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SPECIAL ISSUE: Brain Science and its Related Research Fields

ORIGINAL ARTICLE

Evaluation of Driver-vehicle Matching using Neck Muscle Activity and Vehicle Dynamics

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Abstract: Objective measurement of a car driver's feeling has been a subject of automobile researches. In the present study, we aimed at quantifying the matching between the physiological response of a driver and the vehicle motion. Assuming that the performance of a head stabilization mechanism, the vestibulo-collic reflex, affects driving feeling, we recorded the activity of neck muscles that help maintain the head position. Electromyograms (EMGs) were recorded from the sternocleidomastoid muscles (SCM) using active electrodes and a compact amplifier. Vehicle acceleration and gas pedal movement were recorded with small accelerometers. Subjects were required to perform straight-line acceleration. Four road cars with different characteristics were used. EMG signals were filtered, full-wave rectified and averaged across trials. Main results are summarized as follows. First, the EMG response of a driver's neck muscle depended not only on vehicle acceleration but on its time derivative, jerk. A quantitative analysis showed that, for the data obtained with the four cars, the EMG profile can be reproduced by a linear sum of acceleration and jerk. The correlation coefficient, an index of goodness of matching, ranged from ~0.8 to ~0.95. Second, our analysis indicated that the relationship between the muscle response and the vehicle motion can be characterized by two parameters: the optimal weight for the jerk term and the optimal time lag. The current study proposes a method for characterizing a physiological response of a driver to dynamic vehicle motion. It remains to be investigated whether these parameters are related to the driving feeling.

Keywords: *Driving pleasure, Head stabilization, Physiological measurement, Electromyogram, Acceleration, Jerk*

1. INTRODUCTION

Nowadays, cars are an indispensable tool for many people to engage in a wide range of business, social and recreational activity. Thanks to car manufactures' efforts to improve the performance and quality of automobiles such as responsiveness, acceleration, braking, cornering stability, comfort, quietness and the ease of operation, most cars in the market are of top quality. Although this is good news for those who want to buy a car, it has made it difficult for manufactures to know what changes should be made to create a more attractive model. Car engineers are increasingly interested in methods that can measure a driver's feeling about the car because the subjective impression about the car may be an important factor in deciding whether to purchase it or not.

Emotional factors and affective states have often been the subject of many automotive researches particularly in relation to driving safety and comfort [1]. Driving pleasure has been a crucial factor in automobile market [2] and is thought to be determined by the driving feeling, which arises from the complex relationship among driver, vehicle and environment [3].

In the field of vehicle motion control, it has long been known that the rate of change of acceleration, jerk, influences ride comfort and driving safety. A control system proposed in a previous study uses jerk information and regulates the grip of road cars to assure driving stability [4]. More recently, the same group has analyzed driving characteristics of skilled drivers and found that a smooth, gradual change in vectorial acceleration is a crucial factor for riding comfort during cornering [5]. Similar ideas are seen in other types of vehicles. Ideal motions of an elevator are thought to be characterized by smooth, sinusoidal changes in acceleration and jerk [6]. Minimizing jerk is expected to improve the ride quality, stability and safety of power-assisted wheelchairs [7]. These previous studies have thus indicated the importance of jerk in evaluating positive driving feelings. However, few have focused on the driver's physiological responses and analyzed their relation with the vehicle movement as a clue to the driver's feeling.

From a neurophysiological viewpoint, a driver in a moving vehicle is an interesting model system that receives sensory stimuli and produces appropriate motor output. The driver receives a variety of sensory stimuli: visual information about the outside world ahead, sounds coming from the engine, road surface and wind, and somatosensory stimuli such as pressure and vibration through the seat. In addition, a driver can feel acceleration of a vehicle through the vestibular sense organ in the inner ear. These sensory stimuli would combine to produce a driver's feeling about the car.

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Maintaining the posture is crucial for efficient collection of sensory information and precise control of movement [8]. This applies well to a driver in a moving vehicle. Various inertial forces act on a driver due to acceleration of a vehicle, inducing passive movements of the head. For a clear vision and smooth operation of a car, the head of a driver must be held in a stable position. Our nervous system is equipped with a head stabilization mechanism, called the vestibulo-collic reflex, which senses acceleration acting on the head and adjusts neck muscle activity that generates force to oppose and minimize the unwanted passive movement [8].

Focusing on drivers' positive feelings about dynamic motion of a car, the present study attempts to quantify driver-vehicle matching, a crucial factor for driving pleasure. Based on the hypothesis that stabilization of the head influences how a driver feels about vehicle motion, we analyzed the relationship between the neck muscle activity and vehicle acceleration. The present paper describes how the neck muscle activity may be reproduced by acceleration and its time derivative, jerk. We discuss the physiological significance of the jerk component and possible parameters that could be used to estimate the subjective feelings of a driver. Preliminary reports have been presented elsewhere [9-11].

2. METHODS

2.1 Subjects and Recording Procedures

A total of 9 healthy adult subjects (7 males and 2 females, age: 20's to 50's) participated in the experiments. During experiments, each subject sat behind the wheel in a driver's seat. The electromyograms (EMGs) of the right and left sternocleidomastoid muscles (SCMs) were recorded using surface electrodes with a built-in head stage (so called "active electrodes") and a small, battery-driven amplifier with a filter (BA1104, TEAC, Japan, bandwidth: 5 Hz to 3 kHz). The SCM is a relatively large neck muscle that stretches from the lateral part of the skull base to the medial part of the clavicle as well as to the upper edge of the sternum. The muscle generates force that tilts the head forward and laterally, and therefore is a key muscle that opposes backward inertial forces. Longitudinal and lateral accelerations of a test car were recorded with a compact accelerometer (Crossbow Technology, USA) that was placed near the center of gravity in the vehicle. In some experiments, a second accelerometer was mounted on a fabric head gear attached to the driver's head. Another accelerometer was attached to the gas pedal to record the pedal movement.

2.2 Driving tasks

Straight-line acceleration: The subject was asked to drive a road car (sedan, 3000 cc, or compact, 1500 cc), accelerating from a standstill to ~40 km/h and then decelerating by braking.

Steady-state turning: Two subjects participated in this task. A compact road car was used. The subjects were required to drive along a fixed circle, starting very slowly and gradually picking up speed at a near-constant, small acceleration (0 to 50 km/h over ~35 sec). The task was designed to examine the effect of "constant" lateral acceleration on SCM activity.

2.3 Data Analysis

Data were analyzed offline. The EMGs, vehicle acceleration and gas pedal movement signals were collected at 1 kHz and analyzed using Spike2 software (CED, UK) and an interface (Power1401, CED, UK). EMGs and acceleration were high-pass filtered and low-pass filtered, respectively. The filtered EMGs were then full-wave rectified. The rate of change of acceleration (jerk) was obtained by differentiating the filtered acceleration data. The onset of the gas pedal downward movement was determined by inspecting the pedal acceleration data and used as a reference point for averaging across trials. The EMGs, vehicle acceleration and jerk were averaged over 5 trials for each test car. To facilitate comparison with the vehicle motion, the EMGs were further smoothed with 20-point moving average.

To examine the relation between the EMG and vehicle motion, linear regression analysis was done between the EMG amplitude and a linear sum of acceleration and jerk, as will be described in detail in Results. Those portions of data starting 1 sec before and ending 1.5 sec or 2.0 sec after the reference time (pedal pushing) were chosen for quantitative analysis.

3. RESULTS

3.1 Qualitative observations of neck muscle activity and vehicle motion

To examine how the driver's head is stabilized in a moving vehicle, we compared acceleration of a car and that of the driver's head. Figure 1A shows the data obtained during an acceleration-deceleration sequence in one subject (average of 5 trials). The head acceleration (red trace) and vehicle acceleration (blue trace) exhibit similar time courses. There was a significant positive, highly linear, correlation between the two variables (Fig. 1B, $p < 0.0001$, $r = 0.954$). Similar results were obtained in three other drivers. This finding indicates that the driver's head is held in a relatively constant position in a moving vehicle.

We next compared vehicle acceleration and neck muscle activity in a simple, straight-line acceleration task. Figure 2 shows vehicle longitudinal acceleration (top), EMGs of the right SCM (middle) and of the left SCM (bottom) obtained in two subjects. Each trace is an average across 5 trials. In both subject 1 (left panel) and subject 2 (right panel), the right and left SCMs show similar response profiles, which roughly resemble the vehicle acceleration profile.

3.2 Dependence of neck muscle activity on acceleration

Because neck muscles exert forces, as a result of head stabilization mechanism, to prevent passive tilting of the head, we expected that the driver's SCM activity reflected primarily the acceleration of a vehicle. This was found to be the case when acceleration did not change quickly with time. Figure 3 shows the EMG and vehicle acceleration during a steady-state turning task (rightward turning). As the car velocity, and therefore, the lateral acceleration increased gradually and slowly over ~35 sec, the EMG of the right SCM (purple trace) increased (Fig. 3A, B), opposing the leftward inertial force and preventing the head from tilting. There was a linear relationship between the EMG amplitude and concomitant vehicle acceleration (Fig. 3C, purple trace). The SCM on the other side remained inactive throughout the task (orange trace). When the direction of the turn was reversed, the left SCM activity showed a similar, linear relation with lateral acceleration of the vehicle (not shown).

This linear relation, however, did not hold when acceleration changed at a significant rate. Figure 4 shows the relation between EMG amplitude and vehicle acceleration in a trial that involved quick changes in acceleration. Note that, for a given acceleration, the magnitude of SCM activity is larger when the acceleration is increasing (i.e. for a larger jerk) than when it is decreasing (i.e., for a smaller jerk). This result may suggest that the muscle activity depends on the rate of change of acceleration (jerk) as well as on acceleration.

3.3 Reproducing EMGs with acceleration and jerk

Some physiological signals have been shown to depend on both a physical quantity, e.g. the length of a muscle, and its rate of change. A class of sensory fibers, called group Ia afferents, receives input from a stretch receptor in a muscle and conveys information about the state of the muscle. In response to a step-like change in muscle length,

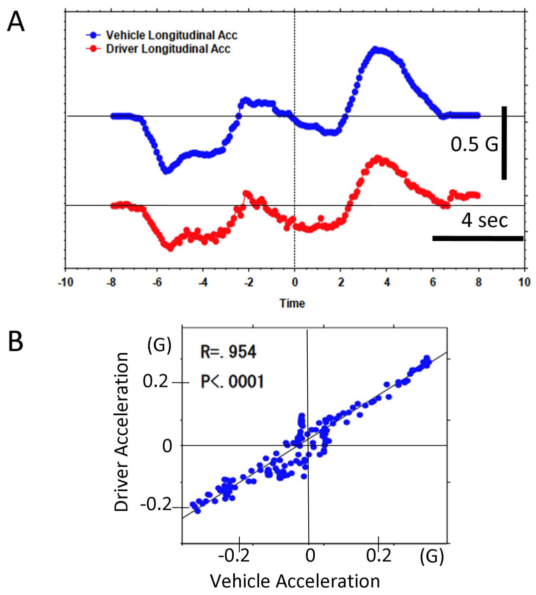

Figure 1: Vehicle and head acceleration.

A. Longitudinal acceleration of a vehicle (blue) and of a driver (red) during an acceleration-turn-deceleration task. Horizontal line for each trace indicates zero acceleration level. The car was accelerated from a standstill for ~5 sec to ~60 km/h. The driver then made a 90° turn (along an arc of 50 m radius) over the next 4-5 sec, and braked the car. The ordinate indicates longitudinal acceleration in G (G = 9.8 m/sec^2). Downward deflection indicates an increase in velocity. Records from 5 trials were averaged on the peak of lateral acceleration (time = 0, not shown).

B. A linear correlation found between head acceleration (ordinate) and vehicle acceleration (abscissa). Same data as in Figure 1A.

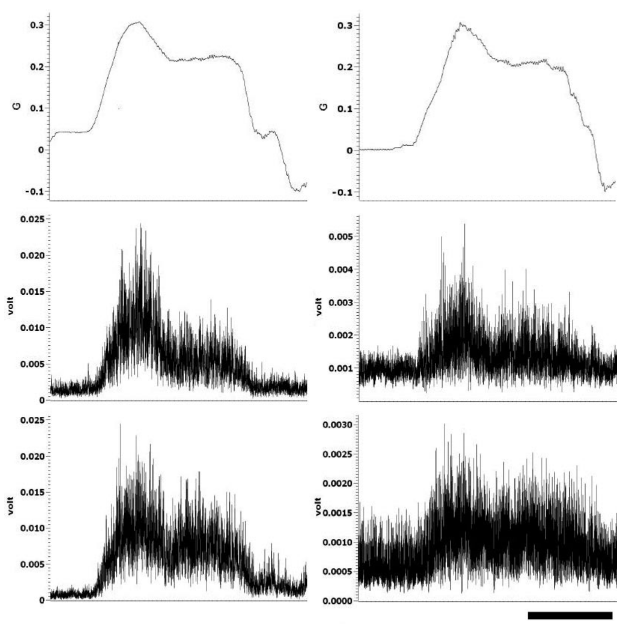

Figure 2: Typical EMG response to forward acceleration.

Vehicle acceleration and neck muscle activity during a simple acceleration task, in which the driver was required to accelerate the car in a straight line from a standstill to ~40km/h and to drive at a constant speed. Left and right columns show recordings in two subjects. Traces are, from top to bottom, vehicle longitudinal acceleration (in G), EMGs of the right SCM and EMGs of the left SCM (in volts). Each trace is an average across 5 trials. Upward deflections in top trace indicate increases in vehicle velocity. Time scale bar indicates 2 sec and applies to all panels.

the instantaneous discharge rate of these fibers shows two components: "tonic" activity proportional to muscle length and "dynamic" activity proportional to the rate of change of the length [12]. A second example is the activity of eye muscles in relation to eye movements. Eye muscle motor neurons, and therefore the muscles that they innervate, exhibit a so-called burst-tonic discharge pattern. Their discharge rate can be expressed as a linear sum of the angular position of the eye and its time derivative (i.e., angular velocity) [13].

These examples, along with the qualitative observations in the preceding section (Figs. 3 and 4), have led us to assume that the EMG response has both acceleration-related component and jerk-related component. In other words, the temporal profile of the EMG may be reproduced as a sum of acceleration profile and jerk profile.

We tested the plausibility of this assumption using example data shown in Figure 5 (obtained in a straight-line acceleration task). When the acceleration profile alone is superimposed with the EMG data, it does not match the muscle response (Fig. 5A). The jerk profile, with an apparently different time course than that of EMGs, does no better (Fig. 5B). However, when acceleration and jerk are combined with relative weights of 65 and 35, respectively, the resultant waveform appears much closer to the EMG response (Fig. 5C). When we introduce a delay of 190 msec, the linear sum nicely mimics the driver's muscle activity (Fig. 5D). Note that the sum is shown in an arbitrary scale. This result suggests that the SCM activity may be reproduced by a linear sum of vehicle acceleration and jerk if appropriate weight and time lag are chosen.

The assumption is expressed quantitatively as follows:

$$EMG(t)=\frac{(100-w)}{100}\times k\times A(t-lag)+\frac{w}{100}\times r\times J(t-lag) \quad (1)$$

where t represents time (in sec), $EMG(t)$ the instantaneous EMG amplitude (in mV). $A(t)$ and $J(t)$ are vehicle acceleration and jerk as a function of time (in m/sec^2 and m/sec^3, respectively), k is the sensitivity to acceleration, r the sensitivity to jerk, and lag is the time lag. The dimensions of k, r and lag are [mV/(m/sec^2)], [mV/(m/sec^3)] and [sec], respectively. A dimensionless coefficient, w, determines the relative contribution of the jerk component.

Note that, in formula (1), $A(t)$ and $J(t)$ are the acceleration and jerk of the *vehicle*, respectively. The formula is

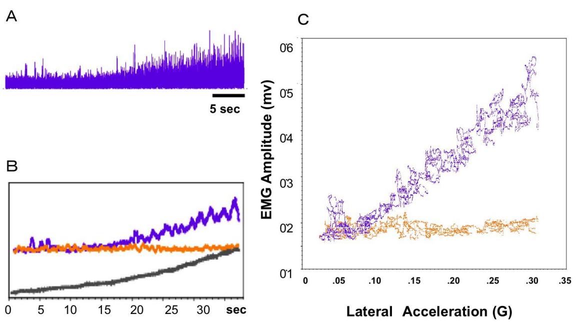

Figure 3: EMG response when acceleration is nearly constant.

The EMG and vehicle acceleration during a steady-state turning task (rightward turning). A. The EMG of the right SCM over a single trial (~35 sec). B. The purple and orange traces indicate EMGs of the right and left SCMs, respectively. Shown in an arbitrary scale. The gray trace indicates the vehicle lateral acceleration, which was zero at time zero. In an arbitrary scale. C. Relationship between EMG amplitude (ordinate, in mV) and lateral acceleration (abscissa, in G). The purple and orange traces indicate the right and left SCMs, respectively.

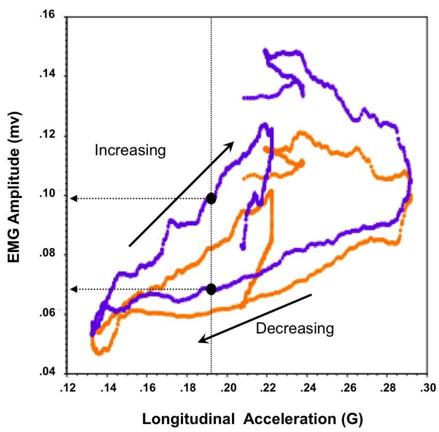

Figure 4: EMG-acceleration relation when acceleration rapidly changes.

The EMG amplitude (ordinate, in mV) and vehicle longitudinal acceleration (abscissa, in G) during a straight-line acceleration task, where forward acceleration increased, decreased and increased again. Note that the vehicle kept increasing its velocity throughout this part of the task. The purple and orange traces indicate the right and left SCMs, respectively. Time is implicit.

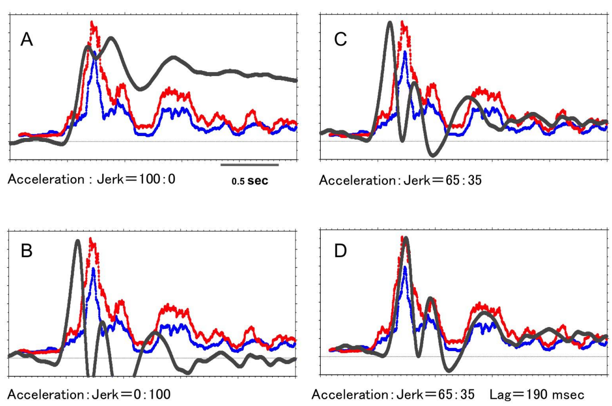

Figure 5: Reproducing EMGs with vehicle dynamics

Red and blue traces indicate, respectively, the EMGs of the right and left SCMs. Gray traces indicate linear sums of acceleration and jerk, shown in an arbitrary scale. Acceleration and jerk are combined with relative weights of 100 and 0 (A), 0 and 100 (B), and 65 and 35 (C, D). In D, a time delay of 190 msec was introduced.

based on the assumption that the time course of the muscle activity faithfully reflects that of the inertial force (and therefore acceleration) that acts on the driver's *head* (see Discussion).

The purpose of our analysis is to estimate how closely formula (1) can mimic actual EMG data and to obtain the values of *w* and *lag* that, in combination, produce the best matching. A correlation analysis was used to find such values. We systematically changed *w* (0 to 50%, with an increment of 5%) and *lag* (0 to 250 msec, with an increment of 5 msec) and, for each combination, performed regression analysis to obtain a correlation coefficient. Note that, because we use linear regression analysis and seek a set of *w* and *lag* that gives the highest correlation coefficient, we do not need to assign weights separately for $J(t)$ and $A(t)$ or add a constant term.

3.4 Characterizing the relationship between EMG response and vehicle motion

To understand how the correlation analysis may actually work, we calculated the correlation coefficient as a function of *w* and *lag*. Figure 6 shows the EMG response to sudden straight line acceleration (grand average of EMG of the right and left SCMs, each averaged across 5 trials). Shown at bottom are linear sums calculated for two sets of *w* and *lag*, i.e., *w* 25 and *lag* 190 msec (black line) and *w* 25 and *lag* 260 msec (grey line). To estimate the degree of matching, the instantaneous EMG amplitude and the corresponding value of the linear sum were subjected to linear regression. As shown in Figure 7A, the lag of 190 msec resulted in a higher correlation coefficient. Figure 7B illustrates how the correlation coefficient varies with *lag* (150 - 260 msec, shown in a 10 msec increment here) for a given weight for jerk (25). For this particular data, the optimal weight and lag were 25 and 190 msec, respectively, yielding the largest correlation coefficient, 0.858.

The EMG responses in Figures 5 and 6 were collected for a relatively small road car (vehicle F) with a 1500 cc engine. Can the linear sum still mimic the neck muscle response in other vehicles having different dynamic characteristics? To address this question, we recorded the EMGs of one subject driving three cars with different characteristics (vehicle N: a 3000 cc rear-drive sports car, first gear fixed mode; vehicle M: a 2500 cc front-drive sedan, second gear fixed mode; vehicle P: a front-drive hybrid car, continuously variable transmission) in a straight-line acceleration task and applied our correlation analysis to obtain *w*, *lag* and correlation coefficient. As seen in Figure 8, the EMG responses (red) in the three vehicles have different time courses. However, the linear sum of acceleration and jerk, the superimposed grey line, appears to reproduce the EMG. Analysis indicated that the optimal weight and lag were 5 and 70 msec for vehicle N, 25 and 130 msec for vehicle M, and 10 and 80 msec for vehicle P, yielding the correlation coefficient of 0.909, 0.946 and 0.847, respectively. The linear sum of acceleration and jerk thus reproduced the EMG response of a driver in several cars with different driving characteristics, at least for a relatively simple acceleration task. The optimal weight and lag differed across vehicles as did the correlation coefficient.

The two parameters derived from the correlation analysis, the optimal weight for jerk and optimal time lag (which together give the largest correlation coefficient) characterize the relationship between vehicle dynamics

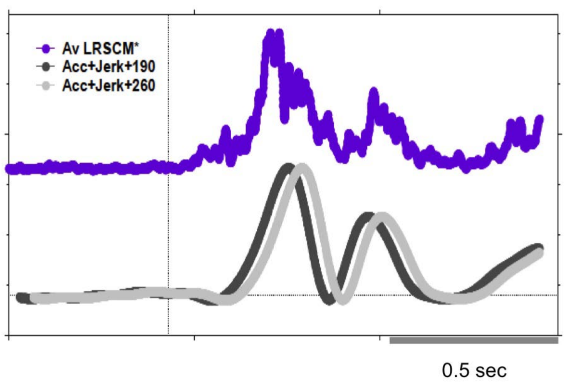

Figure 6: EMG response and linear sums with different lag values

EMGs in a sudden straight-line acceleration and linear sums with different delays. Upper trace (purple) indicates an average EMG of the left and right SCM. Bottom traces show linear sums of acceleration and jerk. Black and gray traces indicate delays of 190 msec and 260 msec, respectively. Shown in an arbitrary scale. Time scale is valid for all traces.

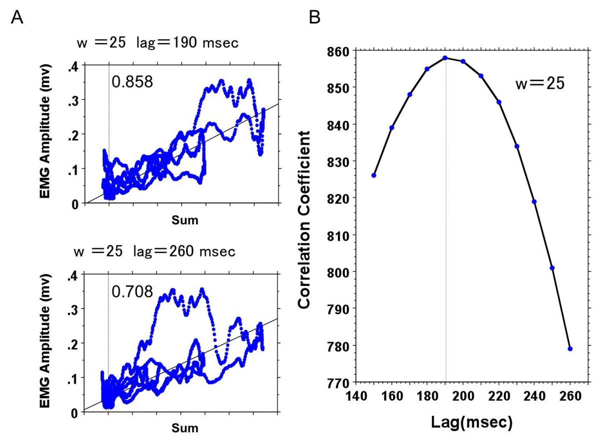

Figure 7: Finding optimal weight and lag

A. Linear regression for the instantaneous EMG amplitude (ordinate, in mV) and corresponding value of a linear sum (abscissa) for the data shown in Figure 6. Upper and lower panels show regression plots for delays of 190 msec and 260 msec, respectively.
B. Relationship between the correlation coefficient (ordinate) and lag (abscissa, in msec) for a given weight of 25% for jerk.

and neck muscle response. As a first step to examine the usefulness of these parameters for predicting the subjective feeling of a driver, we analyzed the EMG response obtained when a subject felt different dynamic characteristics of a vehicle. In this experiment, the subject is required to drive a car (vehicle F) with a gear ratio fixed at a first gear or third gear. He drove the car at a constant speed of ~30 km/h for a few seconds and accelerated it by pushing the gas pedal to the floor.

Figure 9A shows the EMG response (red) and a linear sum (gray line, in an arbitrary scale) obtained with optimal *w* and *lag*. Part of the analysis process is illustrated in Figure 9B, which shows the correlation coefficient-lag relations for several different weight values. The optimal weight, lag and the largest correlation coefficient were different for the first-gear and third-gear conditions: 25, 190 msec, 0.858 and 30, 220 msec, 0.795, respectively. As might be expected from the gear selection, the subject reported that the car was more responsive in the first-gear condition.

4. DISCUSSION

In the present study, we aimed at quantifying the matching between a physiological response of a driver and vehicle motion. Assuming that how well the head is stabilized during acceleration influences a driver's feeling about car performance, we chose to record the activity of neck muscles that help maintain the head position.

There are two main results of the current study. First, the EMG response of a driver's neck muscle depended not only on vehicle acceleration but on its time derivative, jerk. A quantitative analysis showed that the EMG profile can be reproduced by a linear sum of acceleration and jerk. Second, our correlation analysis indicated that the relationship between the muscle response and the vehicle motion can be characterized by two parameters: the optimal weight for the jerk term and the optimal time lag. Although these results are based on the data collected only in a simple driving situation (straight-line acceleration) using four vehicles, the matching between the EMGs and the linear sum appeared good judging from the correlation coefficient ranging from ~0.8 to ~0.95. To what extent the current results can be generalized remains to be tested.

From a methodological point of view, EMGs have often been used to investigate muscle fatigue [for example, 14-18] or expression of laughter [19, 20]. However, there are few reports on studies that have employed EMG recording from a driver during acceleration in a real driving setting. Neck EMGs exhibit a fast time course in response to a sudden change in acceleration: the magnitude of EMGs could change quickly over several msec. Taking advantage of this feature, we were able to quantitatively relate the muscle activity to fast changing vehicle acceleration with a possible accuracy of ~10 msec (for lag) or 5% (for relative weight).

One major finding of the current study is the presence of considerable jerk-related component in the neck muscle activity. As described in previous studies [4-7], smooth changes in vehicle acceleration and jerk seem crucial for ride comfort. In other words, larger jerk tends to create

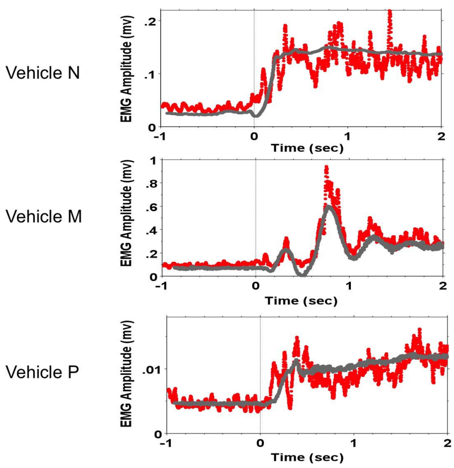

Figure 8: EMG responses in three different cars

Time course of EMGs of one driver in three different vehicles. The three panels, top to bottom, correspond, respectively, to vehicles N, M, and P. In each panel, the red trace indicates EMGs of a driver's SCM, and the gray line indicates a linear sum with optimal weight and lag.

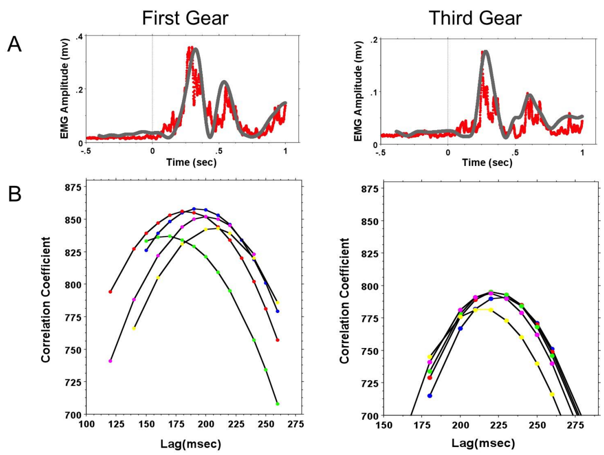

Figure 9: Correlation analysis for the same car in two different conditions

A. Time course of EMG (red) of the same driver in the same car with first gear-fixed mode (left panel) and third gear-fixed mode (right panel). In each panel, linear sum with optimal weight and lag is shown as a gray line. EMG in mV. Sum in an arbitrary scale.

B. Relationship between correlation coefficient (ordinate) and lag (abscissa, in msec) for several different weights (shown in different colors). Each curve indicates the relation for a given weight. Right and left panels show first gear-mode and third gear-mode, respectively.

negative feelings about the vehicle's motion. The muscle activity related to vehicle jerk, observed in our study, may be viewed as a reaction of the driver to minimize the imminent discomfort.

What exactly is the physiological role of the jerk-related muscle activity? We propose that this activity compensates for the lag in head acceleration relative to vehicle acceleration. Let us think of a simple situation where vehicle acceleration is initially zero, increases rapidly, and remains at a constant, positive value (Fig. 10, middle trace, black line). In terms of velocity, the vehicle velocity (with respect to the ground) is first constant, then increases at a progressively higher rate, and continues to increase at a constant rate (Fig. 10, bottom trace, black line). Here we assume that the EMG profile faithfully reflects the time course of the force generated by the muscle. We further hypothesize that the force generated by the neck muscles perfectly counteracts the concomitant inertial force that acts on the head because these forces should cancel each other to stabilize the head in the vehicle. In this hypothesis, therefore, the EMG would have a time course identical to that of head acceleration.

The head acceleration would then be expressed, like the EMG response, as a linear combination of vehicle acceleration and jerk with some time lag (Fig. 10, middle trace, red line). Because of this lag (a fraction of a second), the head would be left behind and move backward in the vehicle until head velocity catches up with vehicle velocity (Fig. 10, bottom, compare black and red lines). In this scenario, the jerk component would be needed to make head acceleration transiently exceed vehicle acceleration (arrow, middle trace) to stop the backward movement of

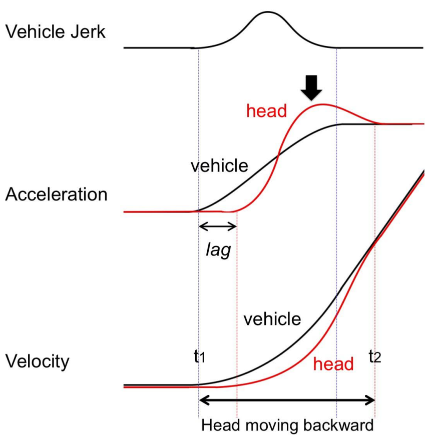

Figure 10: Role of jerk-related activity in head stabilization

Schematic drawing of a simple change in vehicle acceleration and a concomitant change in head acceleration.
Top: Vehicle jerk. Middle: Black and red lines indicate vehicle and head accelerations, respectively.
Bottom: Vehicle (black) and head (red) velocities (time integrals of corresponding accelerations). During the period from t_1 to t_2, the head moves backward relative to the vehicle.

the head with respect to the driver's body and vehicle. In other words, over a period t1 to t2, the time integral of head acceleration should equal that of vehicle acceleration. It can also be seen that a longer lag would require a larger jerk component, which result in a larger weight for jerk.

Our analysis indicated that we have two parameters that can characterize the relationship between the driver's EMG response and vehicle motion: weight and lag. On the basis of discussion about the role of the jerk component, they seem potential predictors of how a driver feels during acceleration. Both parameters, probably dependent on each other, could be viewed as an index for the imperfectness of head stabilization. If better stabilization was related to a driver's positive feeling about the car, the relative weight for jerk and the time lag might reflect some aspects of the feeling. We have investigated the usefulness of these parameters and will report the results in our companion paper.

5. CONCLUSIONS

Objective measurement of positive feelings or emotion has been one of the central topics in kansei engineering. A typical approach may be comparing a physiological index, such as heart rate, and the subjective score, and analyzing the relationship between the two. In the current study, we regarded the EMG as a motor response of a driver to a sensory stimulus (i.e. acceleration) and attempted to quantify this stimulus-response characteristics. Results indicated that the muscle response could be represented by a linear combination of vehicle acceleration and jerk. Rather than directly seeking a relation between the EMG itself and the driving feeling, we expect that some aspect of the feeling might be predicted based on the EMG-vehicle motion relationship.

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