Analysis of Driver Reaction During Braking and Avoidance Maneuver

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Abstract. One of the parts of the accident analysis is also the objective assessment of the responsibility of accident participants related to their behavior and objective ability to avert the imminent critical situation. During a critical situation, the driver can respond by avoidance maneuver, critical braking or a combination of both. However, most of the research studies have been focused on the analysis of the driver’s brake-reaction time. The aim of this paper is to analyze the driver’s reaction time in detail during the avoidance maneuver and critical braking. For the purpose of this study, the electromyography has been used. The combination allows detailed and accurate determination of the onset of the muscle activation during the reaction. For the elimination of the result distortion, the measurements were carried out in a real vehicle on a predetermined route and also in simulated condition. Participants responded to the various types of the critical incidents, mostly sudden braking of the leading vehicle. The obtained results demonstrate differences in the time necessary for the activation of the lower and the upper limb during a critical situation.

1. Introduction

Road safety has been influenced by the interaction between road infrastructure – vehicles and mainly human factor. [1], [2]. The driver’s ability to quickly react to the critical situation is essential for the traffic safety; therefore, the driver’s reaction time is one of the most important characteristics of the driver’s behavior in the critical situation. However, the definition of the reaction time varies across the researches. As stated in [3], although the terms are often used interchangeably, there are minor differences between their definitions, especially in the determination of the beginning and the end of the measured interval. For the purposes of forensic engineering, the reaction time is defined as the delay between the perception of the critical situation and the execution of activities necessary to the avoidance,
respectively a maneuver to avoid the collision performance. The reaction time is prolonged e.g. in unusual situations where it is necessary to react in a way that is not learned.

The end of reaction time is most often defined as the moment when the system has been initiated by the driver (typically, e.g. a brake-pedal contact) [4-5]. Some of the reaction time definition includes the system latency [6]. RT consists of two stages - cognitive and movement time. The movement component could be defined as the time which takes the muscles to perform the programmed motion. In general, the more complex movement leads to the longer the reaction. During a critical situation, the driver can respond by avoiding maneuver, critical braking or a combination of both. However, most of the research studies have been focused on the analysis of the driver’s brake reaction time. The movement component is then defined as a visible lower limb movement from the accelerator pedal to the brake pedal.

In previous studies, we focused on the differences between the activation of the lower limb muscles themselves and the visible movement using electromyography. The use of electromyography provides an earlier glimpse into the motor response. For the purpose of this study, we want to focus on the strategy of the driver’s response, the choice of the type maneuver to avoid collision - whether the hand and foot response is approximately simultaneous. In particular, the aim of this study is to analyze whether can be seen simultaneous activation of lower and upper limb muscles.

2. Electromyography

Electromyography, shortly EMG, is a method serving to acquire the electrical activity from muscles. Acquisition of EMG signals refers to how the monitored muscles work. Basically, it can be stated when the monitored muscle has been activated due to the acquisition of EMG signal.

There have been some studies that used the electromyography for the analysis of the driver’s kinematic behavior [7-10]. The main purpose of these studies is to determine the effect of force on activated and relaxed muscles during the vehicle deceleration. Most of the studies have been focused on the rear-end impact especially on the mechanism of whiplash injury. Current studies also analyzed the differences in muscle activation during the driver’s response and autonomous emergency braking or differences in kinematic behavior in various types of position.

3. Methods

Measurements were carried out on predetermined. For the results’ comparison, also the experiments in simulated conditions were carried out. Eights drivers have participated in this study (4 on the test track and four in driving simulator). Drivers were exposed to various types of critical incidents - e.g. suddenly thrown box or braking of the leading vehicle. Drivers were instructed to react on the critical incidents by avoidance maneuver and braking.

Movements related to the accelerator pedal abandonment have been most noticeable as an activity of three selected muscles of lower limb - musculus triceps surae as a primary mover of plantar flexion; musculus tibialis anterior as a primary mover of dorsiflexion and foot inversion; musculus peroneus longus as a main mover of foot eversion as well as foot abduction.

Avoidance maneuver realized by upper limb reaction has been most noticeable by forearm muscle activity analysis: musculus flexor digitorum longus as a prime mover of finger flexion during firm grip of the steering wheel and musculus pronator teres as an initiator of forearm pronation connected with the evasive maneuver of the wheel to the left side.
During our experiment, the wireless EMG device Cometa was used to obtain signals coming from muscles involved in measured reactions. EMG electrodes were mounted on three muscles of the right lower limb and two muscle of right upper limb. All monitored muscles can be observed in Figure 1 below.

![Monitored muscles](image)

**Figure 1.** Monitored muscles

4. Detection algorithm

For the comparison of the muscle activation of lower and upper limb, the time of the muscle onset needs to be determined. To find out this time moment, a lot of detection algorithms could be used.

To detection of muscle activity onset, there is the simplest and the most used group of a detection algorithm based on filtering EMG signal and its thresholding. The threshold can be determined from the mean value or from the multiple of the standard deviation of EMG signal baseline. Determining the exact multiple of the standard deviation of the resting EMG signal level as a threshold is experimental; the literature indicates 1.4 times the standard deviation [11], [12] or more times standard deviation [13-17]. The threshold value can also be determined on the basis of the amplified EMG signal, which was filtered by a low-pass filter at 50 Hz. The threshold value itself is determined from three times the standard deviation of the resting EMG signal (the signal length for determining the threshold is 50 ms). It is possible to use a condition that the threshold must be exceeded in the one whole signal section lasting 0.025 seconds [18].

In our case, the detection algorithm is based on pre-processing of EMG signal and thresholding too. Pre-processing of EMG signal is not based on filtering but on Teager-Kaiser operator (TKEO operator) and on Empirical Mode Decomposition of EMG signal (EMD).

TKEO operator is a non-linear operator representing the energy of the harmonic signal. Definition of TKEO operator is derived from the second order differential equation describing the simple model of the mechanical-acoustic system [19]. Non-linear TKEO operator for the continuous signal is determined according to equation 1:

$$\psi(x(t)) = (x^2)'(t) - x(t)x'(t).$$  \(1\)
After mathematical treatments the definition of TKEO operator for discrete signals can be stated in equation 2:

\[ \psi[x(n)] = x^2(n) - x(n+1)x(n-1) \]  

(2)

EMD algorithm is based on signal decomposition into its intrinsic functions and this method serves to process non-stationary signals. Intrinsic function of EMG should fulfill two elementary conditions. The first condition is that the number of extremes and zero passes is the same or different by one. The second condition is that the average estimated from the envelopes of the local maxima and minima is zero at each time moments (or very close to zero). The found intrinsic function is a one-component signal with zero mean value [20].

The own detection algorithm consists of pre-processing EMG signal. Firstly, the EMD algorithm was applied to EMG signals. Secondly, the TKEO operator was applied to the first intrinsic function and thirdly, detection of muscle activation onset was performed on pre-processed first intrinsic function. The threshold of detection was derived from multiple of the standard deviation of EMG signal (i.e five times the standard deviation). Example of the first intrinsic function is shown below in Figure 2.

![Example of EMG signal from m. tibialis anterior and its first intrinsic function](image)

**Figure 2.** Example of EMG signal from m. tibialis anterior and its first intrinsic function

5. Results

For the comparison of the differences between lower and upper limb muscle activation, the activation of each limb muscle was always used. Therefore, from the analyzed three muscles of the lower limb and two upper limb muscles, the muscles that were first activated were selected. Subsequently, the differences between the activation of the first muscle of the lower limb and the first muscle of the upper limb were analyzed.

Example of detected onsets of muscle activation is shown below in Figure 3. The rising edge of the footswitch signal (footswitch sensor was mounted on the brake pedal) was stated at the end of the driver’s reaction.
First of all, the results obtained from the driver’s reaction on the predetermined route were analyzed. The Shapiro Wilk test indicates that the differences between the lower and upper limb activation do not have a normal (Gaussian) distribution (p value 0.002). One sample Wilcoxon test retains the null hypothesis that the differences between activation divers from zero (p value 0.081). Thus it could be said that the activation of the lower and upper limb during the driver’s reaction can occur simultaneously, therefore the driver can simultaneously react by braking and avoiding.

A more detailed look at the driver’s response strategy provides statistical testing of differences between the drivers. The Kruskal Wallis test shows significant differences between the drivers (p value 0.000). The Man Whitney test indicates statistically significant differences between the first and the second driver as well as between the first and the third driver. The other differences are not statistically significant.

Thus, the comparison illustrates that the lower and the upper limb could be activated simultaneously (Figure 4). However, the reaction strategy has been influenced by learned driver’s behavior. Most drivers start with moving of the lower limb from the accelerator pedal to the brake pedal before realization of the evasive maneuver.

**Figure 3.** Detected onsets of muscle activation coming from all investigated muscle, the signal from the footswitch
Figure 4. Box plot of differences between lower and upper limb muscle activation

To minimize results’ distortion caused by a limited number of the drivers, the experiments were also realized with different 4 drivers in the simulated condition. The Shapiro Wilk test indicates that the differences between the lower and the upper limb activation (Figure 5) on a test track as well as on the simulator do not have a normal distribution (test track p value 0.002, simulator p value 0.048). The Man Whitney test indicates statistically not significant differences between these two measures (p value 0.522). The analysis of the drivers confirms separately the previous analysis of individual drivers. There are some statistically significant differences between selected drivers. The multiple comparison indicates statistically significant differences between drivers 1 x 2, 1 x 3, 1 x 7. Simultaneously, analysis of all results together (differences between the activation rate of the lower and the upper limb obtained from test track and simulated condition) shows that the differences have been statistically significant.
6. Conclusions
Based on the obtained results it could be assumed that the activation of the lower limb and the upper limb can be performed simultaneously. The reaction strategy has been influenced by the driver’s behavior especially the driving habits and experience. Most of the reactions follow the sequence of initiation of the lower extremity and then the beginning of the upper limb. The biggest deviation can be seen in the first driver’s reaction strategy on the test tracks, which has always braked before the beginning of the evasive maneuver. In contrast, the medians of the differences between the activation of the lower and the upper limb of the second and the third driver are lower than zero. These drivers more often activate the muscles of the upper limb faster compared to the lower limb.

In particular, the aim of the further measurements should be the database extension of the type of situations to which the driver reacts, as well as the larger number of participants, especially on the test track where the conditions are close to the real traffic. Also, not only the difference in the activation of the individual muscle groups should be analyzed, but also the difference at the beginning of the visible reaction should be analyzed.

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