DETAILED ANALYSIS OF 3D OCCUPANT KINEMATICS AND MUSCLE ACTIVITY DURING THE PRE-CRASH PHASE AS BASIS FOR HUMAN MODELING BASED ON SLED TESTS

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ABSTRACT

Today, human models are frequently used for improvements in occupant and pedestrian protection. The models have been carefully prepared with respect to anthropometric and biomechanical validity but do not include muscle activity.

Hence, primary safety issues cannot be addressed by the model, since during low loading the model is not stabilized by muscles. Therefore, the OM4IS ("Occupant Model for Integrated Safety") project was initiated by a large consortium including scientific (Virtual Vehicle Research and Test Center, Graz University of Technology, Bundesanstalt für Straßenwesen BASt) and industry (PDB, Bosch, Toyoda Gosei Europe, TRW, DYNAmore GmbH) to examine muscle activity from volunteer tests and implement the results in a human model. The second aim is to find movement patterns which will be integrated in the simulation to develop active restraint systems.

The main focus in this project is set on two different driving maneuvers. The first one is an emergency braking maneuver the second one is a lane change maneuver. In a first step these two maneuvers were simulated with sled tests and later these maneuvers had been carried out with a real vehicle on a test track. The purpose of the sled tests was to generate first input data for the numerical simulation and to check if it is possible to measure necessary information without vehicle tests. A seat was fixed on a sled and accelerated longitudinally to simulate the emergency braking maneuver and afterwards turned by 90 degrees to simulate lateral loading.

In total eleven volunteers, weight and height correlated to the 50% male, were tested and analyzed. Kinematic analyses were performed using two different motion capturing systems, one infrared based system and one high-speed video system. Two different systems were chosen to evaluate the adaptability for vehicle tests.
Additionally muscle activity was measured with surface EMG (Electromyography) for upper body muscles.
First results showed a significant difference among volunteers. Repeated tests with the same volunteer showed minor differences. Movement patterns varied significantly between different tests. Detailed information concerning simulation is presented in a separate paper [7].

INTRODUCTION

Today`s restraint systems are developed with different crash tests and simulations. Mostly these tests are evaluated with dummies and dummy models. Integrated vehicle safety is also a challenge for simulation models. Human models like THUMS [9], HUMOS [10] or as included within MADYMO [11] are used increasingly for these research purposes. THUMS for example is used for pedestrian and occupant safety. But the improvement of occupant safety and pedestrian safety is an ongoing challenge to update existing human models. Furthermore different crash scenarios need to be analyzed and for the development of new active restraint systems the kinematics of occupants before the crash is interesting. To obtain correct position information of occupants it is necessary to assess typical movements of humans for various scenarios. For these patterns the function of muscles is a relevant part.
Most of the currently available human models are validated by means of high impact PMHS tests neglecting muscle activation and low impact situations [1]. But for the above mentioned movement patterns the muscle activity is a necessary component. A common measurement system for muscle analysis is surface EMG which is often used for biomechanical topics [2]. Praxl et al. [3] showed significant differences in the kinematics during a rollover scenario comparing the behavior of a dummy model with the overall kinematics of a passive human deformable facet model provided by MADYMO. Also Adamec et al. [4] showed differences between different dummies

and volunteer sled tests. Ejima et al. [5] conducted sled tests with five volunteers, three male and two female. They analyzed the kinematics and muscle characteristics and found that the difference in muscle activity governs the motion based on the acceleration and EMG electrodes. The study showed that depending on the location of the muscle the reflextime varied. M. latisimus dorsi and paravertebral muscles were mainly activated and reflex time of head, neck and torso muscles was around 70 ms to 200 ms. Begeman et al. [6] also did a study with low impact tests. He identified a reaction time from 50 ms to 150 ms and that the tone of the lower extremity muscles changed the occupant's dynamics.

TEST SETUP

The main focus was on the pre-crash phase for two different driving maneuvers. To cover the basic movement directions the emergency braking maneuver and lane change maneuver were simulated with sled tests.

Sled Design

For these tests a test vehicle (Figure 1) was constructed. The vehicle had standard car tires and a hydraulic braking system. On the vehicle a frame for the camera systems was mounted.

Figure 1. Sled design for the lane change simulation

Also a simplified seat without cushion was fixed on the vehicle (referred to as sled). The seat frame was taken from a serial production seat, only the cushion was removed. For the seating area wooden plates covered with leather were used. These modifications were done in order to eliminate the influence of the seat cushion and therefore simplify the boundary conditions for the simulation.

Realization

The sled was accelerated longitudinally to simulate the emergency braking maneuver. Due to the fact that the sled could only be controlled in one direction the seat had been mounted backwards for this maneuver (Figure 2). Afterwards the seat was turned perpendicular to the acceleration direction to simulate the lateral loading.
In order to constrain the movement a fixed lap belt was used, such that there was minimal movement in the pelvis area. This procedure was chosen to provide well defined boundary conditions for the simulation. Additional support by a 3 point belt complicates the identification of movement patterns, which was another reason for choosing the lap belt.
Furthermore the volunteer did not get any information about the start of the maneuver because the task was to measure the pure reaction of the volunteer during unanticipated acceleration.

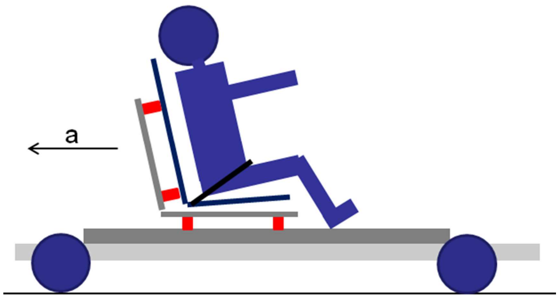

Figure 2. Principle test setup with direction of acceleration a

The acceleration was measured in the center of the vehicle and was analyzed from the start point up to the point where the acceleration started to decrease. This interval was used as input for the simulation. The acceleration characteristic depends on the automatic control of the crash test facility and the decrease of the acceleration was significant after 500 ms. The acceleration data after 500 ms was not important for the analysis.
Three frontal tests with a maximum acceleration of 0.8 g (Figure 3) and three lateral tests with a maximum acceleration of 0.5 g (Figure 4) were performed with each volunteer. Each test was repeated twice because the influence of the anticipated maneuver also was interesting for the project.

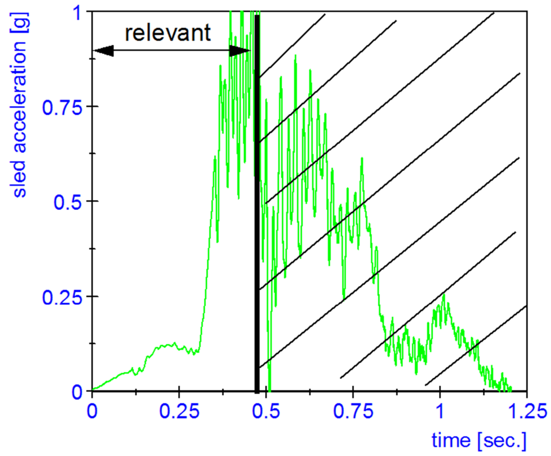

Figure 3. Sled acceleration frontal test

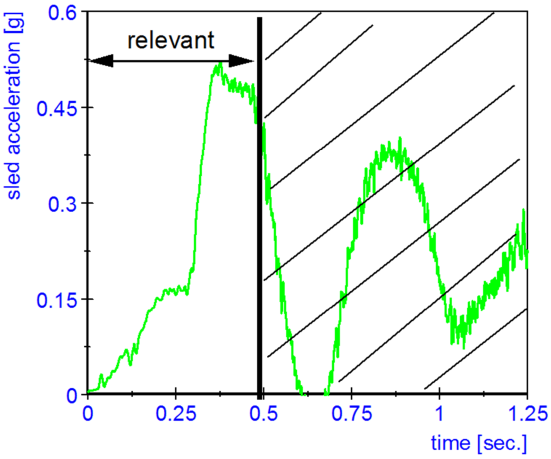

Figure 4. Sled acceleration lateral test

The specific acceleration characteristics were chosen due to safety reasons and to mimic accelerations in the full vehicle tests.

Volunteer

The body size and anthropometric data of the volunteers corresponded to the 50% male (175cm height, 78kg weight, Table 1).

volunteer	height [cm]	weight [kg]
volunteer 1	178	75
volunteer 2	186	75
volunteer 3	175	74
volunteer 4	173	69
volunteer 5	180	75
volunteer 6	183	80
volunteer 7	172	70
volunteer 8	185	80
volunteer 9	174	71
volunteer 10	180	70
volunteer 11	181	71
average	179 (+/-5)	74 (+/- 4)

Table 1. Volunteer height and weight

Measurement Systems

The kinematic analysis was performed using two different 3D motion capturing systems. An infra-red based system (VICON [14]) and a standard optical high-speed video system (WEINBERGER [15]) were used. Four volunteers were measured with the infrared based system and seven volunteers with the standard high-speed video system.

<u>Infrared based motion capturing system</u> Cameras with infrared strobes recorded images of passive markers, small spherical objects, wrapped with retro-reflective foil, attached to the subject's body and to the surrounding structure. A calibration process was performed prior to the experiments, where a known geometric structure was recorded by all cameras. Thereby the camera positions, orientations and lens parameters could be determined. The system consisted of 8 cameras set to a strobe frequency of 100 Hz. The advantage of the infrared system is that there is no need for additional lighting. The system allowed capturing around 50 markers simultaneously. A very tight suit was used, which led to marginal displacements due soft tissue movement. The same markers were used for frontal test and lateral tests (Figure 5).

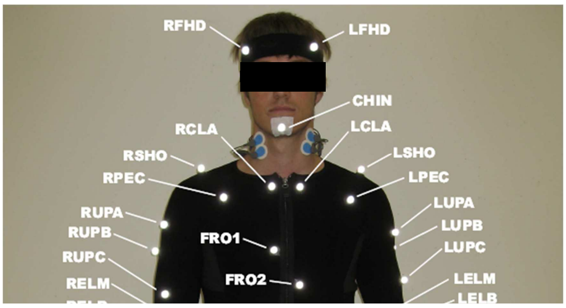

Figure 5. Targets infrared system (frontal and lateral tests)

One handicap of the system is that only the trajectories of the targets are recorded and can therefore be visualized. For a real video an additional digital camera is necessary.

<u>High-speed video system</u> In this system two high-speed cameras have been used. The system allows the use of more cameras but due the fact that the sled was only accelerated in one direction and the upper part of the body was of interest two cameras were sufficient. The captured frequency was 1000 Hz. A calibration process was performed prior to the experiments, with the so called FALCON CamFolder procedure [12]. To record 3D kinematics it was necessary that each target was recorded by both cameras. Targets were only put on the most important points of the body. For the frontal and the lateral test two sets of targets were used. Three targets on the head, one on the shoulder, elbow, wrist joint, hip and the knee were measured in the frontal test, see Figure 6 and 7.

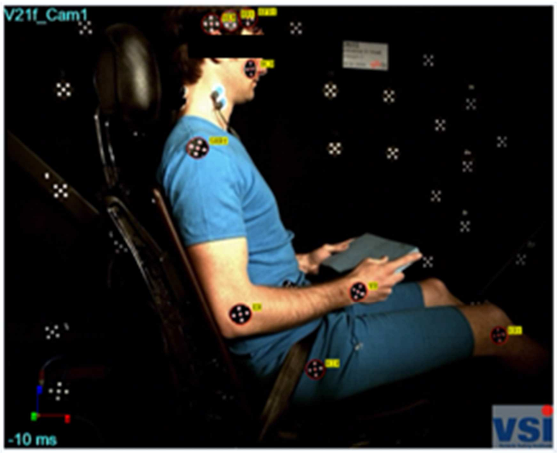

Figure 6. Targets high-speed video system frontal tests

In addition to these two more targets in the thorax area were recorded for the lateral test (Figure 7).

Figure 7. Targets high-speed video system lateral tests

An advantage of this system is that a real video is generated, while the drawback is that powerful additional lighting is needed.

<u>Surface EMG</u> Muscle activity was measured with a TeleMyo 2400T surface EMG measurement system by NORAXON [13]. The system transmitted real-time EMG by wireless transmission. The recorded frequency was 1000 Hz. Seven different upper body muscles were chosen to be captured, the same ones on the left and right side of body. The same set of muscles was recorded for the braking and the lane change simulation.

On the frontal side the muscles Sternocleidomastoideus, Rectus abdominis and the Obliquus externus abdominis were analyzed, see Figure 8.

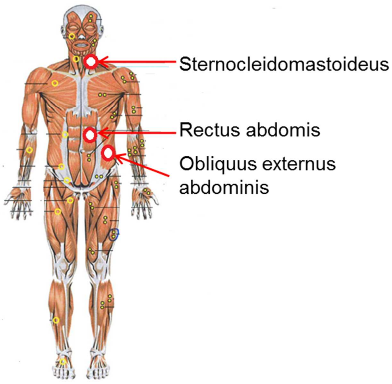

Figure 8. Muscle frontal view (mod. from [8])

On the dorsal side the muscles Neck extensors, Trapezius p. descendez, Latissimus dorsi and the Erector spinae (lumbar region) were measured (Figure 9).

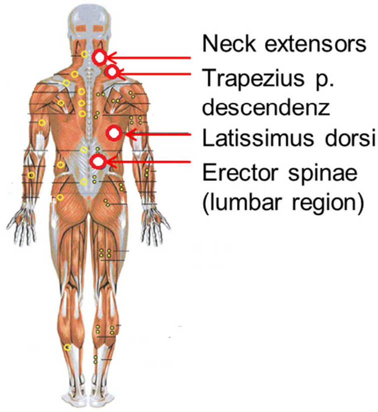

Figure 9. Muscle dorsal view (mod. from [8])

The main purpose of these sled tests was to get first kinematic information of the volunteer's movement for the two maneuvers. Additionally the muscle activities during the different maneuvers were analyzed. Another task was to decide which motion capturing system was the more efficient one to use in a full vehicle test.

RESULTS

<u>High-speed video system</u> In the following figures the motions of different targets and volunteers are represented. In Figures 10-14 the red graph shows the relative trajectory of the volunteer with the largest movement, while the green graph is the relative trajectory of the volunteer with the smallest movement. The gray graphs show the trajectories of the remaining volunteers.

In Figure 10 the motion of the head target of all seven volunteer can be seen. A big difference in the movement among the volunteers was noted. A maximum amplitude of 500 mm (x-direction, parallel to the acceleration direction) and 140 mm (z-direction, parallel to gravity) was recorded during the frontal test, while the minimum amplitude was 118 mm (x) and 10 mm (z).

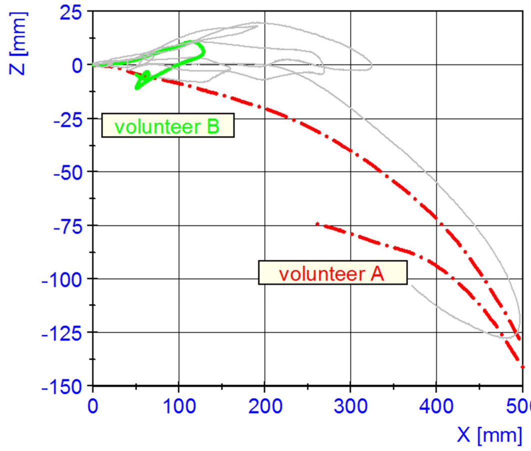

Figure 10. Head trajectory frontal test

Also the shoulder target movement (Figure 11) showed a large difference among the subjects. A maximum amplitude of 390 mm (x) and 47 mm (z) was recorded, while the minimum amplitude was 100 mm (x) and 22 mm (z).

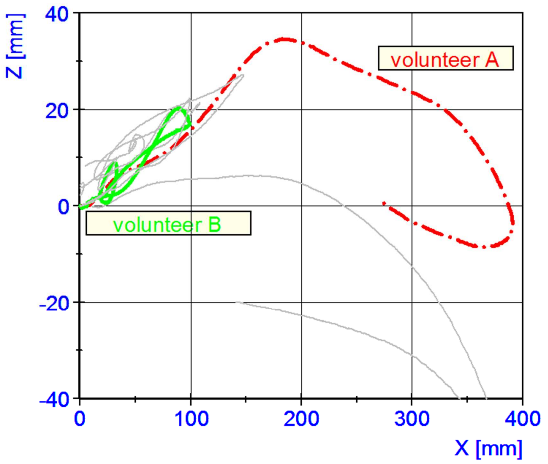

Figure 11. Shoulder trajectory frontal test

For the lateral test three targets were analyzed. The head target (Figure 12) showed amplitudes between 175 mm (x), 30 mm (z) and 90 mm (x) and 5 mm (z).

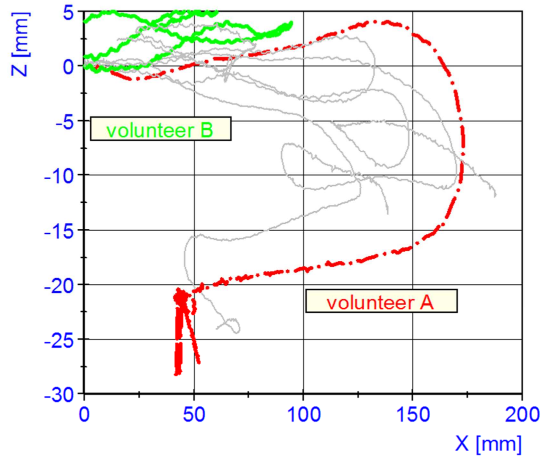

Figure 12. Head trajectory lateral test

Figure 13 shows the relative shoulder marker trajectories. Measured amplitudes ranged between 130 mm (x), 30 mm (z) and 65 mm (x), 15 mm (z).

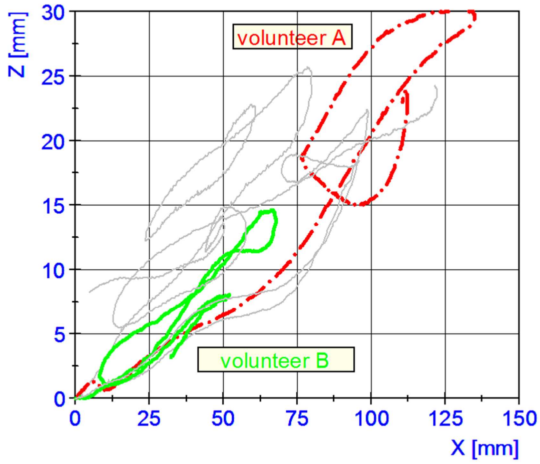

Figure 13. Shoulder trajectory lateral test

For the lateral test additional sternum targets (Figure 14) were recorded. Here a maximum amplitude of 125 mm (x) and 12 mm (z) was recorded, while the minimum amplitude was 55 mm (x) and 3 mm (z).

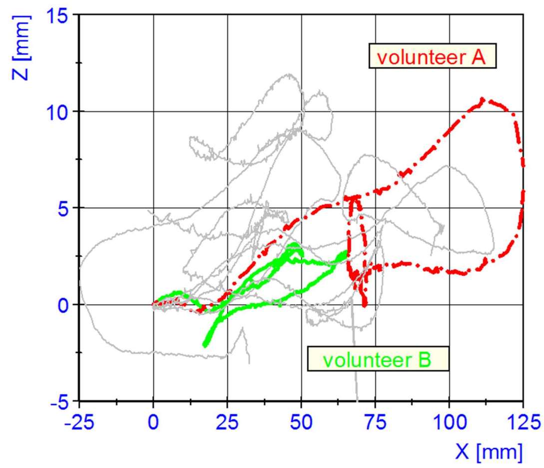

Figure 14. Sternum trajectory lateral test

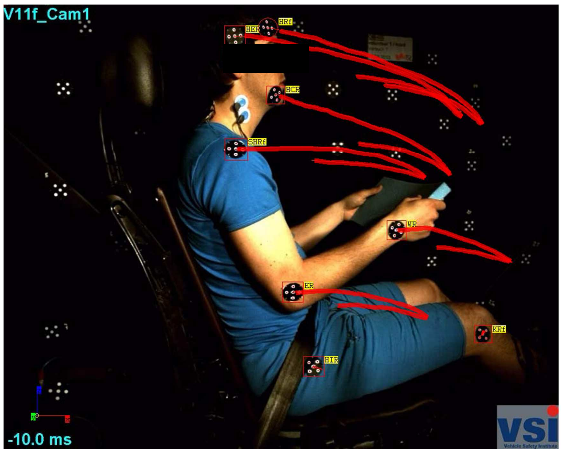

Figure 15. Trajectories high-speed video system

In Figure 15 the movement of the different targets during the first trial can be seen. Although three trials per volunteer per test were recorded, the analysis concentrated on the initial recording of each test due to time constraints.

<u>Infrared based motion capturing system</u> Four volunteers were captured with this system. As more targets were attached and recorded, there was more information about the volunteer's movement available. In order to visualize the movement positions of adjacent targets were connected by lines.

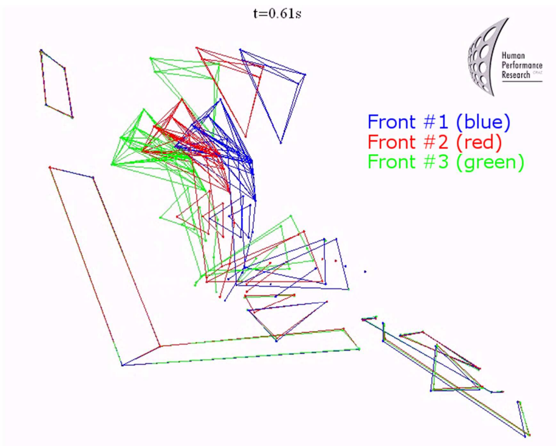

Figure 16. Infrared system frontal test

Figure 16 shows the position of one volunteer during repeated emergency braking simulations at the same time after the maneuver started. For this volunteer the amplitudes of the forward motion decreased with each repetition. An underlying reason for this might be an exercise effect, although not all volunteers showed the exactly same behavior.
Figure 17 displays the three lateral load cases for one volunteer. Unlike the frontal case no significant differences in amplitudes were found among the volunteers. This hints to a different countermovement mechanism than in the frontal case.

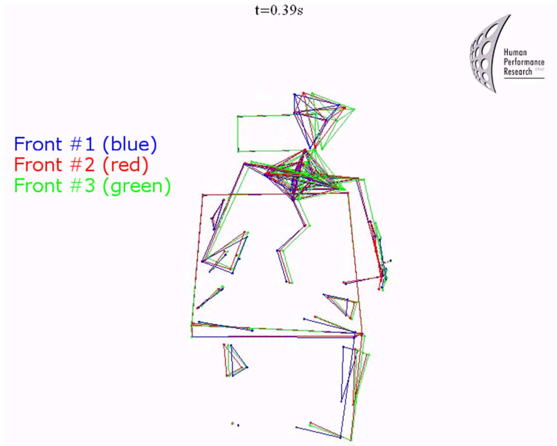

Figure 17. Infrared system lateral test

Using an inverse kinematic model the 3D marker data was used to estimate hip and neck angles, which were then input into the simulation model [7].

<u>Surface EMG</u> In addition to the kinematic measurement EMG data was recorded.

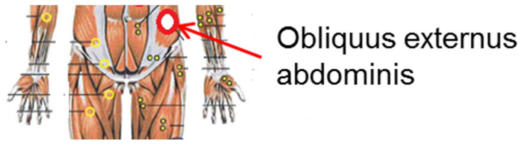

Figure 18. Muscle Obliquus externus abdominis (mod. from [8])

In Figure 19 signals from one selected muscle (Obliquus externus abdominis, see Figure 18) are displayed for the three frontal trials of one volunteer. The peak signal of each repetition is marked in the graph.

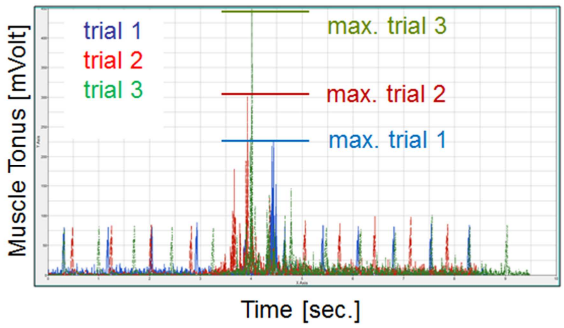

Figure 19. EMG signal of muscle Obliquus externus abdominis

For this volunteer a correlation between the peak signal in the muscle Obliquus externus abdominis (Figure 18) and the movement amplitudes (see Figure 16) is observed.
Such a correlation cannot be found for each muscle.
In Figure 21 the recorded signal of the muscle neck

extensor (Figure 20) is displayed. Again the peak signals of each trial are marked in the graph (Figure 21), but here no correlation to the movement (Figure 16) can be established.

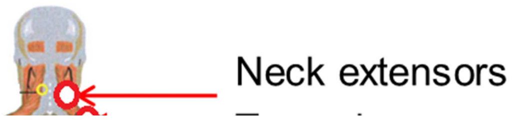

Figure 20. Muscle neck extensors (mod. from [8])

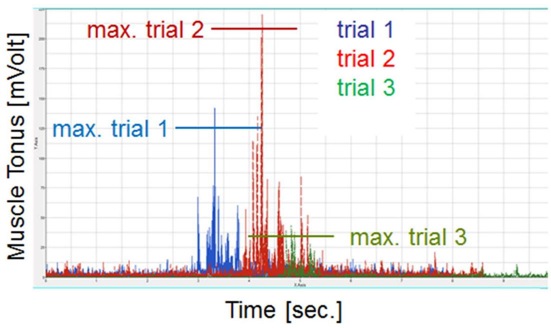

Figure 21. EMG signal of muscle neck extensors

In summary for eleven volunteers no significant correlation between EMG peak signals and movement amplitudes was detected. For further analysis activation onset and duration will be considered.
The character of the movement varies between the volunteers. Note that only the kinematic information from the first frontal and lateral test was used because the analyzed videos showed differences by repeating the load case and the simulation model should reflect the reaction of volunteer.

CONCLUSIONS

In the conducted sled test kinematic data was recorded with two 3D motion capturing systems. The captured data of both systems was of sufficient accuracy to act as input data for the simulation. Due to the additional lighting needed for the high-speed video system the infrared-based system was preferred for the full vehicle tests performed later on.
The first analysis of target trajectories showed large inter-subject differences, not only in the amplitudes, but also in the characteristics of the entire movement. Furthermore significant intra-subject differences in the movement amplitudes were detected for the frontal tests, while for lateral tests no such observation was identified. Due to these findings no movement patterns could be defined with the analyzed quantities.

The quality of EMG-signals was also adequate but for the sled test a correlation between movement and EMG peak signals could not be detected.

OUTLOOK

Volunteer tests with a real vehicle as part of the project were conducted and will be presented in a separate publication later on. Like in the sled tests two different maneuvers, an emergency braking and a lane change maneuver, were performed. The body size of the volunteers corresponded to the 50% male (175cm height, 78kg weight). Kinematic data was measured with the infrared based system and additional EMG data was recorded. Maneuvers with a large number of volunteers were recorded and the experienced loads were closer to real world driving situations than the sled test. Thereby the pool of available data for the numerical simulation was extended significantly. Analysis of the full vehicle experiments is in progress and will be presented in the future.

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