

## Experimental electromyograph muscle tension measurements in drivers while driving with an adaptive device

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### ABSTRACT

The aim of the study was to determine the activity zones and the level of load on the driver's upper limb muscles while driving a vehicle with the use of adaptive devices, based on experimental studies using electromyography. The tests were carried out under dynamic conditions, during actual driving under controlled conditions. For the purposes of the experiment, a research procedure was developed involving the implementation of a defined sequence of vehicle manoeuvres. The measurements were made using surface electrodes placed on the skin in the area of the examined muscles. Changes in the amplitude of the EMG signal recorded in mV units were analysed. The results obtained made it possible to identify the characteristic patterns of muscle activity and differences in the level of muscle load during the operation of individual adaptive devices. The research confirms the usefulness of EMG in assessing the muscle load of drivers and may form the basis for further ergonomic analyses in the field of adaptive vehicle control systems.

**Keywords:** driver, disability, EMG, vehicle adaptation, vehicle, effort, people with special needs.

### INTRODUCTION

Vehicles adapted to be driven by drivers with special needs are an important element for self-driving and active participation in society, especially in terms of covering longer distances. With the development of adaptive vehicle control systems and the growing number of their users, the assessment of the physical strain on drivers during the actual operation of the vehicle is becoming increasingly important. One of the key factors affecting comfort is the activity and level of muscle tone in the upper extremities, especially when operating adaptive controls, such as the accelerator and brake levers. Excessive or prolonged biomechanical stress can lead to faster fatigue, reduced control precision and an increased risk of musculoskeletal ailments. In biomechanical research, electromyography is one of the basic tools for assessing muscle activity. However, it is most often used under laboratory conditions, in static positions or with strictly controlled movements of the examinee. This approach limits the ability to fully assess the actual

muscle load that occurs during complex dynamic activities such as driving. For this reason, it is justified to conduct tests using surface electromyography under dynamic conditions, corresponding to the actual use of a vehicle equipped with adaptive devices. Analysis of the activity of the upper limb muscles during typical vehicle manoeuvres can provide important information about the technical solutions used and provide the basis for their further optimisation.

This review carried out on mobility of people with special needs, adaptive devices and universal design. Attention was paid to the topic of drivers with disabilities in the context of road safety. The items used to measure muscle activity using an electromyograph (EMG) were described [4].

The implementation of universal standards and design principles in individual means of transport translates into an expansion of the user group. Among them will also be people with motor limitations. In the research conducted under laboratory conditions in the Warsaw University of Technology at the Faculty of Transport, the measurement

of muscle activity of drivers without disabilities was verified, using an electromyograph recording the EMG signal. For the purposes of the study, the tests were carried out in a simulator, which was alternately equipped with two types of steering wheels. The drivers who took part in the tests drove on a traditional steering wheel, and then on an innovative model equipped with rims that allow acceleration and braking manually. In total, 32 drivers took part in the tests, and each ride was recorded by devices used to record the signal of muscle activity in the form of an EMG signal. In the last phase, the goal and plans for further work on deepening the experimental method of testing and observing the driver's upper body during steering wheel operation were presented [10, 11]. The preliminary considerations drowes regarding the expectations associated with achieving high intellectual abilities or coping with intense cognitive load in professions such as pilot or professional driver. Data collection was carried out using a device that monitored the subject's eyesight. The technique used was combined with the methods used in machine learning. After data analysis, procedures were developed to improve the level of classification of cognitive load [7, 12].

The principles focused on the aspects of universal design that are also applied to the work environment of high-risk occupations. Work performed by a rescuer in an environment often in motion (ambulance) should be performed safely and effectively. The research made it possible to determine the most troublesome and the greatest problems during the performance of typical medical procedures. Measurements and analysis of the rescuer's movement kinetics were performed during the movement of the ambulance and during a standstill. The research used the myoMotion system, which made it possible to carry out measurements when the subject assumed forced positions, and also measured the range of motion of individual parts of the body. The summary suggested what changes should be made so that the life-guard's activities take place in an ergonomic interior and are safe for him. Researches described in which situations the positions adopted exceeded the applicable norms regarding overloading the musculoskeletal system. The final recommendations included the procedures for the spatial development of the ambulance, medical supplies and its layout in relation to accessibility during the works carried out inside [2, 8].

The topic of communication between the driver and the vehicle, using systems installed in the vehicle, was raised, m.in example, through the implementation of a multi-stream CNN network and coordination of the EMG signal. For the purposes of the research, several models were created to check whether the vehicle user is tired, sleepy, lets go of the steering wheel, or is tense. The next stage was how the system interpreted the situations described. As part of the research, a model was developed that shows greater accuracy regarding the driver's upbringing. Directions for the development of software interpreting biological signals in the vehicle space were proposed [5, 6].

The factors influencing the driver's behaviour, translating into the decisions made, safety while driving are fatigue – drowsiness. The research team doubled their attempts to conduct studies using an electromyograph (EMG) with electrodes placed on the surface of the skin. Electrodes were placed on both forearms, and then the muscles most involved in holding the steering wheel were measured. During the tests, attention was paid to the correlations between the tension of the tested forearm muscles and the driver's well-being. The results emphasised that the frequency of the graph indicates a weakened grip on the steering wheel and correlates with the driver's feeling of fatigue – drowsiness. The final indications show how the developed test method can be used to build a system for the early detection of fatigue – drowsiness in drivers. Mobility, freedom of movement, are important assumptions that determine the decision when choosing a means of transport. The analysis of factors influencing the decisions made by users of individual means of transport has initiated research on the mechanisms and factors related to driver behaviour. The research focused on the analysis of individual models of driver behaviour. The direct causes are presented and the factors influencing the optimisation of driver behaviour in road traffic were listed. The final conclusions were presented by the developed models of driver behaviour. In the long term, the research has shown the need to continue research with functional analysis in mind [3, 21].

The research conducted by the CIOP-NRI employees focused, among other things, on the description of the model defining the muscular effort that must be performed by the people employed in the following positions: teachers, firefighters, nurses. At the beginning of the paper, threshold criteria are presented, which had

a significant impact on the development of occupational diseases in the studied groups. For the purposes of the study, an evaluation of computer models created for the observation of the studied musculoskeletal load processes was carried out. The tests carried out on the models made it possible to simulate and collect data on the internal load occurring in the joints. A model has also been developed to assess muscle fatigue using an EMG signal for low levels of muscle strength [14, 18–20].

## TEST PROCEDURE AND RESEARCH TOOLS

The aim of the study was to determine the activity zones and the level of load on the muscles of the driver's upper limbs while driving with the use of adaptive devices, based on experimental studies using surface electromyography. On this basis, the following research hypothesis (H1) was formulated – drivers with mobility limitations show higher levels of muscle tone when operating adaptive throttle and brake levers compared to drivers without mobility restrictions.

A vehicle adapted to be driven by drivers with special needs is one of the key elements enabling independent travel over longer distances. The conducted research focused on the analysis of the activity and level of muscle tone occurring in the driver while driving a vehicle with the use of adaptive devices. To visualise and record muscle activity, a measuring apparatus using surface electromyography (EMG) was used, allowing measurements to be carried out in real driving conditions.

The measurements were carried out with the use of surface electrodes, placed on the skin at precisely defined measuring points of the upper limbs. The electrodes recorded the bioelectrical signals generated by muscle activity and transmitted them to the recording device in the form of electrical pulses. During the test, the electromyograph allowed continuous reading and analysis of the activity of selected muscle groups. The signals were recorded while the driver was performing a defined sequence of vehicle manoeuvres.

The recorded pulses, expressed in microvolts ( $\mu\text{V}$ ), were analysed in the form of changes in the amplitude of the EMG signal. The test used current pulses of low voltage and intensity, completely safe for the test subject. The impact of the impulses on the nerve cells of the examined area

caused only gentle, usually painless muscle contractions. The entire measurement process was non-invasive and did not cause negative feelings in the study participants.

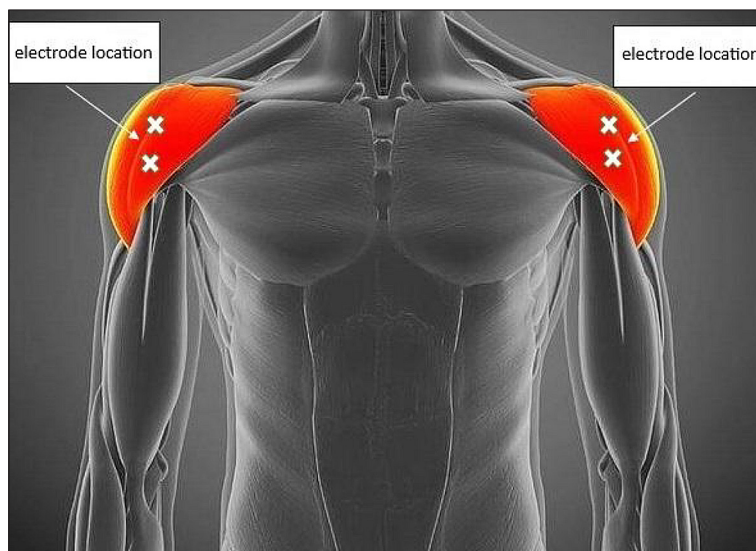
Electromyography is usually used to assess muscle tone under laboratory conditions, most often in static positions and with relaxed muscles. In the developed method, muscle tone was measured under dynamic conditions, i.e. during actual driving [1].

The location of the electrodes (Figure 1) during the measurement and selection of the muscle for the examination were determined on the basis of a review of scientific articles. Taking into account the diversity of the study group (people without dysfunction, people with paraplegia, tetraplegia), the deltoid muscle, the front part and the left and right upper limbs were selected. The exact position of the electrodes was located on the deltoid muscle, which was verified on the example of the distance of one finger from the shoulder protrusion towards the line between the shoulder protrusion and the thumb. The location and its choice resulted, among other things, from differences in the way drivers in the research groups drove the vehicle [13, 15, 17]. A common part of all the groups that the drivers used while driving was a selected part of the shoulder muscle [9, 16].

The test procedure was as follows: interview with the test participant, conducting an assimilation ride, a series of driving tests in a closed yard, using adaptive devices and an electromyograph to monitor muscle tone, performing exercises, performing one ride (exercises 1–4) in 5–8 minutes, and the total test for one driver does not take more than 10 minutes.

Characteristics of the study group: 12 participants, age: 25–60 years, 4 with tetraplegia, 4 with paraplegia, 4 without disabilities, category B driving licenses, mixed recruitment based on the recommendation method, participation in the study was voluntary, and each participant has the right to withdraw from the contract.

During the study, differences in muscle tone, i.e. lack of them, during driving behaviour between drivers with and without disabilities (tetraplegia, paraplegia) were observed. Due to the experimental nature of the study, it was desirable to observe the differences characteristic of each of the study groups. The influence of factors other than those mentioned above was not taken into account in the evaluation of the collected results.



**Figure 1.** Location of electrodes

Hand position: starting position (for example, driver with paraplegia) – Figure 2, The left hand was on the handlebar-mounted knob handlebar. The steering wheel was operated by rotating the installed device along the axis. The right hand rested on the device for manual acceleration and braking of the vehicle. Acceleration was accomplished by gradually turning the lever downwards, while braking was done by pushing the lever forward (in the direction of travel). The driver performed all activities related to driving the vehicle with his upper limbs. The exercises were performed in such a way as to maximise the level of contractility of the muscles on which the electrodes were placed. The focus was on taking measurements in three groups, all subjects had the functional part of the shoulder on which the tests were performed.

#### Device used in the study – description

The measurements were made using the Myo-Plus2 Pro device equipped with a diagnostic module that allows reading at a level of  $0.2 \mu\text{V}$ , and a comparable standard for a similar class of devices is about  $15\text{--}20 \mu\text{V}$ . The device allows performing the EMG stress test that was used for the measurements. For example, the measured voltage values during shrinkage average about  $1.7 \mu\text{V}$ , and the sensitivity score of the device can be compared with the standard shown by other devices, which is about  $15\text{--}20 \mu\text{V}$ . Considering the devices with measurements in the range of  $2 \mu\text{V}$ , it was found that research measurement can be difficult. During an implementation with such low registration

accuracy, the contraction of the observed muscle group may not show the work of very weakened or severely numb muscles at all. Therefore, a device that records data with an accuracy of  $0.2 \mu\text{V}$  was chosen, which allows for precise observation of the EMG recording. Figure 3 shows the MyoPlus2 Pro measuring devices [22–25].

The measurement was carried out using the VERMED Lead-Lok, R-LFO-320 disposable electrodes shown in Figure 3, which enabled the recording of a high-quality signal, among other things, thanks to the use of a low-resistance gel. Silver-plated Ag/AgCl sensor housed in a flexible PE foam base to reduce artificial noise interference. The dual-channel device required a one-time application to test four electrodes measuring 32 mm by 36 mm.

#### Tests with a modified vehicle

The tests were carried out in the closed area of the Institute of Motor Transport. The designated test track shown in Figure 4. The test track – ITS illustrates four types of exercises performed during tests by drivers with tetraplegia, paraplegia and without disabilities.

Before the start of the ride, each participant was informed about how the test was carried out and all the details related to the exercise were discussed. Each driver could take an assimilation drive in the vehicle used during the tests. The total length of the ride was about 600 m, and four types of exercises were performed during one lap. At station no. 1, a static exercise was



Figure 2. Basic position – the position of the hand on the devices

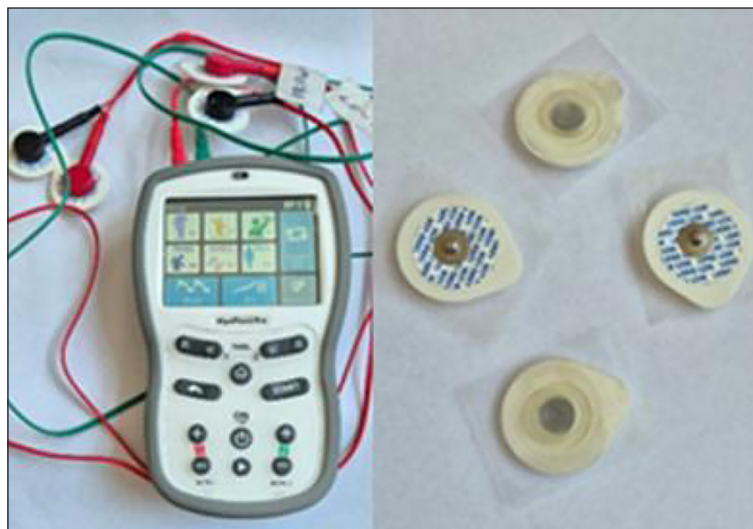


Figure 3. MyoPlus2 pro measuring devices, complete measurement electrode kit

performed, which checked the maximum strength of muscle tension of the driver in the front part of the shoulder. The exercise consisted of keeping the right shoulder joint in a tense position by pushing it forward and keeping the muscles tense for 5 seconds, then resting. The whole exercise ended after measuring both shoulders. In the next part, the driver was asked to drive to station no. 2, where the ride took place between the posts set every 5 m. After the start command was issued, the exercise – slalom – began. The priority for proper driving performance was the precise use of adaptive devices (lever for manual acceleration and braking of the vehicle and a handle in the form of a knob) when driving between cones.

The ride began and ended after passing the transversely arranged information posts marking the start and finish lines. While driving, muscle tension when controlling the steering wheel with the handle located on the steering wheel (left hand) and muscle tension used when operating the lever enabling acceleration and braking of the vehicle (right hand) were recorded. Station no. 3, the driver was to start driving gently and then start braking until the vehicle came to a complete stop. The essence of the test was to maintain the parameters of smooth driving, including starting, acceleration and braking process recording. Next, the driver was to perform exercise no. 4, during this task, the drive was carried out on the section marked



Figure 4. Tor – ITS

with arrows (on the internal road surrounding the building of the vehicle inspection station), then the driver had to park by reversing in position no. 1 in any place, and then leave and park the vehicle backwards in position no. 2. where the drive of exercise 4 ended. After signalling the end of the task, the driver completed the test drive.

#### Diagnosing the predisposition of drivers with disabilities

The analysis of the results focused on the circumstances in which the driver performed the sequence of movements (exercises 1–4). As a result of the tests, 24 sequences were obtained, during which the device recorded the current on the electrodes – two for each of the 12 transmitters. During the test, the current changed depending on the tension of the shoulder muscles near the electrode. The entire test included for each driver: channel 2 – muscle tension of the left hand (when operating the steering wheel), while channel 1 illustrated the muscle tension of the right hand (when operating the brake and accelerator levers). The group of drivers taking part in the tests consisted of fit people, people with paraplegia and tetralogy. The observations were made after the driver performed one test, during which he performed four exercises. Table 1 shows the average muscle tone value associated with the records for channel 1 (right hand responsible for operating the accelerator/brake lever) and channel 2 (left hand operating the handlebar grip), depending on the exercise performed.

It was determined that the average value of muscle tension for channel 1 while driving was  $68.23 \mu\text{V}$ , and for channel 2 was  $77.78 \mu\text{V}$ . The

difference between the channels during observation was  $9.55 \mu\text{V}$ , suggesting an uneven distribution of muscle tension between the two hands. Higher muscle tension was noted on the left limb, responsible for control. Higher measured values were recorded when performing the exercises related to the need to manoeuvre the vehicle intensively under real driving conditions. On the other hand, when performing exercise 2 (slalom test) and exercise 4 (manoeuvring in motion), the voltage value of channel 1 (right hand) is about 70% of the value of channel 2 (left hand). The highest values for channel 1 were recorded during exercise 3, described as the acceleration/braking process. According to the assumptions made regarding the procedure of the described exercise, the driver, moving the vehicle in a straight line, used his left hand to control the direction of movement of the vehicle, while operating the accelerator/brake lever with his right hand.

#### STATISTICAL ANALYSIS

In the part of the research concerning the statistical analysis of the collected data, the initial stage consisted in separating the individual data from the rest of the collected data. Due to the high sensitivity of the device used for measurement, the obtained waveforms were strongly noisy. In addition, the numerical values depended on both the degree of muscle tension and the conductivity of the skin near the electrode. In particular, the latter made it difficult to compare waveforms for individual transducers.

Taking into account the need to exclude the factors above, the recorded values (waveforms)

**Table 1.** Recording muscle tone values during exercise

Exercises performed	Channel 1 right hand	Channel 2 left hand
Exercise 1 Measurement of maximum mean muscle tone	50.88 $\mu$ V	48.43 $\mu$ V
Exercise No. 2 Slalom test	72.60 $\mu$ V	110.06 $\mu$ V
Exercise 3 Acceleration/deceleration process	83.12 $\mu$ V	57.10 $\mu$ V
Exercise 4 Manoeuvres on the move	66.31 $\mu$ V	95.51 $\mu$ V

were filtered by replacing each value with the average of the adjacent seventeen values.

The course of muscle tension was filtered using a low-pass filter in the form of local averaging in the time domain. In this operation, each signal sample was replaced by the average value of the 17 adjacent samples. In practice, such an operation is equivalent to filtering by means of a signal weave with a rectangular time window 17 samples wide and 1/17 high. The choice of filtering method was dictated by the specific nature of the waveform, which contains elements similar in nature to the functions with a discontinuous derivative, and sometimes even to step functions.

In the next stage, the waveforms were standardised. The values of each run were divided separately by the maximum value of the waveform. As a result, the obtained values ranged from 0 to 1. The value obtained in this way was called relative muscle tension and was treated as a dimensionless unit.

Further action was to determine the average value for each waveform of relative muscle tone. The obtained value showed the extent to which the driver’s muscles relax after work. Average values close to 1 would mean a complete lack of relaxation, while values close to 0 would mean complete relaxation.

In the final stage, the courses were grouped according to the motor dysfunctions of the drivers: tetraplegia, paraplegia and lack of dysfunction. For each group, 4 tracks for the left and 4 for the right – for each of the 4 drivers in the group. The grouped rates were presented on common charts.

Figure 5 shows the course of relative muscle tone in the right arm for four drivers with tetraplegia. At the beginning of the recording, you can see a clear increase in tension, such a recording was interpreted as the beginning of the vehicle’s departure. However, the final recordings provide the basis for the conclusion that due to the subsequent strong tension, the driver began to brake until the

vehicle came to a complete stop. The recording shows that the voltage still exists between the starting and braking processes, although it is slightly lower. The average values of muscle tone for drivers from the tested group are 0.3.

Among the collected data, attention was paid to the tracks that presented the results shown in Figure 6, showing the relative muscle tone of the right arm in four drivers with paraplegia. The nature of the chart is very similar to the previous case. Similar average values in this group of drivers are also similar. In conclusion, there is no significant difference between muscle tension in drivers with tetraplegia and paraplegia when operating the brake and accelerator levers.

The characteristic course of the examined symptoms can be observed in Figure 7, where the course of relative muscle tone of the right arm for four drivers without dysfunction is presented. There is a clear difference between the state of muscle rest and the state of muscle tension. A characteristic of the reaction under study is an increase in muscle tension, which occurs during the initiation and inhibition activities. However, it is equally important that the relative muscle tension drops to almost zero between these activities. It can be said that after the work is done, drivers without dysfunction relax the hand muscles much more.

Further analysis of the collected materials shows that the average values of muscle tone in this group of drivers are 0.17, which can be said to be almost halved than in the people with any motor dysfunction.

Taking into account the route shown in Figures 8–10, one can notice similarities in the measured muscle tone values for the three groups of drivers. A common feature of all the illustrations, which is worth mentioning, was the relative tension of the muscles of the left hand when operating the steering wheel. During the analysis of the described track, no significant differences in the way the tested muscle group

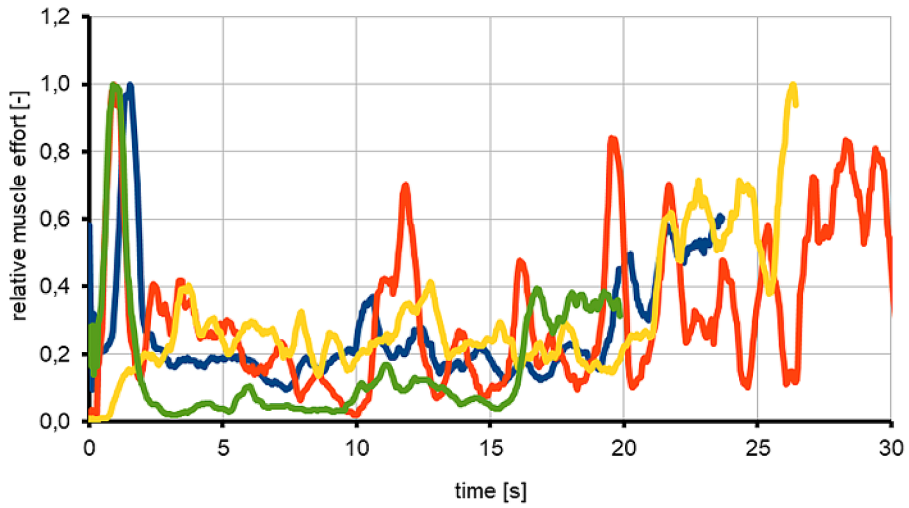


Figure 5. Course of relative muscle tone in drivers with tetraplegia when operating the brake and accelerator levers

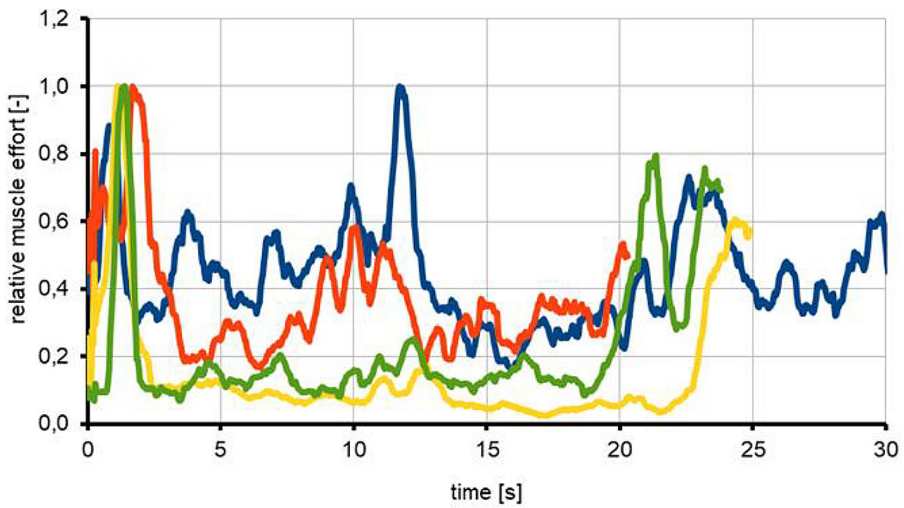


Figure 6. Course of relative muscle tension in drivers with paraplegia when operating the brake and accelerator levers

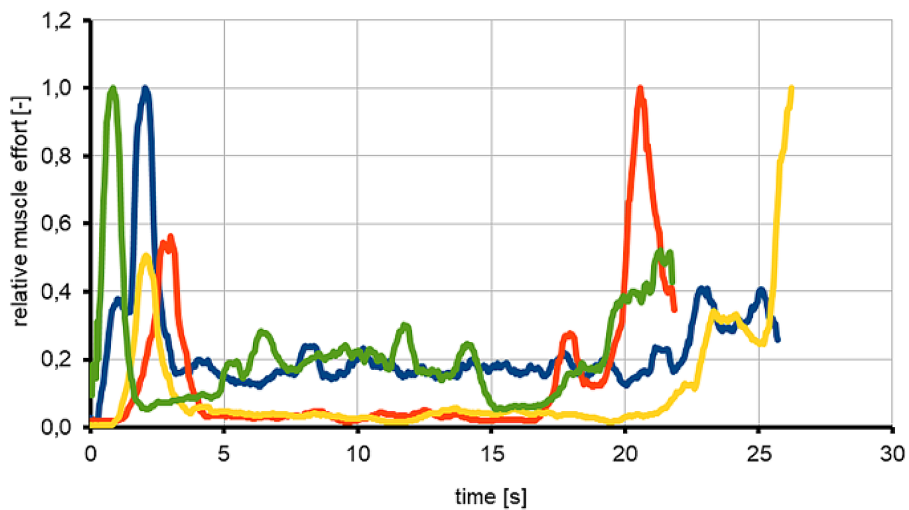


Figure 7. Relative muscle tone waveform in the drivers without dysfunction when operating the brake and accelerator levers

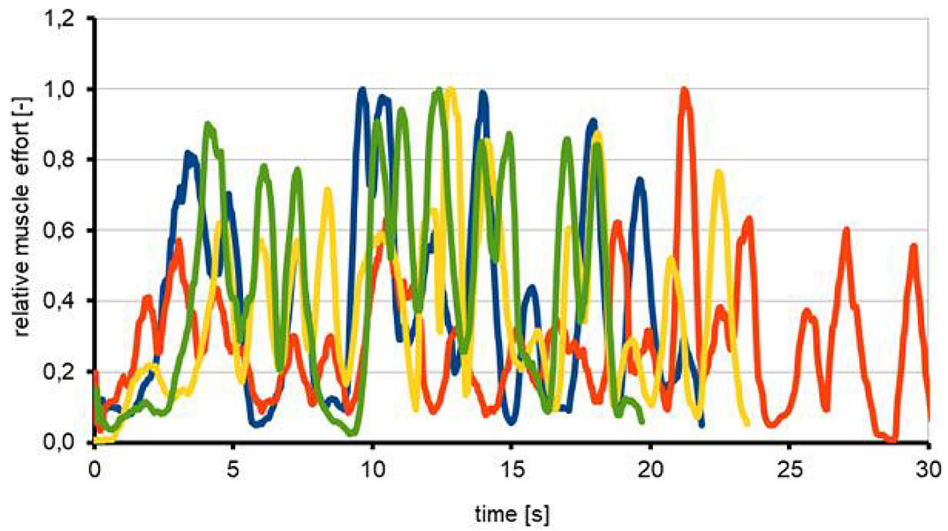


Figure 8. Course of relative muscle tone in the drivers with tetraplegia when operating the steering wheel

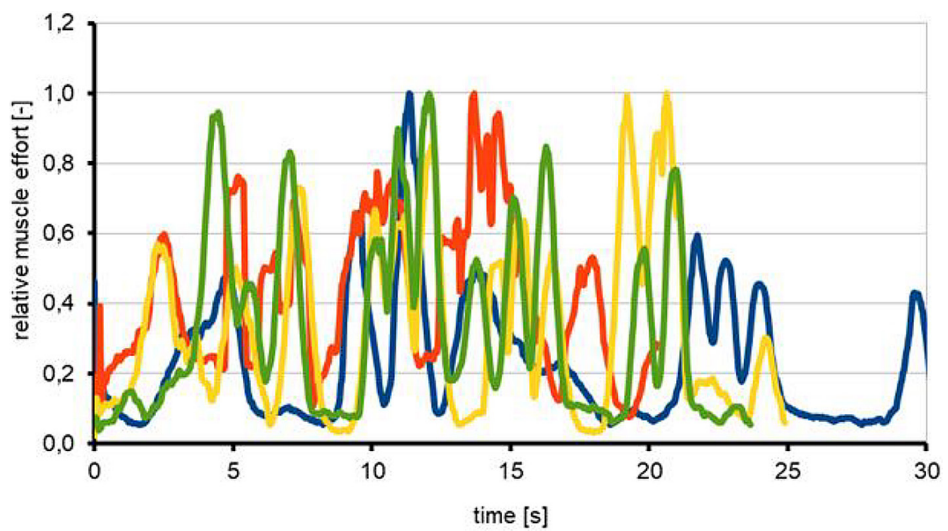


Figure 9. Course of relative muscle tone in the drivers with paraplegia when operating the steering wheel

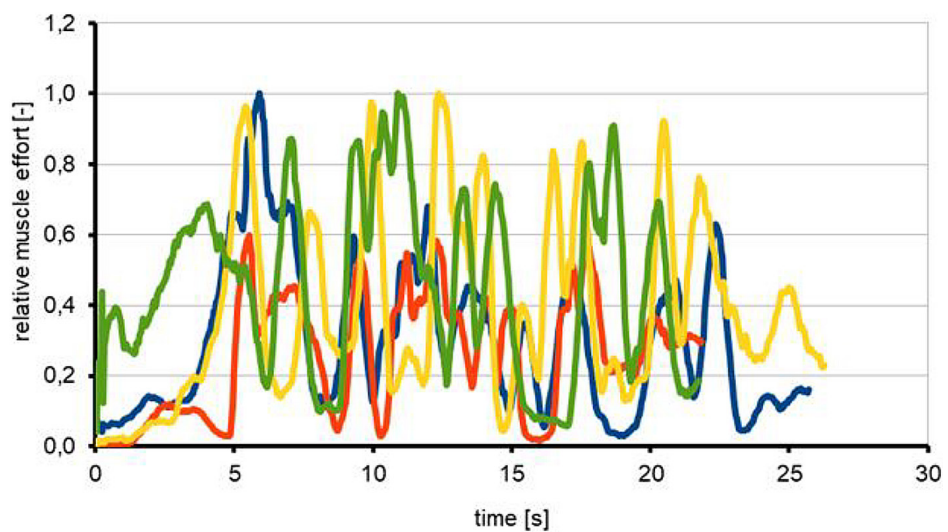


Figure 10. Course of relative muscle tone in the drivers with paraplegia when steering wheel

was tensioned between the riders of each group were observed. Importantly, the average values of muscle tone in all cases maintained a similar scale. From the observation of the routes, you can also notice periodic increases and decreases in tension, which corresponded to alternating turns to the right and left during the slalom.

## CONCLUSIONS

On the basis of the analysis of the collected data, it can be seen that the people with movement disorders tense their muscles differently when using the lever used to accelerate and brake the vehicle, unlike drivers without dysfunction. The observed differences may be due to the fact that after completing a task, the drivers without dysfunction significantly relax their muscles, in contrast to the drivers with disorders, who relax the tested muscle group to a much lesser extent. This type of situation can eventually lead to faster fatigue in the drivers with mobility disorders. An interesting observation worth discussing is the similar feeling of the studied phenomena among both groups of drivers with paraplegia and tetraplegia. It was also characteristic of all the surveyed groups of drivers that no significant differences were observed when measuring muscle tension while operating the steering wheel. On the other hand, the fact that the electrodes were properly connected, periodic voltage changes can be observed on the tension routes of the muscles responsible for the movement of the steering wheel, which in turn can be interpreted as corresponding to the nature of slalom riding. On this basis, it can be concluded that the electrodes worked properly during the tests together with the measuring device. Consolidating this, it is believed that the lack of differences in individual groups of drivers is not due to an incorrectly conducted measurement.

After evaluating the collected results of the study, it was noticed that the people with movement disorders tense their muscles differently when working on the throttle lever, unlike drivers without dysfunctions. The people with disabilities showed higher muscle tonnage, which was noticed when interpreting the results. The people with lower limb dysfunction showed higher tone values, partially compensating for the lack of lower limb stability with the upper limbs. This type of stabilisation is important for

increasing muscle tone in the upper limbs. Further research is recommended to collect more data from drivers with paraplegia and then compare. A certain difference has been observed in a situation where the people without dysfunction significantly relax their muscles between activities, while the people with dysfunctions relax them to a much lesser extent. In the process of assessing muscle strength, factors affecting muscle levels were also taken into account, which were influenced by, for example, age, gender, height, body weight. The activity was performed during the verification of the maximum average muscle tension strength. An additional circumstance taken into account during the analysis of the collected materials was also the demonstration of differences related to the muscle system between the sides of the examined upper limbs. The reason why they affect the indicated differences between the left and right sides is that one of the sides dominates. As evidence that this process occurs while driving, it appears that the differences in the values achieved by disabled and able-bodied drivers have been observed when performing individual exercises, which may be related to retained and non-retained body functions (e.g. maintaining a sitting position while driving, precision and hand grip strength).

Taking into account all the phenomena described in the people with driving dysfunctions, the possibility of faster fatigue should be taken into account. However, from the perspective of the studied groups, it seems interesting that this phenomenon occurs to a similar extent in the group of drivers with paraplegia and tetraplegia. Characteristic of the collected results of the research was the fact that during the study of muscle tension during the movement of the steering wheel, no significant differences in the way they were tensioned were observed.

However, to demonstrate that the measurement was made correctly, it was noted that the muscle tone movements responsible for the movement of the steering wheel showed periodic changes in tension corresponding to the nature of slalom riding. Such fluctuations in the record presented in graphic form – i.e. a graph – may indicate the proper operation of the measuring devices. To sum up, the topic is based on the assumption that the lack of differences in individual groups of drivers does not result from incorrectly conducted measurements.

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