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The impact of autonomous car functions on muscle tension in drivers with disabilities

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ABSTRACT

The purpose of this article is to present the results of research on the impact of selected autonomous vehicle features on the muscle tone levels of drivers with disabilities. The study utilized a quantitative approach, measuring muscle tone levels using electromyography while using adaptive devices in city traffic. The study results showed that in able-bodied drivers, the use of assistance features such as adaptive cruise control and lane keeping assist led to an average reduction in muscle tone of 12 percentage points. Simultaneously, an increase in muscle tone was noted in specific muscle groups: by 10 percentage points in the right hand (accelerator and brake pedal) and by 13 percentage points in the left hand (steering wheel). For drivers with paraplegia, the use of assistance features resulted in an average increase in muscle tone of 4 percentage points, with corresponding values of 7 percentage points for the right hand and 1 percentage point for the left hand. The authors recommend the introduction of intelligent driver assistance systems as standard equipment in passenger cars. The data obtained may be of significant importance for determining new directions of research, emphasizing the need to use electromyography in the context of diagnosing drivers with disabilities.

Keywords: vehicle, disabled driver, EMG, autonomous functions, adaptation.

INTRODUCTION

A vehicle designed for people with disabilities allows them to cover greater distances than using technical aids such as wheelchairs, crutches, walkers, or canes. A vehicle adapted to the driver's personal needs facilitates overcoming architectural barriers and shortens the journey to the destination. This paper addresses the use of technology commonly used in vehicles manufactured after 2024, which is intended to increase safety.

The aim of this study was to examine the impact of using autonomous vehicle functions on muscle tension in drivers without mobility limitations compared to drivers with disabilities. Active driving assistance systems were used during the tests. The functions tested were designed to temporarily reduce the tension in the tested muscles. This muscle-relieving phenomenon was intended to positively impact well-being while driving by delaying the onset of fatigue.

The accelerated development of automotive technologies has led to a significant increase in interest in autonomous vehicles. They are particularly important in the context of drivers with mobility disabilities, for whom traditional driving activities can pose a significant physical and mental burden.

Drivers with motor impairments typically drive using adaptive devices [1] and operate the vehicle with their hands. This causes increased strain on the upper limb muscles, which leads to faster fatigue and, consequently, reduced mobility in drivers with disabilities.

Muscle tone [2] is one of the key parameters for assessing a driver's neuromuscular activity. Its measurement, most often performed using electromyography (EMG), allows for the quantitative analysis of muscle activity levels during specific activities, such as steering, accelerating, or braking. Increased muscle tone can result from both physical exertion and psychophysical factors such as stress, uncertainty, or cognitive overload. In the case of drivers with disabilities, this phenomenon can be particularly pronounced due to the need to compensate for motor deficits and increased concentration on performing manual tasks.

For individuals with mobility impairments, muscle tone is particularly important because it is closely linked to compensating for motor deficits. Depending on the type and severity of the disability, muscle activity may be improperly distributed, leading to strain on muscle groups. For example, drivers with lower limb amputations often intensively use their upper limbs when operating controls, resulting in increased muscle tension in the shoulder girdle and forearms. Individuals with paresis, on the other hand, may exhibit an altered distribution of muscle activity, requiring constant compensation through excessive tension of specific stabilizing muscles.

BACKGROUND

The paper by Grabarek et al. [3], addresses the issue of emergency worker activity in the context of activities performed in the vehicle. During the study, muscle tension measurements were taken to assess the critical moments at which the measured tension reaches the highest values. A number of recommendations were presented for the rescuer's work to be more efficient and reduce the risk of injury when adopting awkward positions. The authors also developed a number of recommendations regarding the need to modify the vehicle interior to make it more ergonomic for ambulance rescuers.

The papers [4–7] described the effect of suggested exercise models on muscle activity at two critical moments (maximum extension and maximum contraction). The work also used an EMG-enabled device [8] to determine muscle tension thresholds. The conclusions suggest the most effective way to perform a given type of exercise to achieve the best results.

The authors [9–12] proposed measuring muscle tension using EMG surface electrodes. During the testing process, information about the activity of the forearm muscles was recorded. The source material was used to create a model algorithm to expand the understanding of myoelectric control decoding of fixed arm positions in subsequent tests. The study [13–16], addressed the issue of obtaining facial muscle signals that can be defined as characteristic signs of driver fatigue. During the study, data on facial muscle activity were collected. For the purpose of this study, filter feature selection methods were analyzed for performance. In the final phase, a drowsiness detection model was defined based on data collected from the EMG device. The data were then separated using the most accurate filter feature method using a Polynomial Support Vector Machine (SVM) classifier, which achieved an accuracy of 91.67% for eight muscle features. This demonstrates the potential of the filter used to identify significant features with considerable accuracy. In summary, it was determined that the orbicularis oculi and the chi-square filter used are essential and demonstrate the highest potential for selecting an appropriate feature model for detecting symptoms of driver drowsiness based on facial EMG [17,18].

Research study [27] addresses the use of electromyography during steering. The method developed concerns the measurement of muscle activity used to generate torque while operating the steering wheel. The study utilized measurements of the electrical conductivity of the upper limb muscles and their response to electrical impulses generated by the measuring device. Based on the collected research results, a mathematical model was developed that allows for the gradation of muscle groups involved in the direct generation of torque on the steering wheel. The research was expanded to include more detailed measurements, determining the muscle tension generated in the right and left forearm areas. Measurements were performed using eight candidates. The developed method enabled the precise determination of muscle contraction during the generated torque of the steering wheel. This observed phenomenon is to be subjected to further research [19–21]. The research paper by Rahman, Mustafa, Sulaiman, Samad, and Abdullah, concerning "EMG signal segmentation to predict driver's vigilance state," highlights related to tracking the electromyography signal in relation to diagnosing the causes of decreased alertness while driving [22–24]. Researchers have noticed that driver loss of alertness is an important factor influencing the number of road accidents. This phenomenon is usually caused by increasing fatigue, leading to falling asleep and, consequently, a road collision with another road user. During the research, the measured EMG signal was defined in terms of its increase. The obtained values presented in the electromyogram were classified, then various methods for interpreting the obtained recordings were developed in relation to the studied phenomenon [25, 26]. As a result, the obtained signal was filtered and then subjected to the feature extraction method. In the final stage, they were evaluated in the segmentation process. For more accurate the recording evaluations, which took place over two hours, were divided into 60- and 30-minute periods. Individual characteristics and differences in muscle condition were considered during the evaluation of each segment. The conclusions describe useful parameters that facilitate the assessment of the driver's condition in relation to fatigue.

Analysis of EMG signals in the context of fatigue while driving is a topic discussed by Naim et al. [30]. In this study, the recorded signals were analyzed using an electromyograph to identify the moment when the driver experienced drowsiness, which could have resulted in the inability to properly assess other road users. Data was collected based on muscle tension generated in the arm area of both upper limbs. This specific recording method allowed for the definition of a set of time-domain features responsible for drowsiness in the studied drivers. Fifteen samples were collected during the study and classified using six classifiers. The best value highlighting the studied situation, assessing a single feature for the long-term mean absolute slope signal, allowed for its determination with 80% accuracy.

The study of fatigue symptoms in drivers while driving was conducted in a study focusing on EMG signal analysis [28, 29]. Initially, the driver's condition was assessed using a specially developed questionnaire. The obtained result determined whether the subject was fatigued or slightly fatigued fatigued, or whether fatigue is a result of their habit. Next, surface electrodes were attached to the brachioradialis muscles located on the forearms. After connecting the electromyograph, the subject sat in a driving simulator and, under virtual reality conditions, performed a ride during which EMG recordings were made [31–33]. The entire test lasted 120 minutes. The collected recording was filtered and standardized to exclude noise that could interfere with the proper interpretation of the results. Significant results were the mean and variance in the frequency domain of power spectral density (PSD), which was extracted from the PSD peak frequency for each received signal. The results were presented in three areas: no fatigue, mild fatigue, and fatigue. Among other things, the final results presented the values determined in the analysis expressed using the mean peak frequency: no fatigue: 13.379 Hz, mild fatigue: 11.969 Hz, and clearly defined fatigue for the frequency: 12.782 Hz.

The research material describes a real-time measurement method based on various measures of detecting symptoms of driver fatigue while driving [34–36]. The collected data were measured and evaluated using electroencephalograms, electromyograms, and electrooculograms. Based on previously acquired knowledge and the application of appropriate filters, the researchers separated the data of interest. To isolate significant features of the data recording, threshold values were set and then further analyzed. Using appropriate classification, the results were grouped. They were also divided based on the area of mutual correlation. As a result, the researchers were able to determine the obtained values within three fatigue forests measured in real time. The final conclusions propose a number of aspects regarding the need for further work on the described method. It was also proven that it could be used as an optional vehicle equipment, which would include a system warning the driver of an approaching period of fatigue, which would translate into a real impact on reducing the number of road accidents.

Research conducted using an electromyograph was also used in a study on the development of a method for driving a vehicle using an EMG interface [37–39]. Tests were conducted with individuals with special needs (disabled individuals, elderly individuals). Electrodes were placed on the hands and on a specific cervical region. The subject could interact with the vehicle through pre-defined movements, thus steering it. Using the EMG signal [40–42], processed in the device into a binary signal, the effective frequency band of this frequency allowed for the effective drive of the differential motor of the electric vehicle. Experimental studies involving maneuvering an electric vehicle also utilized a method to verify the driver's sensations while driving [43–46].

Diagnostic work was also conducted to utilize EMG signals to develop a model enabling simple tasks such as grasping various objects using a prosthetic upper limb [47–49]. The research involved conducting a series of tests, after which the researchers were able to determine how to determine the force required to grip the prosthesis on individual objects for lifting or holding them. The study aimed to help the user of the prosthesis use it as closely as possible to natural movement. The research method was based on a model of an efficient controller processing the EMG signal in real time. During data acquisition, characteristics related to the biceps muscles of the forearm at maximum contraction and relaxation were classified. The tests were designed to provide a sufficiently large data sample to allow for the development of a simple, inexpensive, and sensitive model. During the experiment, 20 tests were performed in various positions. The final results showed that the developed model could perform grasping with a high accuracy of approximately 96%. The time in which the prosthesis performed the grasping action was similar to the time of the human hand, which was approximately 250.80 ms, in comparison, the human hand needs about 300 ms to perform a similar movement.

RESEARCH PROBLEM AND METHOD

The aim of this study was to investigate the impact of autonomous vehicle functions on muscle tension in drivers without mobility limitations compared to drivers with disabilities. Active driving assistance systems were used during the tests. The functions tested were designed to temporarily reduce tension in the tested muscles. This muscle tension-reducing phenomenon was expected to positively impact well-being while driving by delaying the onset of fatigue.

For this purpose, a series of tests were conducted in real-world traffic, using a car equipped with adaptive devices and driver assistance functions. Muscle tension was measured using an electromyograph equipped with electrodes attached to designated areas of the driver's upper limbs. Tests were conducted with the vehicle's assist functions turned on and off. Muscle tension was then compared under different conditions.

During the tests, an attempt was made to verify driving assistance systems (intelligent adaptive cruise control – IACC, lane keeping assist – LTA) in the context of their use by drivers with paraplegia in urban traffic. An electromyograph (EMG) was used for the measurements. As part of the study, each of the 30 drivers performed four alternating drives: driving without autonomous functions, driving with autonomous functions. The tests were carried out on the same route, using adaptive devices (hand throttle/brake). The voltage waveform was measured on the front part of the shoulder.

During the measurements, attention was paid to the extent to which driver support functions (autonomous functions of the car) were able to reduce the load on the driver's hand muscles and, consequently, delay his fatigue and indirectly increase the mobility of drivers with motor dysfunctions.

The choice of the measurement location as the front part of the shoulder was deliberate, because the mentioned area seems to be a common area used by drivers while driving. Rapid hand muscle fatigue is a common phenomenon among drivers using adaptive devices. Vehicle operation is then performed using the upper limbs. Furthermore, individuals using devices to manually control the vehicle's acceleration and braking often experience reduced trunk stability, which they compensate for by even more intensely engaging their hand muscles. If the symptom in question is combined with weakened hand strength (as in tetraplegia), the problem becomes significant and can lead to reduced mobility for drivers with disabilities. Driving under constant muscle tension can significantly impact decision-making during travel, and the onset of accelerated fatigue can limit the distance and intensity of travel.

The benefits resulting from the use of autonomous functions will be presented, among others, in the following measures: the average difference in the percentage of driving time when the driver's muscles are at rest between driving with the autonomous functions switched off and on, the average difference between the total relative muscle tension in driving with the autonomous functions switched off and on.

Description of the research process

- conducting a demographic survey (EMG test form),
- conducting a series of driving tests in real-world traffic, using adaptive devices, autonomous functions, and an electromyograph to monitor muscle tension,
- performing tests alternately: with and without autonomous driver assistance functions,
- completing one trip within 15 minutes,
- completing two trips with autonomous driving functions disabled and two trips with the functions enabled – alternating between them. The total test for one driver will take no more than 60 minutes.

Data analysis

- normalizing and filtering the recorded muscle tension waveforms to prepare them for further analysis,
- assessing the repeatability of the recorded waveforms within the completed trips of a single driver and the same driving mode (with or without autonomous functions),
- assessing the repeatability of the recorded waveforms within a given driving mode for all drivers simultaneously,
- assessing the differences in waveforms for each individual driver between two driving modes, assessing the differences in waveforms between driving modes common to all drivers,
- assessing repeatability and differences, first by visually observing the graphs representing the muscle tension waveforms and then by applying statistical tools selected based on previous observations,

Characteristics of the study sample

- 30 participants,
- Age: 25–60,
- 12 women and 18 men,
- Category B driving licenses,
- Mixed recruitment based on the recommendation method,
- Study participants were not offered compensation,
- Participation in the study was voluntary, and each participant has the right to withdraw from the contract.

Research tools

The electromyograph, model: MyoPlus2 Pro, is certified and used for medical applications according to the EU 93/42/EEC standard and bears the CE 120 mark. The device is equipped with a diagnostic module and electrodes for application to the skin – for measuring muscle tension while driving. The measurement method was performed using surface electromyography (EMG), a method of measuring and visualizing the action potential in skeletal muscles during rest and exercise. The device used for the study allowed for the observation of muscle activity from a level as low as 0.2 μV, which is helpful in observing partially weakened muscle groups (Figure 1–3).

Test procedure

1. Informing the participant about the study,
2. Signing the declaration and GDPR,
3. Completing the EMG study form,
4. Introduction to the study:
   - applying electrodes,
   - verifying correct electrode connection (raising the connected limb, leaving the connected limb at rest),
5. Assimilation run on the ITS premises,
6. Test measurement attempt (test run on the closed ITS premises),
7. Whether the test subject is ready to perform the

Figure 1. A car equipped with adaptive devices for drivers with motor disabilities and autonomous driving functions: active cruise control, lane assist

Figure 2. Test route in real road traffic in Warsaw, which will reflect typical city traffic in a representative way

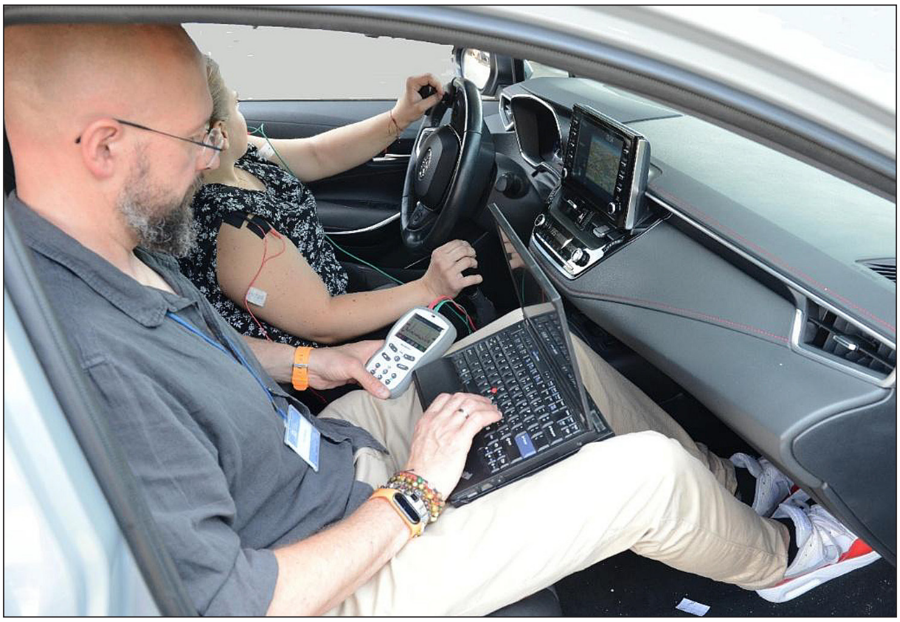

Figure 3. The research was conducted by 2 people: 1 person supervises the proper conduct of the research procedure, supervises the proper conduct of the research (ensures standardization), 2 person operates the measuring equipment (EMG)

actual run in street traffic,

8. Run to the test section,
9. Initiation of the run procedure::
   - travel with autonomous functions disabled,
   - travel with autonomous functions enabled,
   - travel with autonomous functions disabled,
   - travel with autonomous functions enabled.

   Each run took place on the same test section, using adaptive devices.
10. Return from the test section to the ITS,
11. During the tests, the following was recorded:
    - muscle tone of the driver's deltoid muscles (using an electromyogram),
    - autonomic function status.

The key muscles for assessing upper limb load are the deltoid muscles, on the outer side of both limbs. For the measurement, electrodes were applied to the outer sides of the arms. Applying the electrodes was not painful, and accessing this skin area did not cause discomfort.

Participants were informed in advance about the electrode placement site so they could decide whether they consented to it, and were also given the opportunity to prepare for electrode application in terms of clothing. A contributing factor was that the study was conducted during a period of slightly higher temperatures, when short-sleeved shirts, or perhaps with an additional covering in the form of a cardigan, would be acceptable.

Driving a vehicle equipped with adaptive devices also presented no obstacles; participants quickly adapted to driving with the aid of additional controls.

To mitigate the adverse effects of these factors, drivers were given the opportunity to familiarize themselves with the vehicle and drive it within the ITS's closed area before the tests. Merging into traffic occurred only with the participant's full consent, when they expressed that they felt safe driving. The researcher did not exert time pressure and ensured that the participant actually felt safe.

RESULTS

The input data recorded by the device (electromyograph) were in the form of CSV files. Separate columns contained the following results: time sampling, electrical voltage at channel 1 electrode, and electrical voltage at channel 2 electrode. The two channels corresponded to electrodes mounted on the left and right shoulders, respectively, near the deltoid muscles. As a result, the data in each file could be interpreted as separate electrical voltage waveforms on the skin surface of the driver's two hands. For each driver, four to six such waveforms were acquired, depending on the number of test runs. Some of these corresponded to driving with assistance features enabled, while others did not. This dataset was obtained for each of the 32 drivers. Data analysis was performed in MS Excel.

The data was standardized. In the first stage, it was filtered and threshold values were determined. During data collection, it was observed that in able-bodied drivers, with the assistive functions enabled, muscle tension decreased by an average of 12 percentage points. Distributing the obtained results between the limbs, the obtained results were 10 percentage points for the right hand (operating the gas and brake) and 13 percentage points for the left hand (operating the steering wheel). Interesting results were observed in people with paraplegia; the assistive functions increased muscle tension by an average of 4 percentage points. This was 7 percentage points for the right hand and 1 percentage point for the left hand.

On Figure 4 illustrates of a fragment of the muscle tension waveform of the driver's left hand while driving. Despite the visible noise, a minimal voltage value is noticeable. This parameter was interpreted as the hand at rest. All hand movements were characterized by a significantly higher tension level. To ensure correct detection of the resting state, the waveform was filtered.

For the muscle tension waveform, low-pass filtering was performed in the form of local averaging in the time domain. In this operation, each signal sample was replaced with the average value of 21 adjacent samples. Using this type of filtering is equivalent to filtering the signal using a rectangular time window 21 samples wide and 1/21 high. The choice of filtering method was due to the specific nature of the waveform, which contained elements similar in their characteristics to functions with a discontinuous derivative, and sometimes even to step functions (Figure 5).

On Figure 6 shows the muscle tension curve with a threshold value. This separates the muscle tension values corresponding to the states of rest and exertion. The selection of the threshold value itself will be described later in this paper. The purpose of introducing this value is to isolate the sections of the curve in which the driver engaged in actions with the analyzed hand once, while their hand was at rest.

Based on a comparison of muscle tension waveforms with a threshold value, a unipolar function was applied. It takes the value 0 where muscle tension indicates resting of the hand and the value 1 where muscle tension indicates exertion (Figure 7).

The described approach to the research results does not distinguish between intensity of exertion, only its duration. This is justified by the phenomenon of driver assistance studied by auxiliary systems available in cars: active cruise control and lane keeping assist. While driving, the driver exerts effort with their hands depending on traffic conditions. Assistance systems can perform some of these actions automatically, eliminating driver effort. In the case studied, the question of how much rest time a driver gains for their hands by using functions generated by the auxiliary system while driving was analyzed.

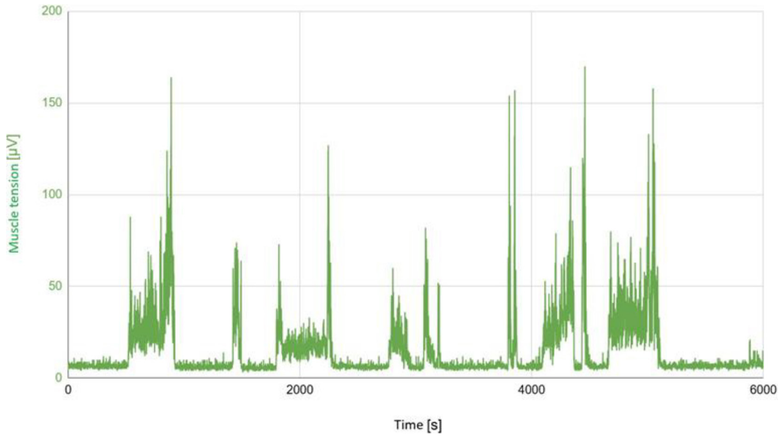

Figure 4. The course of muscle tension in the left hand

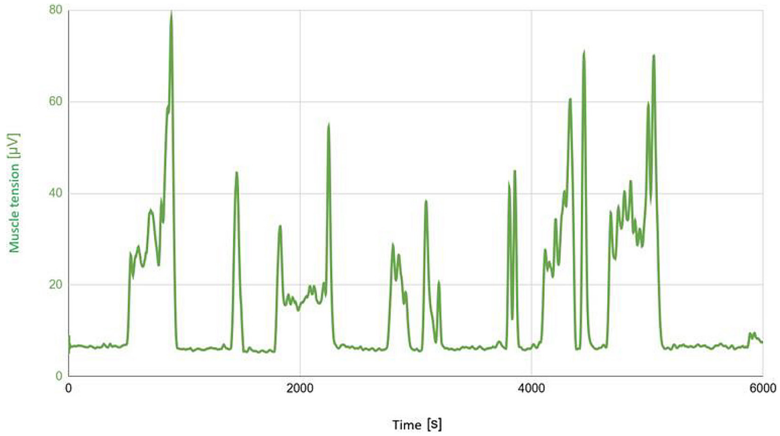

Figure 5. Muscle tension curve after filtering

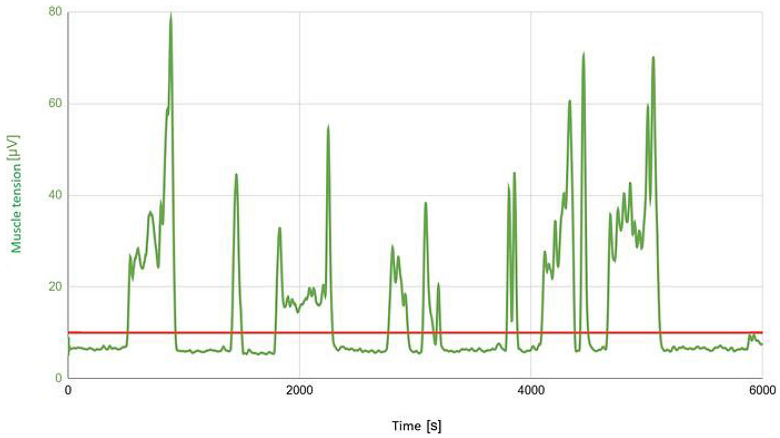

Figure 6. Muscle tension course with the limit value marked

Therefore, what is of interest is the working time, the rest time, and the ratio between them, not the muscle tension values during hand work.

Defining the threshold value separating rest and work was not straightforward. Therefore, for each muscle tension curve, the proportion of work time relative to the total travel time was determined for the adopted threshold value. Determining the threshold value allowed for the identification of the proportion of work time, which would change with the adopted threshold value.

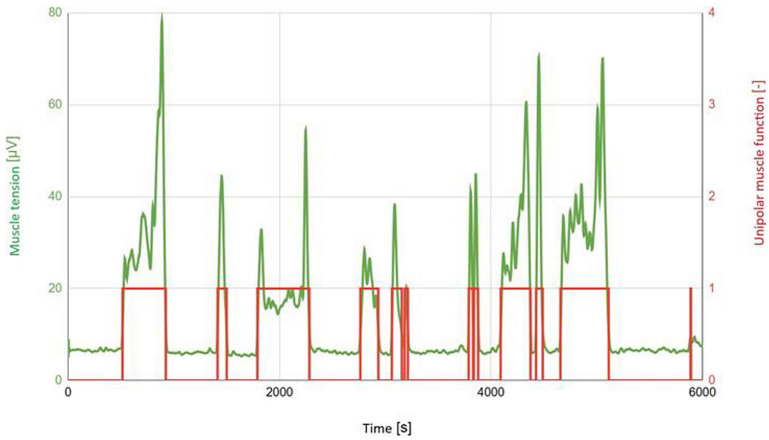

Figure 7. Unipolar function superimposed on the muscle tension waveform

On Figure 8 shows a graph of the relationship between the proportion of muscle work time and the threshold value of muscle tension for an example muscle tension curve from the left arm. At a threshold value of approximately 10 μV, a distinct inflection is visible in the graph. This point was adopted as the baseline because it corresponds to the ideal threshold below which values associated with muscle rest would be interpreted as lack of work.

On Figure 9 presents the percentage of time spent working the left hand muscles for individual drivers. The values correspond to driving without assistance functions. This refers to steering wheel operation. The mean value of this percentage is 43%. It has a relatively high standard deviation of 13%. This indicates significant variation in the percentage of time spent working the left hand muscles among individual drivers. The presented values correspond to driving without assistance functions enabled.

In practice, a low percentage of time spent working the left hand muscles often means that the individual driver often kept their hand at rest. In extreme cases, the driver engaged in left-hand work for only 25% of the driving time. A significant percentage of time spent working the left hand muscles means that the driver kept their left hand tense for most of the driving time. This phenomenon could be caused by frequent steering wheel operation or was a manifestation of stress in the tested driver.

On Figure 10 presents the proportion of time spent working the right hand muscles for individual drivers. The values correspond to driving without assistance functions. This corresponds to operating the gas and brake levers. The average value of this proportion is 70%. It is characterized by a relatively high standard deviation of 20%. There is a noticeable increase in muscle involvement in the right hand, which remained under tension most of the time. This may be due to the need to constantly press the gas pedal while driving.

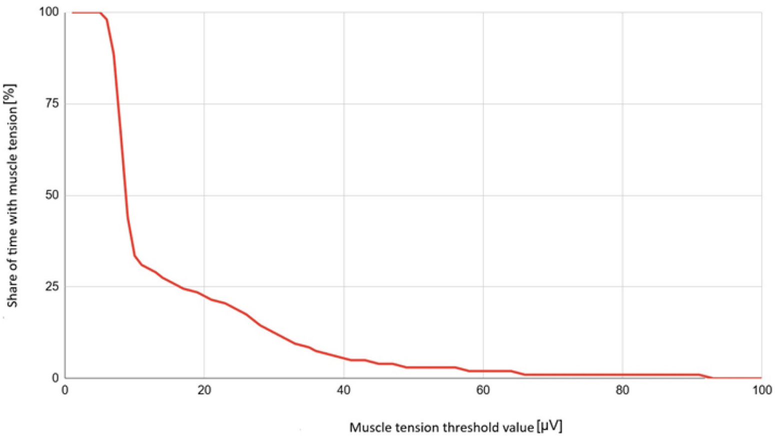

Figure 8. Dependence of the proportion of muscle work time on the limit value of muscle tension

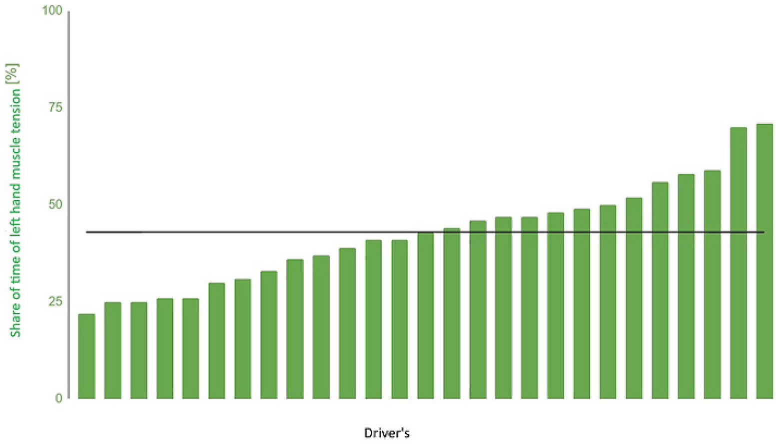

Figure 9. Share of left hand muscle work time for individual drivers

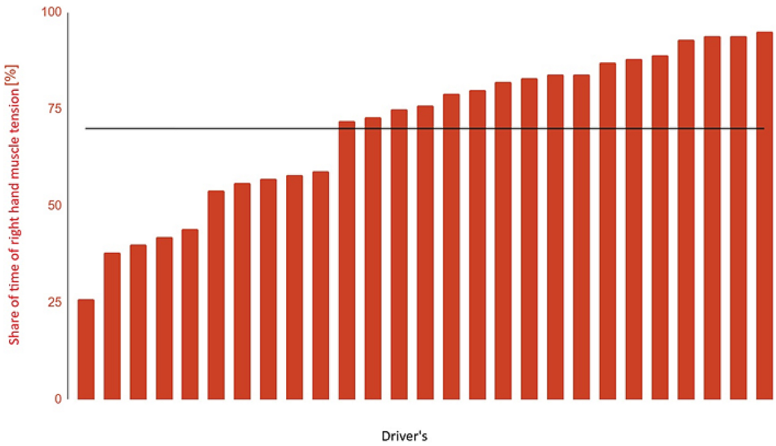

Figure 10. The proportion of time spent in tension of the right hand muscles for individual drivers

The presented values correspond to maneuvering the vehicle without any assistance functions enabled.

With the assistance functions, such as active cruise control and lane keeping assist, some of the steering wheel, accelerator, and brake lever operation could be performed by vehicle-mounted devices. By utilizing these functions, the driver could reduce some of the effort. However, they were aware that they could still operate the steering wheel and lever independently at any time. The recording of the phenomenon being studied could also indicate additional muscle tension resulting from stress or being on standby in the event of a malfunction of the assistance functions.

The effect of activating assistance functions was not clear-cut, as it could either lead to an increase or a decrease in muscle work time. Indeed, in individual driver cases, both effects of the phenomenon under study were observed.

On Figure 11 shows the relative change in the proportion of left-hand muscle work time for individual drivers, expressed as a percentage. A positive value of the relative change indicates an increase in the proportion of muscle work time. A negative value indicates a decrease in the proportion of muscle work time.

It was observed that some drivers found the activation of assistive functions helpful, while others found it detrimental. There were also drivers who reported no significant change in left-hand muscle engagement.

On Figure 12 illustrates the relative change in the proportion of right-hand muscle activity time for individual drivers, expressed as a percentage. As in the previous example, a positive value of the relative change indicates an increase in the proportion of muscle activity time. A negative value indicates a decrease in the proportion of muscle activity time.

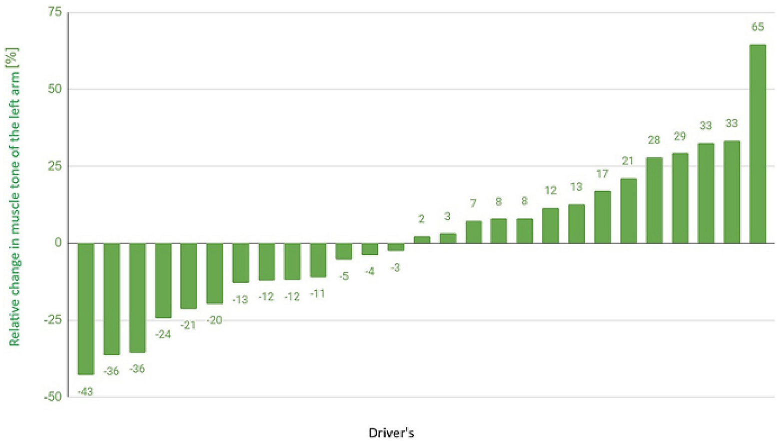

Figure 11. Relative change in the share of left hand muscle work time for individual drivers

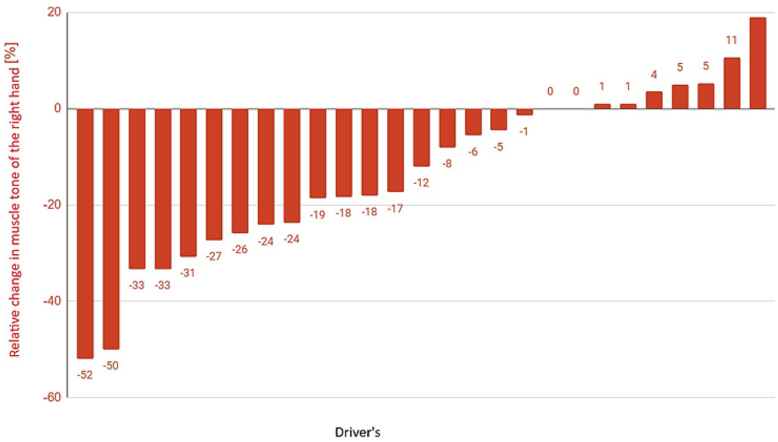

Figure 12. Relative change in the share of right hand muscle work time for individual drivers

It is clearly visible in the presented graph that the majority of drivers used the assistance functions. This means that the proportion of time engaged in the right-hand muscles was significantly lower in many cases. A small number of drivers were also noted for whom activating the assistance functions increased the engagement of the right-hand muscles.

When interpreting the studied phenomenon, the question arose as to why the beneficial effect was observed more frequently in the case of the right hand when the assistance functions were activated? This may be due to the fact that drivers were constantly ready to react to acceleration or braking of the vehicle. This action was performed using the right hand, operating the gas and brake levers. The recorded muscle tension in the right hand is a translation of the active cruise control function. According to the researchers, adaptive cruise control worked reliably more often than lane-keeping assist. Its operation was more likely to require no driver intervention. Furthermore, without the assistive functions, the right-hand muscle involvement was significantly greater than the left. This may have created greater potential for reducing driver muscle strain.

On Figure 13 presents the sum of the relative changes in the proportion of muscle work time in the left and right hands for individual drivers. The average value for all drivers combined is -6. A negative value indicates a general favorable trend in the use of assistive functions. Thanks to their use, drivers saved an average of 6% of muscle work in both hands. However, this average value does not reflect the relatively large variation in the impact of assistive functions on individual drivers. It is therefore worth emphasizing that the positive or negative impact of these functions is highly individual. Some drivers were able to gain as much as 30–40% of muscle rest time, while others increased their muscle workload in driving.

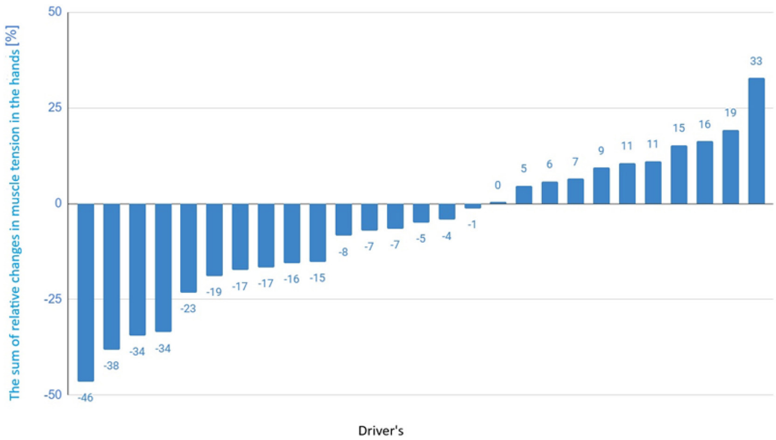

Figure 13. Relative change in the proportion of time spent on muscle tension in both hands combined for individual drivers

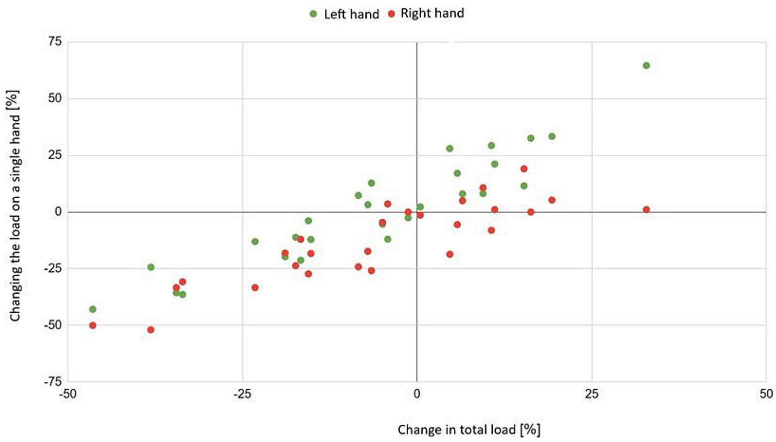

Figure 14. The dependence of the relative change in the proportion of time spent in the muscle tension of individual hands on the relative change in the proportion of time spent in the muscle tension of both hands combined

When interpreting the collected results, it was observed that the impact of driver assistance features while driving was considered independently for the left and right hands. However, the question arises: were the benefits for muscle engagement in one hand the same as those for the other hand?

On Figure 14 illustrates the relationship between the relative change in engagement of the left and right hands separately and the relative change in engagement of both hands combined. A correlation is noticeable between the change in the proportion of work performed by the left and right hands. Therefore, drivers who saved some effort in one hand, in most cases, also saved some effort in the other hand. Conversely, drivers who were adversely affected by the assistance features may have experienced increased effort in both hands.

CONCLUSIONS

The research conducted as part of the statutory work included an analysis of the use of intelligent safety systems by drivers with disabilities, using an adaptive "pull/push" device.

The results showed that in able-bodied drivers, the use of assistance systems such as adaptive cruise control and lane keeping assist led to an average reduction in muscle tone of 12 percentage points. At the same time, an increase in muscle tone was noted in selected muscle groups: by 10 percentage points in the right hand (accelerator and brake pedal) and by 13 percentage points in the left hand (steering wheel). For drivers with paraplegia, the use of assistance functions resulted in an average increase in muscle tone of 4 percentage points, with these values being 7 percentage points for the right hand and 1 percentage point for the left hand, respectively.

The analysis of the results suggests that individuals with lower limb impairments partially compensate for the lack of lower limb stability by using their upper limbs and proper trunk positioning, resulting in higher muscle tone in the upper limbs.

It is advisable to expand further research on systems commonly used by vehicle manufacturers, including the functions under investigation. This work should focus on obtaining more data to enable comparisons and verification of results.

Another research direction could be the analysis of muscle electrical activity in relation to the perception of discomfort and the assessment of the impact of additional devices stabilizing the driver's trunk. Such studies would allow for the assessment of whether the technical device used reduces muscle tension under various operating conditions. The need for further research on the use of electromyography (EMG) in the context of functional diagnostics for drivers with disabilities suggests further research directions.

Verifying the range of motion of the upper limbs and measuring muscle tension during the use of adaptive devices would allow for the collection of data necessary to standardize the test device used in the diagnostic process and select equipment tailored to the individual needs of drivers.

Developing a diagnostic system based on EMG signals for people with disabilities is a desirable direction from a universal design perspective. A properly designed system should identify movements such as an open hand, a bent hand, a raised arm, and a lowered arm. Based on the collected data, it is possible to develop a pattern of movements related to operating the steering wheel, accelerator and brake pedals, and changing direction. A precise model of this type allows for increased measurement accuracy to approximately 98%, reflecting the driver's natural driving behavior.

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