation of effects of drivability on driver workload by using electromyogram. JSAE Rev, 2004, 25: 91–98

14 Kuramori A, Koguchi N, Kamijo M, et al. Study on driving ease evaluation focusing on muscular activity of driver. J Soc Autom Eng Jpn, 2007, 61: 116–121

15 Tajima T, Oshima T. Effect of improvement of steering system of vehicle based on muscular cooperated control model. Japan Society of Precision Engineering, Animal Inspired Robot Dawn Net workshop, 2004

16 Okamoto Y, Nakano K, Ohori M, et al. Evaluation of ride comfort with EMG. J STAGE, 2010, 62: 267–270

17 Perotto A, Delagi E F. Anatomical Guide for the Electromyographer: The Limbs and Trunk. 4th ed. Springfield, IL: Charles C Thomas Publisher, 2005. 1–345