ASSESSMENT OF DRIVER'S AND PASSENGER'S BEHAVIOUR WHEN FACING AN IMMINENT SIDE CRASH

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ABSTRACT

The aim of this study was to identify changes in the position and posture of front seat occupants that occur in a pre-crash environment. The study involved placing male volunteers in a driving simulator with programmed crash scenarios. Analysis of human reactions were recorded with the use of surface electromyography (EMG) by electrodes placed on the upper limbs. The simulated impact velocity, time of crash, time and angle of steering wheel rotations and initiation of braking were recorded. Subjects were also videotaped to assess the overall body motion and reactions. The study found that both isometric and isotonic muscle reactions were observed with varying amounts of left, right, or bilateral muscle movement. The study was conducted within APROSYS SubProject 6 – Inteligent Systems.

Keywords: BIOMECHANICS, VOLUNTEERS, SIDE IMPACTS, SIMULATOR, APROSYS

THE HYPOTHESIS is that the adverse driving situation on the road will cause upper limb and shoulder movements. The aim of WUT's activities was to determine the changes in driver's position, which occur as a reaction to driving conditions on the road. Appropriate recognition and definition of these reactions may be useful for designing the pre-crash sensors to improve safety systems and to reduce the effect of out-of-position situations.

The surface electromyography method is well recognised to be suitable for the assessment of muscle activities associated with an exertion of force. The amplitude of the EMG signal quantitatively represents muscle activity [1,2] and has been used in studies of various vocations to estimate muscle loads in tasks involving upper limbs [3,4].

Professions that require upper body and limbs, for example drivers, are very common. In those cases spine and lower limbs remain static for extended periods with simultaneous activities that are done with upper limbs.

The relationship between the external workload typical for the performed task and musculoskeletal load or fatigue has been shown in numerous studies, where individual authors discussed various indices of load and fatigue of the musculoskeletal system [5,6]. Numerous studies documented that EMG parameter values depend on the external load. In an analysis of an upper limb activity, it is important to express muscular activity quantitatively. This makes it possible to distinguish differences depending on the conditions of the external load.

During a given, performed task, muscles in shoulder region are subject to various types of tension, depending on exposure to risk factors. The force, which the muscle exerts as well as muscle tension, expressed by the amplitude of the EMG signal depend on muscle length (upper limb location) [7], as well as on other factors, for example psychological. There are suggestions that the muscle tension of upper limbs is influenced not only by physical factors [2], but also by psychological factors [8,9]. Psychological factors are related to the character of performed task, precision and pace of performed work, its complexity, attention-related activity as well as social factors. Therefore, muscle activity during the exertion of force can be spread out between muscle activity, to stabilise upper limb in its defined position, and activity related to the exertion of external force, as well as activity of additional tension caused by psychological factors.

MATERIAL AND METHODOLOGY

THE AUTOPW SIMULATOR

The AutoPW Automobile/Truck Driving Simulator was built at the Warsaw University of Technology. It is the main tool used for research at the Laboratory for Simulation Tests of the Vehicle Motion and Dynamics in the Faculty of Transportation. This is a stationary, automobile-cabin simulator, where vehicle motion on a horizontal road surface is simulated. The vehicle body and the road wheels are treated as rigid bodies. The vibrations of body and suspension elements were ignored. The changes of normal reaction on the wheels arise as a result of the quasi-statistic action of external forces and moments. In this area, the resultant flexibility of the suspension and pneumatics in vertical direction is taken into consideration in relation to each wheel. Freeplay and dry friction in a steering system were ignored. Both those phenomena may stand, in a literal way, to fulfil the real conditions. The gyroscopic moments accompanying turning the rotating steered wheels were also ignored. It was accepted that in every moment of the simulation the following variables are known: the steering wheel angle, angle defining location of the engine control mechanism (e.g. opening the throttling valve in the gasoline engine), transmission ratio, force of pressure on a brake pedal, parameters of the condition of road surface (determining tire shear forces), components of wind velocity vector. Model's output quantities are: coordinates of the centre of vehicle mass on the road plane, yaw angle and their 1st and 2nd derivatives, vehicle velocity (corresponding to indications of speedometer), the stabilizing moment on a steering wheel. The model was verified through experimentation. Both experimental and simulation tests were based on ISO standards and recommendations [10,11].

The inputs generated by the driver are:

- steering wheel rotation angle,
- force onto the brake pedal,
- displacement of the accelerator pedal,
- displacement of the clutch pedal,
- position of the gearbox lever.

The picture is projected 2.34 m in front of driver's eyes. View angle (**Figure 1)** in the horizontal plane is about 94°, in the vertical plane is 38 to 42 degrees. The presented values can be slightly altered according to driver's eye position as this depends on the driver's height and seat position.

Fig. 1 – View from inside the simulator cabin

The AutoPW Simulator is a tool that enables to acquire and to improve driving capabilities under simulated conditions corresponding to both regular and dangerous road traffic situations, where severe accidents might occur. The simulator enables to investigate driver's skills, behaviour and reactions

while driving under the influence of medicines, facing danger or feeling tired. The driver's reaction time measurement accuracy is from 0.02 to 0.04 sec.
The main outputs from AutoPW simulator are:

- two co-ordinates of the position of the vehicle weight centre in a system related to the road
- yaw angle
- speed in an inertial system
- angle of steering wheel
- load on the brake pedal
- angle of opening the throttle

ELECTROMYOGRAPHY SIGNAL – EMG

To examine muscle activity, surface electromyography (EMG) was applied. In experiments, the EMG signal from the main muscle of shoulder girdle and of forearm were registered. Area of muscles involved in performed task depends on the kind of task and usually subjects muscles to various patterns of load. This study considered muscles, which support the upper limb in a determined posture and those involved in activities of driving a car like keeping and turning the steering wheel and changing gears. Muscles of arm and shoulder usually support upper limb in a defined position. The role of the trapezius muscle is to support posture, as the forearm muscles are strongly involved in handgrip force exertion.
The examined muscles were: extensor digitorum superficialis (EDS) and trapezius pars descendents (TR). Those muscles were selected because they play different roles and have different degree of involvement in performed task (**Figure 2**). Therefore, different degrees of involvement of the analysed muscles in performed task of driving were expected. The EMG signal was registered for both sides of the body.

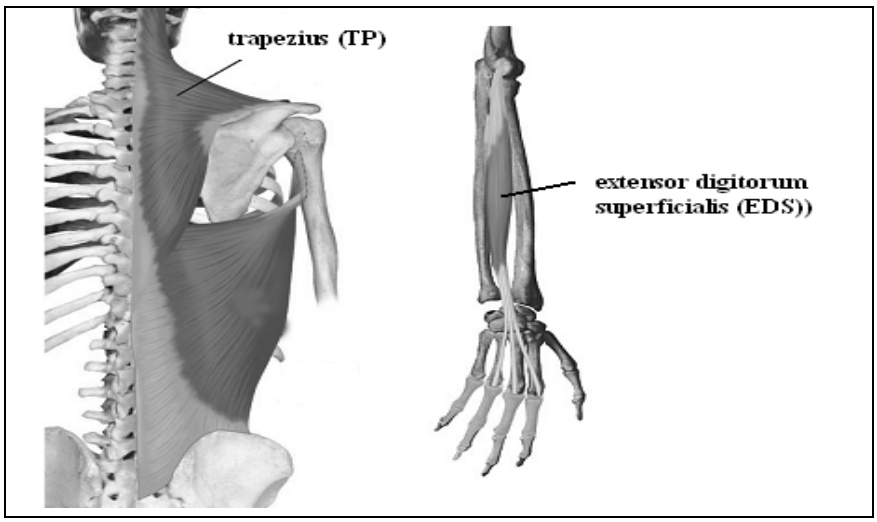

Fig. 2 – Muscles examined during experiments: a) trapezius pars descendents; b) extensor digitorum superficialis

The anatomic positioning of the muscles was done tacitly as the participant put them to isometric tension. Electrodes were attached in line with the direction of the muscle fibres, in the central mass of the muscle. The myoelectric signal was picked up with bipolar disposable Ag-AgCl (Blu Sensor Medicotest, Ølstykke, Denmark) electrodes, which active areas are 5mm x 5mm. The electrodes were applied to the skin with an inter-electrode distance of 20 mm, above and parallel to the assumed direction of the fibres in the central part of the muscles (**Figure 3 and 4**). The skin was properly prepared (including necessary shaving, slight abrasion and cleaning with alcohol solution) to obtain inter-electrode resistance below 2 kΩ.

Fig. 3 – The electrodes applied to the extensor digitorum superficialis (EDS)

Fig. 4 – The electrodes applied to the trapezius pars descendent (TR)

The ME3000P (Mega Electronics, Finland) device was used for the measurements and analysis: it enables observation and recording of a raw signal and its subsequent analysis. Preamplifiers located close to the electrodes made it possible to register the non-artefact signal (**Figure 5**).

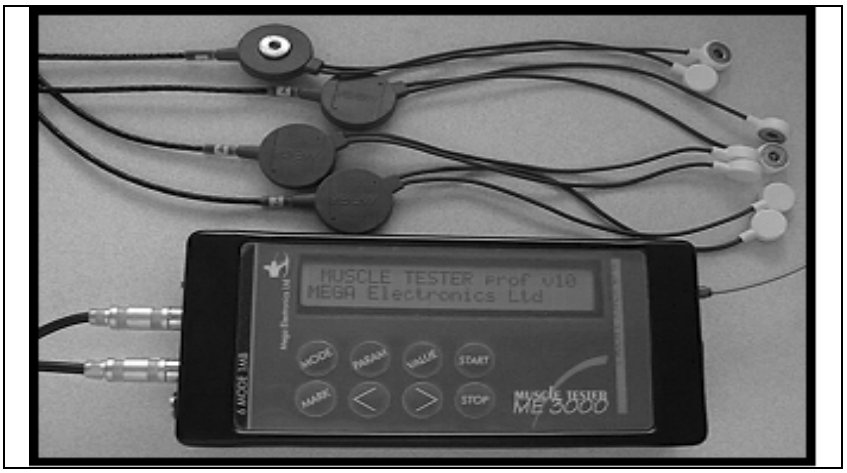

Fig. 5 – Registration of EMG - ME3000p

The EMG signal was amplified with a differential amplifier and a Butterworth filter (-3dB bandwidth: 8-500 Hz). Input impedance was established at 10 GΩ and CMRR 110dB. The signal-to-noise ratio amounted to -75 dB. The EMG signal was sampled through a 12-bit A/D converter with a sampling rate of 1 kHz.

An experimental session consisted of a preparatory phase and an experimental phase. During the preparatory phase maximum strength capabilities were measured (Maximum Voluntary Contraction - MVC). Maximum muscle activities (MVC) were used to determine the level of the external relative activities corresponding to muscle trapezius and muscle extensor digitorum superficialis.

A calibration platform equipped with two adjustable slings was used for the measurement of maximum EMG signal from trapezius pars descendent. The participant stood on the platform in a neutral position with both arms hanging down and pulled the sling handles (**Figure 6**). The procedure was performed by pulling the handle smoothly and by using the shoulders (without flexion in the elbow joint).

Fig. 6 – Posture during exertion of Maximum Voluntary Contraction for muscle trapezius

The maximum signal for extensor digitorum superficialis was accepted as measured during maximum handgrip force. During exertion of the force, the volunteers were standing with their backs straight and upper limbs hanging down. The volunteers were asked to increase the force gradually without jerking and to hold the exertion for 3 seconds. During the maximum exertion of force, muscle activities were registered (**Figure 7**).

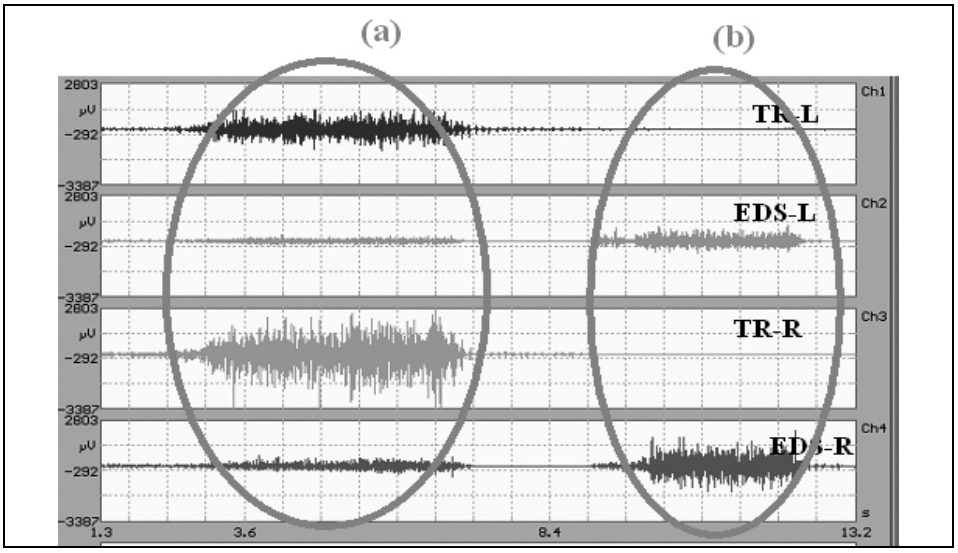

Fig. 7 – Amplitude registered during Maximum Voluntary Contraction for muscles trapezius (a) and for muscles extensor digitorum superficialis (b)

The analysis of the EMG signal was based on software supplied with the MESPEC 4000 equipment, which was used for measuring and registering the EMG signal. For analysis, integrated amplitude of the EMG signal, which converts information about muscular tension at a given muscle, was employed. The EMG signals were full wave rectified and averaged within the range of 0.5 in length (IEMG).

For each of the four examined muscles a ratio between IEMG measured during the experimental phase (simulation of driving the car) and IEMG measured during the preparatory phase (measurements of MVC) was calculated.

TESTS SET-UP

The two different side-impact scenarios were investigated in the AutoPW simulator:

1. real accident case from the city of Kielce in Poland – scenario consists of 3 identical crossroads (**Figure 8**). According to the road signs the driver cannot drive away from the loop.
2. generic environment (called DISTRICT – **Figure 9**) – straight road with blocks of flats on both sides and several crossroads.

Fig. 8 – Real accident crossroad from Kielce town and its implementation into AutoPW simulator – called TOWN

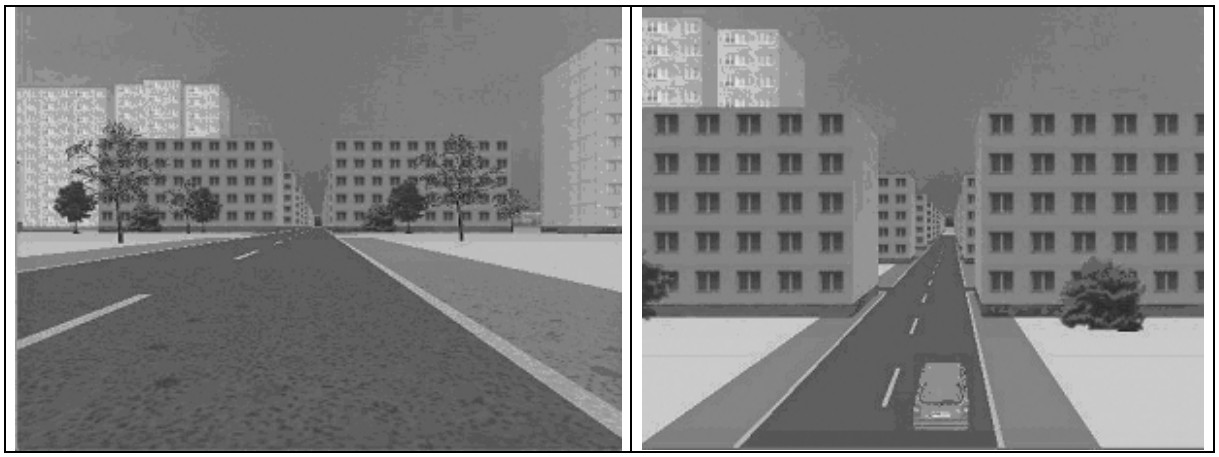

Fig. – 9 General environment – called DISTRICT

Tests were performed on 32 volunteers – 28 men aged 20 to 30, 2 men aged 30 to 40 and 2 men aged more than 40. They were required to have driving licenses and to have little or no experience in playing computer games. The poll was conducted among volunteers before the tests were carried out. All replies are presented in the **Table 1**. During each test, driver's position was registered by digital video cameras. Additionally, the EMG signals from 4 muscles were registered to assess possible muscle tension. Before the test, drivers were not aware of unavoidable collision.

For how long have you had a driving licence? [year]	No 1	Less than 1 year 2	Between 1 to 5 7	More than 5 22	
How often do you drive a car?	Other 1	Once a month 5	Once a week 9	Every day 17	
How often do you play computer games?	Very often 1	Often 7	Seldom 14	Never 10	
Are you tired? Scale 5(Yes)-1(No)	Yes 1	1	16	7	No 7

Tab. 1 – Characteristics of volunteers

During experimental phase volunteers performed simulated driving task. The participant was supposed to drive as in regular traffic conditions, which means changing gears, turning steering wheel etc. The surroundings were visualized on the screen. To simulate a collision, the bullet car was directed to drive into the volunteer's car from the right side (**Figure 10)**. This moment of simulation was named the crash. The participant's reaction to this event, registered in electromyography signal from examined muscles was analysed. The drivers could not avoid the collision because they had only 6 meters from seeing the bucket car to the crash location. The speed of the bullet car was always the same as the target car.

Important information related to muscle activities during the crash was obtained on the basis of ratio between the amplitude registered during crash and the amplitude registered during driving without any incidents.

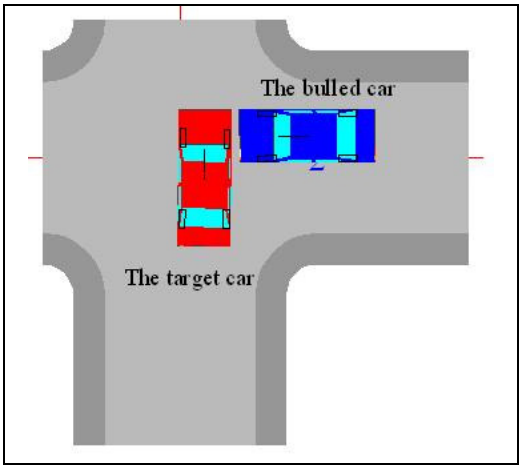

Fig. 10 – The relative position of target and bullet cars

RESULTS

EXAMPLE OF ANALYSIS

The hazardous situation during the test DISTRICT caused an increase in activity of both muscles in both upper limbs (**Figure 11**). Such situation suggests reaction to hazardous situation by turning steering wheel with both hands. The high value of these signals signifies that turning was very rapid and exaggerated.

muscle	driving	crash
TR-L	**6,5**	**23,0**
TR-R	**2,3**	**9,8**
FDS-L	**1,5**	**82,9**
FDS-R	**2,7**	**93,3**

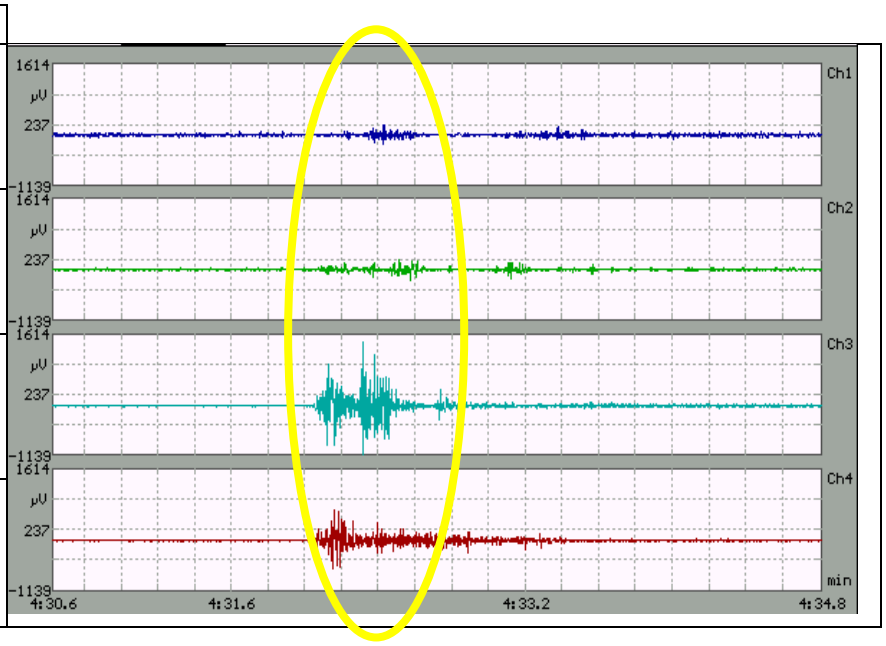

Fig. 11 – Participant "1_8" EMG amplitude [%MVC] from the examined muscles as reaction on crash in test DISTRICT (FDS-L: flexor digitorum superficialis of the left side; FDS-R: flexor digitorum superficialis of the right side; TR-L: left trapezius; TR-R: right trapezius)

The parameters of the car simulator were registered (**Figure 12**), and the most important are presented below:

- speed in an inertial system
- angle of steering wheel
- load on the brake pedal
- yaw angle

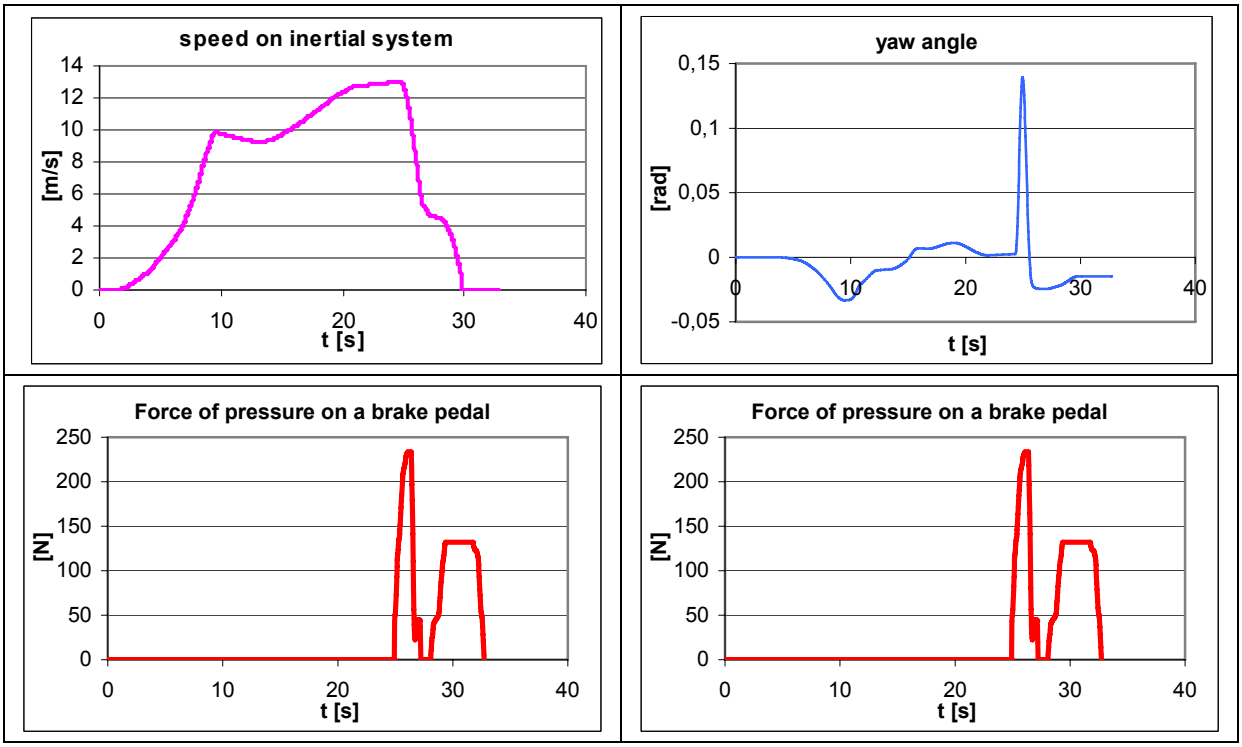

Fig. 12 – The most important car simulator parameters

Fig. 13 – Volunteer reaction on crash

Comparing this data with the video (**Figure 13**) enabled us to perform analyses of human reactions to an unexpected crash. The following parameters were investigated:

- Speed – speed during collision
- Time of crash – precise time when cars collide
- start of turning the wheel – time when the turning of steering wheel appears as a reaction to the crash
- max angle of the wheel – maximal angle of turning the steering wheel during reaction to the crash, in brackets there is time when this angle was at its maximum
- start of braking – time when volunteer started braking

Time "zero" describes the start time of recorded simulator output parameters.

	Tests DISTRICT				
	speed [m/s] [km/h]	time of crash [s]	start of turning the wheel [s]	max angle of the wheel [rad] /[s]/	start of braking [s]
1_8	13.0 46.8	24.33	24.2	2.31 /24.55/	24.95

Tab. 2 – Time of "Participant 1_8" reaction during crash

Participant 1_8 drove in the DISTRICT test with the speed of about 13 m/s during the time of crash. He started turning the steering wheel before the crash, but he obtained the max angle in time of 0.22 sec. after that. He also started braking, but in time of about 0.5 sec. after the adverse condition occurred (**Table 2**).
The examples of volunteers' reactions and their impact on muscles activities' are presented in the Appendix 1.
During the test 1_7, which involved examining the volunteer without a driving license, an interesting reaction was observed. In this test the percentage of his MVC while driving was very high – for TR's muscle about 35 %, for FDS's muscle 20 %. Comparing this to other volunteers, whose recorded values were below 10 %, it can be deducted that this driver was much stressed. The volunteers' muscle activity reactions (without any movements) also change the natural "position" of the driver in the case of crash.

CONCLUSIONS AND DISCUSSION

The two tests were performed with different scenarios regarding road events. However, in both cases the crucial point was the sudden appearance of the car driving from a perpendicular direction to the test car. The drivers could not avoid the collision in these tests, because they could notice the bullet car only about 6 meters before the crash designed location.
The 64 cases of simulated driving were analysed. Measurements of EMG allowed us to present muscle activities during regular driving and during the sudden, unexpected situation. Participants reacted variously to this hazardous situation, because of the diverse upper limb positioning during the drive. The following reactions can be observed:

- in 23% of tests (15 of 64) – no reactions
- in 30% of tests (22 of 64) – no upper body movements reaction, in 68% of them (15 of 22) the muscles contraction as the typical "fear" reaction was observed
- in 50% of tests (32 of 64) – turning steering wheel, in 73% of them (22 of 30) the reaction was commenced before the crash
- in 25% of tests (16 of 64) – backward movements of upper body was observed
- in 3% of tests (2 of 64) – forward movements of head and upper body was observed
- in 15% of tests (9 of 62) – the volunteer started braking before the crash

The main aim of the study was to create a pattern of driver behaviour while facing an imminent side crash and its influence on EMG signal. The following results can be listed:

- Increased activity only in the left side muscles – in this case the volunteer drove the car with only their left hand. When the signal from muscles is very high the driver also quickly turned the steering wheel at the time of crash without any backward movement.
- Increased activity only in the right side muscles – quick movement of the right leg toward braking pedal, without turning movement
- Increased activity only in FDS muscles – backward movement of the upper body without turning the steering wheel
- Increased activity in all muscles – significant turning combined with backward movements and braking. When driver turns a steering wheel during the crash, the muscle activity of this movement covers the possible reaction of muscles contraction.
- Increased muscle activity without any movement – typical "fear" reaction

To summarise, it can be stated that an unexpected traffic situation causes additional muscle activity. This can result from muscle contraction as reaction to stress or contraction caused by upper limb movements.
Comparison of the results with the video recording showing participants' reaction reveals that in a few cases the changes in muscle activity occurred without noticeable changes in participant posture. The conclusion is that the muscle contraction is the reaction caused by the adverse traffic conditions on the road.

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Appendix 1 – tests 1_x

	Test TOWN [%MVC]								Type of the driver reaction
	TP–L		TP–R		FDS–L		FDS–R		
	drive	crash	drive	crash	drive	crash	drive	crash	
1_1	4.1	4.1	2.8	2.5	**0.8**	**12.9**	**0.9**	**1.8**	backward movement, driving only left hand, no turning, no braking
1_2	**2.6**	**7.7**	2.8	3.6	**3.3**	**10.2**	1.2	0.8	only left hand on the steering wheel, right on the gear stick, no reaction
1_3	3.1	4.1	1.5	1.8	**4.8**	**7.4**	**3.5**	**15.3**	Both hands on steering wheel , no reaction
1_4	**2.4**	**29.1**	7.2	10.1	**11.7**	**36.1**	**6.3**	**20.1**	During crash right hand moves to the gear stick, only left hand on the steering wheel, large turning
1_5	3.4	4.2	4.2	2.8	**5.6**	**34.0**	2.8	3.5	Driving with only left hand, very small turning and backward movements, braking
1_6	**6.7**	**25.7**	**4.3**	**9.8**	**3.5**	**53.0**	**5.1**	**50.4**	Two hands on the steering wheel, very large turning movement, without braking
1_7	40.2	42.8	32.0	45.6	17.4	18.1	22.8	28.6	no reaction
1_8	**5.2**	**51.3**	1.5	2.3	**6.1**	**80.6**	2.7	4.0	Only left hand driving, turning and backwards movements

	Test DISTRICT [%MVC]								Type of the driver reaction
	TP–L		TP–R		FDS–L		FDS–R		
	drive	crash	drive	crash	drive	crash	drive	crash	
1_1	**2.6**	**20.7**	**4.0**	**9.1**	**0.8**	**60.9**	**1.8**	**29.8**	backward and quick only left hand turning movement, braking
1_2	2.1	1.6	1.2	0.8	3.3	2.6	0.8	0.4	without movement, both hands on the steering wheel, no reaction
1_3	**3.1**	**12.0**	**0.4**	**3.7**	**2.1**	**28.6**	**2.8**	**11.8**	Both hands on the steering wheel , quick turning with backward movement, no braking
1_4	**0.8**	**8.0**	**4.3**	**11.6**	**5.0**	**42.8**	**11.1**	**20.1**	Both hands on the steering wheel , very small but quick turning, no braking
1_5	5.1	5.1	3.5	3.9	**1.1**	**31.1**	0.7	0.7	Only left hand driving, very small turning movement
1_6	**7.0**	**30.6**	**4.5**	**22.4**	**3.5**	**34.9**	**8.0**	**67.3**	Two hands on the steering wheel, very large turning movement, without braking
1_7	14.5	16.6	**11.7**	**66.0**	2.9	3.9	**15.5**	**51.5**	No reaction
1_8	**6.5**	**23.0**	**2.3**	**9.8**	**1.5**	**82.9**	**2.7**	**93.3**	Two hands on the steering wheel, large and quick turning movement, without braking

Tab. 3 – Muscle activity [% MVC] and type of the driver reaction during tests TOWN and DISTRICT

	Tests TOWN					Tests DISTRICT				
	speed [m/s] [km/h]	time of crash [s]	start of turning the wheel [s]	max angle of the wheel [rad] /[s]/	start of braking [s]	speed [m/s] [km/h]	time of crash [s]	start of turning the wheel [s]	max angle of the wheel [rad] /[s]/	start of braking [s]
1_1	11.7 42.2	X	no	no	112.93	14.3 51.5	15.50	15.65	1.74 /15.8/	15.68
1_2	16.7 60.1	63.5	no	no	no	12.5 45.0	35.52	no	no	no
1_3	12.3 44.28	117.05	no	no	no	16.7 60.1	13.28	13.4	0.73 /13.65/	no
1_4	13.9 50.0	110.15	110.05	1.51 /110.4/	no	15.2 54.7	35.73	35.95	0.18 /36.08/	no
1_5	12.2 43.92	109.18	109.3	0.17 /109.38/	109.3	13.0 46.8	27.43	27.48	0.21 /27.68/	no
1_6	11.1 40.0	122.83	122.6	2.35 /123.13/	no	14.0 50.4	46.23	46.18	2.63 /46.6/	no
1_7	9.22 33.2	141.9	no	no	141.83	12.1 43.6	39.43	no	no	no
1_8	10.2 36.7	124.08	123.8	1.59 /124.18/	no	13.0 46.8	24.33	24.2	2.31 /24.55/	24.95

Tab. 4 – Time of volunteers reaction during crash