Local Muscular Load Measurement with the Help of a Datalogger

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Abstract: The aim of this research was the development and verification of the local muscular load measuring methodology as a valid and recognized measurement in order to subsequently strengthen injury prevention of occupational diseases among workers of both manufacturing and non-manufacturing companies. A milestone in the project was construction of a measuring device to obtain data for evaluating local muscular load with the use of force measurement, frequency of movements and positions and a device called datalogger. This measuring device was then tested and its functionality has been successfully proved in 40 measurements in both manufacturing and non-manufacturing enterprises. The reason for the development of this equipment was especially a requirement to learn the load (force generation) of the individual fingers when operators work, implemented by different grips, e. g. tridigital, pentadigital and so on. Such quantification is not possible with the current EMG method.

The developed equipment had to be validated with existing certified methodology called electromyography, which allows only summative evaluation. The results of correlations of both measurements while evaluating the local muscular load are analyzed in this article. The aim of this paper is also to describe how the new device was developed and tested: the Datalogger for measuring local muscular load and its advantages and limitations. Based on the defense carried out, the Industrial Property Office subsequently issued a letters patent for the invention with a number PV 2015-820 earlier this year. The invention relates to an ergonomic device developed for monitoring of local muscular load, and is especially useful in workplaces where there is increased stress, particularly stress on your hands when multiple / repetitive movements, often involving spending increased muscle strength. Measurements can also be made for operators wearing different preservative gloves commonly used in practice.

In this article the authors will introduce not only new patented apparatus itself, but a new methodology for local muscular load measuring with the datalogger as well.

Keywords: ergonomics; local muscular load, carpal tunnel syndrome; datalogger; long-term, integrated electromyography (EMG)

1 Introduction

We are definitely at the beginning of Industry 4.0. Industry 4.0 is the next phase in digitalization of the manufacturing sector. Most of the digital technologies have been brewing for some time. Some are not yet ready for application at scale [1]. Industry 4.0. is based on informatics, technical and autonomous pillars. But, in our article we focused on human factor. The human factor it is the most important factor in companies. Therefore, it is essential to create healthy and supportive working conditions. Otherwise, the employee risks exposure to occupational diseases, serious illnesses, etc. In this case, the employer is then exposed to liabilities stemming from not creating suitable working conditions, such as compensation, increased recruitment costs, etc. In this context, the very important role is played by social environment and political and legal environment that is created by the state authorities [2].

In the Czech Republic and Slovak Republic management is being increasingly responsible for occupational diseases stemming from “local muscular load” of employees. In the rest of the world it is also known as the repetitive strain injury (RSI).

We will compare results of our measuring with those that we achieved by traditional certified apparatus for the Local Muscular Load – Electromyography (EMG holter). The reliability is possibly expressed by a relative reliability coefficient, and we study it by using several methods, e.g. parallel test measuring, which means a measurement conformity with other adequate measurements of the same construct. In our procedure, a maximum reliability is offered thanks to using the EMG holter, which is then studied by algorithm of searching for the highest conformity – correlation.

2 Ergonomics – Specifics in the Czech and Slovak Republics

Ergonomics is the discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance” [3, 4]. At the same time, suitable ergonomic solution is the way to success and product profitability [5]. There are at list two main parts of ergonomics: overall physical load and local muscular load.

Measurement methods based on spending muscle forces are used especially in Czech and Slovak Republic. Other countries measure local muscular load more subjectively, through evaluation sheets (ergonomic checklists). However, methods presented in this article are more precise and objective.

In Czech and Slovak Republics, the EMG measurement is a standard method of diagnosing the carpal tunnel syndrome. When doing medical examination of the nerve through the carpal tunnel, a lower sensitivity as well as prolonged distal motor latency occurs. Moreover, a dispersion of potentials is often revealed. If suffering from severe disorders, a lower number of amplitudes of a summing operational potential is typical. According to the values measured, we quantify and stratify the seriousness of disorder in the field of neurography. In the Czech Republic, there is the Standard of Electrophysiological Carpal Tunnel Syndrome Diagnosis effective for the purposes of reporting on occupational diseases [6].

The research team focused on the illnesses caused by local muscular load because they are the most frequent occupational diseases in the Czech Republic. Among them, occupational carpal tunnel syndrome (CTS) is the most frequent. Minks et al. [6]. note that "Carpal tunnel syndrome is the most common mononeuropathy and the most common occupational disease [6]. Also the costing point of view it is very important in the context of healthcare [7]. For elimination of LML we can use the ABC costing. An activity based costing system assigns costs as they actually exist at a point in time, not as they should or could be performed [8].

2.1 Integrated Electromyography as a Classical Measuring Method

After identifying the risk factors in the workplace, an evaluation (objectification) followed. The evaluation was carried out with the use of integrated electromyography (EMG) to generate standardized measurements. In the Czech Republic, the EMG method is the only officially recognized method for measuring local muscular load, and only the authorized companies can carry out the measurements.

The expended muscle strength, the number of movements and the operating position of the limbs are identified and verified during the evaluation of local muscular load, depending on the extent of the static and dynamic parts of a person´s work during an average eight-hour shift.

The EMG method has been widely used in the past to investigate central fatigue, by evaluating gears responses of the central nervous system (i.e. changes in the motor unit recruitment). The methods for measuring can vary a little, especially during prolonged maximal voluntary contraction (MVC), whereby the EMG amplitude decreases progressively in parallel with the force output [9, 10, 11]. Conversely, during submaximal contractions, whereby the EMG amplitude progressively increases in order to retain the force output [12, 13, 14]. Other methods exist around the world measuring muscular activity, e.g. surface electromyography (sEMG). A portable EMG system (MyoGuard) was used to collect myoelectrical signals on-line and analyze them using a computer [15].

Some articles confirm that it is possible to decrease local muscular load in factories by using mini-load multi-shuttle Automated Storage and Retrieval Systems (AS/RS) and discrete event simulation. The simulation model for multi-shuttle AS/RS consists of two lines (single depth) of Storage Racks (SR), an SR machine, Input and Output locations (I/O Location), and other manipulation equipment [16].

However, for typical measurements of local muscular load in the Czech Republic (to obtain the values and type of expended muscular strength of extensors and flexors of the forearm of both upper limbs of a measured person), non-invasive electromyography was carried out using a Holter EMG. The Holter EMG (i.e. data collection station) is shown in Figure 1.

Figure 1
Holter EMG [17]

As Figure 2 shows, five electrodes were placed on both upper limbs to scan the muscle activity. Two electrodes were located on the extensors, two on the flexors and one ground electrode on the tendon in the elbow.

Figure 2
EMG electrodes placed on the arm (own processing)

Prior to taking measurements, it was necessary to individually determine the maximum muscle strength for each upper limb. Each limb was put into a predetermined position (upper arm parallel to the body, with the forearm held at a right angle). The highest activity of electrical potential was recorded as 100% Fmax for measuring the muscle groups of the flexors and extensors of the forearm.

2.2 The Datalogger

This invention is an ergonomic device monitoring local muscular strain. It can be used at workplaces with a higher muscle strain, mainly the one of arms when having frequent/repetitive motions often connected with higher muscle strength. These are particularly workplaces of assembly, but also of other types as well.

Within this project, so-called Measuring device consisting of the Datalogger and measuring gloves was designed and tested. Altogether, four functional samples of Datalogger and measuring gloves were made. The practical use can be seen in Figure 3.

Then, a methodology to measure local muscular strain of employees of manufacturing as well as non-manufacturing companies was suggested. These strains are mainly caused by tunnel syndromes, e.g. carpal tunnel syndrome. A follow-up program application that forms an integral part of the methodology was prepared. This application enables users of the measuring device (Datalogger and measuring gloves) to have a simple and clear measurement output, in the form of graph as well, without having deep knowledge of statistical methods.

The development of this device took place at workplaces of Tomas Bata University in Zlín and Department of Cybernetics and Biomedical Engineering at VŠB – Technical University of Ostrava following standard procedures of HW development in the following stages.

After identifying the risk factors in the workplace, an evaluation (objectification) followed. The evaluation was carried out with the use of integrated electromyography (EMG) to generate standardized measurements.

Figure 3
Sensors, their placement and course of measuring (own processing)

3 New Method of Measuring

3.1 Major Problems the 1st Generation of the Datalogger and Their Solutions

The following major problems occurred when measuring by the datalogger device (1st generation):

1) Incorrect data record on SD card – all sequences missing on the data record (many minutes)
2) Failures – sensors FSR 400 and FSR 402 breakages
3) Insufficient length of testing
4) Low weight of manipulated components of the Minnesota test
5) Having problems when doing an automatic reading of number of motions from the figures of gyroscope and accelerometer
6) Having problems when using gloves

How we coped with the problems when working on modification of measurement methods and the datalogger (2nd generation) itself:

Ad 1) For the purpose of records, it is necessary to use SD cards with the capacity of maximum 32 GB (SDHC) only. The recommended capacity of SD card is 8 GB. SD cards with higher capacity can have different features and time constants as well as SW of keeping the records; therefore, can cause loss of records from the datalogger, i.e. not saving the data.

In the course of pilot measurements, precautions to eliminate the problems with keeping the records on SD card were taken as well as hardware tuning up of the datalogger was done in order not to have an incomplete data record from the sensors. Neither the influence of battery power nor the source of power supply (batteries vs. transformer) was confirmed when having problems with records.

Figure 4
Datalogger - apparatus (own processing)

Ad 2) The sensor breakage is a matter of mechanical wear of these items when testing (taking measurements), when in contact with fingers and the tool a proband is working with. A very simple and efficient protection showed up to be putting a thin adhesive tape on a sensor. The sensor will be protected against the breakages and its lifespan will be longer by using this simple method. Moreover, the measurement results are not distorted at all. For this reason, the number of measurements done by using a particular sensor is approximately 20-50 depending on the type of grasp, work operation, temperature and other aspects of measurements. In other words, having a lifespan of each individual sensor for 100 measurements is possible in exceptional cases only, i.e. under laboratory conditions.

Ad 3) Approx. five-minute length of the test, which is an average length of the standardized Minnesota test, showed up not to be sufficient from time perspective for statistical evaluation. This is for the reason that it was necessary not to consider and evaluate the first sequence of measurement when a proband was getting “initial training”.

We have to consider this when taking measurements or doing analysis of real work in practice as even an experienced worker can be put out of countenance (doing usual routine work), e.g. an attached sensor to his/her finger. It is also the feeling that he/she is being monitored, evaluated, filmed, etc.

Therefore, it is necessary to include the 1st part of measurements, but the phase of training must be read of the total process, and the measurement itself should take approx. 20 min. This is optimal regarding the record and evaluation frequency of 50-60 seconds. From mathematics perspective, it is for the reason that the interval of 50-60 seconds, when being statistically evaluated (see Chapter 7.4. The evaluation of correlation coefficient dependency on a sample frequency for sample measurements), seems to be the most convenient for the rate of final record correlations (values of approx. 0.9).

Moreover, it provides 1,200 records for calculations and the analysis of particular work (using the record after 60s; 20x60s in total).

Ad 4) As the grasp forces were not sufficient for the reason of low weight of manipulated components of the Minnesota test, the chronic fatigue syndrome which results is the carpal tunnel did not occur. Therefore, the components of the Minnesota test as well as the test itself was substituted by a model test, the so-called "puck test". This test is of a similar type; only different numbers of motions and heavier manipulated objects (340g) are considered.

Ad 5) During the pilot measurement itself, it was evident that it is not possible to do reading of number of motions from the gyroscope and accelerometer as the automated motion and trajectory motion frequencies evaluation requires a 3D scan of the rooms as well. Also, the sensor attached to the wrist (gyro + accelerometer) enables us to measure "the angle of the wrist only" (wrist x forearm), but not the work done by fingers in the constant "angle of the wrist".

Ad 6) Using thin gloves (made of nitrile) showed up to be without any problems under laboratory conditions. Nevertheless, further check-up measurements will have to be taken for thicker gloves.

3.2 Measurement Methods

In this subchapter, a more accurate description of checkpoints for practical measurements will be presented. Five methods systematically divided among three checkpoints were used. In the first one, training and filling in the questionnaire was done. In the second checkpoint, the Fmax figures were recorded, EMG and the measuring device were placed, and the load test was done. The last checkpoint was BIA (Bio Impendence Analysis).

1) BIA a certified device
2) EMGH (EMG Holter Measurement); a certified device
3) Tension meter measurement (tension meter – a set)
4) Unique non-standardized load test
5) Measuring device (developed by Department of Cybernetics and Biomedical Engineering at VŠB – Technical University of Ostrava)

3.3 Checkpoint – Questionnaire Filling in and BIA

The probands went through a proper training before starting taking measurements. The goal of a project was explained to them, the whole course of measurements was introduced including the methods used, and consequently, a trainee task was described. First, they had a chance to see it on video recording, and then, they could practice is by themselves. The purpose of this training was to eliminate mistakes during the measurement itself. Moreover, we expect that this could have minimized certain rate of nervousness causing inaccuracy and a lower coordination during the measurement.

In the first checkpoint, the questionnaire of a proband was filled in with the aim to record his/her identification data, laterality and mainly his/her general state of health. A part of it was BIA done by InBody230 device, which was operated by a specialist.

3.4 Checkpoint - EMG

This checkpoint included a tension meter as well as device recording electric muscle activity, the so-called EMGH = electromyography holter. A maximum fist clench was measured – the elbow joint in the angle of 90°.

The EMG device was used before measuring a maximum fist clench by a tension meter (Fmax.; measured in Newton units, N). This was done lengthwise following two muscles; one of them located at the dorsal part of a forearm and the second one on the ventral part. The electrodes were attached to a muscle pad by using the adhesive tape; in the electrode, an electrode cream was applied for optimization of a signal transmission.

Moreover, every electrode itself was secured by another adhesive tape. Consequently, the EMG recording started in order to measure a maximum muscle activity when measuring F_{max}. Each of the probands was measured by a tension meter **twice** for each upper limb. A higher value measured out of two attempts was recorded (measured in Newton units). This was always done in the same order; first, right upper limb (RUL) measurements and then, left upper limb measurements (LUL).

4 Results - Statistical Data Processing

4.1 Unprocessed Datalogger Data Processing

The datalogger data recorded on SD card are then divided on a personal computer by using EGParser application into 7 files. The analogue data, keeping record of AD non-dimensional values, are part of one file only.

Processing, the datalogger and EMG holter evaluation of values and the dependency analysis are done in MS Excel. The information regarding muscle forces used in the course of measurement is presented in the form of analogue data one after another in six columns for LUL (left upper limb) and six columns for RUL (right upper limb) for every individual sensor. Every record starts with a time code – in the first column, consisting of a number defined by seconds; in the following column of an order number in particular second.

The statistical data processing from the datalogger starts by a thorough check-up of the records kept throughout the whole period of measurements. As standard, the device keeps record of between 99% to 100% of data, which represents a record loss of 0-1000 lines (0-10 seconds) per 100 thousand lines of a record.

Consequently, the noise of every individual sensor is filtered out. For the reason of pressure of the sensor on every finger by using the adhesive tape, "a minimum load" is set. This level (minimum values needed for the sensors to start measuring) is then, in the course of statistical processing, taken away from all values of a particular column. The same procedure is used for all sensors attached, or more precisely the data columns in the output files for LUL and RUL.

Then, millisecond records of AD values are re-calculated by using the equation for calculation of force in Newton units (see Chapter 3.2), and the forces for each upper limb are add up. Due to this, two input variables for left and right upper limb are obtained, i.e. a record of real forces used during the task.

By averaging, the values regarding a muscle activity per second are obtained in order to analyze dependency in relation to the EMG record of values measured on-line per second by using PC. Moreover, the analysis keeps track of correlation regarding one-second, ten-second and sixty-second average values of both devices. A progressive increase in correlation coefficient (sixty-second average values – most often between 0.7 and 0.9) confirms conformity with the primary research hypothesis.

4.2 Research Reliability and Validity

Both devices measure muscle load when making simple mechanical changes in muscle activities. The force used by the person tested is a metric variable which varies in the course of testing – different levels of location and variability – providing consistent information in certain time sequence.

J. Hendl: “The reliability is expressed by a relative reliability coefficient, and we study it by using several methods, e.g. parallel test measuring, which means a measurement conformity with other adequate measurement of the same construct.” [18]. In our procedure, a maximum reliability is offered thanks to using the EMG holter, which is then studied by algorithm of searching for the highest conformity – correlation.

The correlation coefficient as a primary correlation measurement indicator for both devices.

The expected linear dependency between the EMG values and the muscle forces used monitored by the sensors is studied by using statistical analysis methods, to be more precise the correlation and regression analyses. For the newly developed measuring device values, a strong dependency is expected. By using a regression model, the dependency with a high rate of explained variability and the incorrect component E is revealed. Moreover, an extreme systematic deviation occurred.

The measurement validity is an ability to clarify what the object of measuring is (offering correct information, which means that “the measuring procedure really measures what we expect to be measured”). According to Hendl [18], the validity concerns “adequacy, meaningfulness and utility of specific conclusions that are based on measurement results”. The validation of measuring methods is a process supporting such belief. The validity confirmed under certain circumstances (context + purpose) is valid for this context and identical purpose only [19]. When checking-up validity, the content validity, criterion and construct validity are studied [18].

4.2.1 Content Validity

We check to what extent our measurement really represents typical features or the quality [18]. In order to have the content validity of good quality, it is essential to specify the area of measuring itself [20]. Regarding the content validity, our measurement really represents the feature, i.e. it tests a minor muscle load of a hand and forearm when manipulating. The newly developed device (the datalogger) can measure the muscle force used on fingers and the palm. An average muscle force for grasp vs. time is a quantity precisely evaluating the degree of a muscle load which a tested subject must cope with while working. It includes an aspect of fatigue which is really important for us when studying occupational diseases.

4.2.2 Criterion Validity

We assess results and their consensus of the newly developed procedure with another type of measurement that has been verified earlier [18]. When assessing the criterion validity, the results obtained can be compared to other values characteristic for a particular criterion. In our measurements, we wanted to compare the results from our device with the results measured by using the

Minnesota manipulative tests that are standardized with having the norms processed. The aim was to prove that both tests can reveal the same failure in performance, i.e. people performing above standard according to the Minnesota test will be detected by our measuring device and the parameters measured as well. In our country, the EMG measurement is a standard method of diagnosing the carpal tunnel syndrome. When doing medical examination of the nerve through the carpal tunnel, lower sensitivity as well as prolonged distal motor latency occurs. Moreover, a dispersion of potentials is often revealed. If suffering from severe disorders, a lower number of amplitudes of a summing operational potential is typical. According to the values measured, we quantify and stratify the seriousness of disorder in the field of neurography. In the Czech Republic, there is the Standard of Electrophysiological Carpal Tunnel Syndrome Diagnosis effective for the purposes of reporting on occupational diseases [6]. We checked whether the EMG results will be identical to the ones measured by the datalogger. This should be a valid method of finding out about the nerve conductivity disorder (in this case of a central nerve) as this may influence the force of innervated muscles (i.e. wrist flexors and 1st-3rd finger). The method of studying the criterion validity most often used is the correlation coefficient calculation between these two values.

4.2.3 Construct Validity

It concentrates on theoretical aspects of the construct measured (variables, quantities). The evidence of the construct validity is of convergent or discrimination character. If it is of convergent character, the test confirms relations to the variables that we expect from theory. If it is of discrimination character, there is no relation of the test to the variables when we do not expect the relation. In this phase of testing a new procedure, it is important that the results are the ones expected from theory [18].

To assess the construct validity, there is a need for evidence that the test really measures the feature or characteristic needed. We check whether the datalogger measurements of a minor muscle load of workers in practice can reveal a lower performance of those who have suffered from the carpal tunnel syndrome or other occupational diseases. The content validity focuses on measuring the feature researched as a whole. It is researched by studying the literature, theory of the feature, seeing the previous empirical research and the expert opinion. The third one from a group of tools for identifying validity is, on the contrary, the criterion validity. This one is well-measurable by comparing it with certain objective and already validated criterion. This is done either concurrently, the so-called concurrent validity, or prospectively, the so-called predictive validity. The last approach to identify validity is the construct validity. This one is proved when a mutual relationship between the indicator and other variables is found out from the data obtained and which we would expect from studying theory. The convergent validity is proved when one indicator of the concept researched is associated with other indicators of the same concept, but of different character. On the contrary, the discrimination validity is proved when the variable values measuring the concept are not strongly associated with measuring different, but related concepts. The basic tools for measuring the convergent as well as discrimination validity are the exploratory and confirmatory analyses and their various aspects. From theoretical and methodological perspective, the MIMIC model is the most complicated approach to measuring the construct validity. We used this theory also in some other researches [21].

This one places a measuring tool of research, usually a range of these, in the context of conceptually similar as well as different variables. In addition, it specifies possible causal relations between variables, and compares the data with theory. In case these correspond with the theory, this finding confirms the construct validity of the variable studied.

5 Discussion

Five key probands were chosen for detailed analyses when all well-known problems had been checked carefully for 20 minutes. There were also the following precautions taken: the frequency setting for turning the pucks according to metronome, the sensors being attached to four fingers not to be taken off, keeping a double-record of values – on SD card of the datalogger thanks to a particular format and type of the SD card, a record check-up throughout the whole measurement period, a check-up of all sensors and their functionality right after the end of measurements.

These evaluations were carried out without any support of a later-developed SW application**.** The aim was to find dependency between the EMG measurements and the muscle force recorded by the datalogger. The value averaging set per every minute was later confirmed to be very close to an optimal sampling frequency. As an illustration, the records of two probands are mentioned below. But in total we tested more than 100 probands and for about 30 operators at the production lines (Figure 6). The rest of elevations, in a form of unprocessed data, were added on the CD-ROM enclosed (together with the application developed). All this data were handed to the Moravian-Silesian Automotive Cluster c.a. (hereinafter referred to as MAK) and Ministry of Industry and trade Czech Republic and (MIT CR), and to The Industrial Property Office in Czech Republic (IPO CZ) too.

Table 1
Dependency between the EMG measurements (Flexors LUL,LUR) and the muscle force recorded by the datalogger (LUL, RUL datalogger): Proband A – 1x 20 min

Time	Flexors LUL	Flexors RUL	LUL-datalogger	RUL-datalogger
12:00:17	14.50	12.18	3.49	2.75
12:01:17	13.47	11.50	3.2261525	2.8365554
12:02:17	13.18	10.01	3.3788313	2.4720185
12:03:17	13.47	10.46	3.7328694	2.6778192
12:04:17	11.06	9.39	3.2591333	2.7932303
12:05:17	10.95	9.16	2.4964413	2.1003172
12:06:17	10.89	9.12	2.6344152	2.1253838
12:07:17	9.85	9.05	2.8381982	1.9965359
12:08:17	11.25	9.20	3.0447249	2.2497033
12:09:17	10.68	8.95	2.9297469	2.1580144
12:10:17	10.62	9.58	2.73	2.31
12:11:17	10.75	9.62	2.9933314	2.4385115
12:12:17	9.79	9.28	2.6689625	2.3447799
12:13:17	9.12	8.18	2.5253218	2.0219681
12:14:17	10.17	7.90	2.641671	1.936453
12:15:17	10.02	8.48	2.6497252	2.0183217
12:16:17	10.41	9.01	2.5791602	1.9634366
12:17:17	9.60	8.61	2.5194543	1.9121674
12:18:17	9.38	9.02	2.4235038	1.9146724
12:19:17	9.78	9.84	2.7883636	2.0028123
CORRELATION	LUL	RUL		
	0.86243	0.79174		

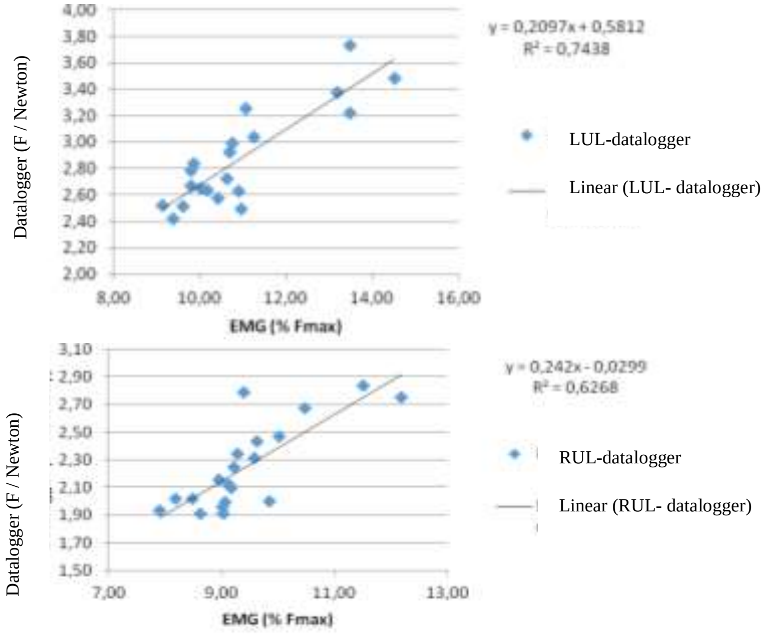


Figure 5
The demonstration of evaluation of A proband´s left (up) and right upper limb (down) (own processing)

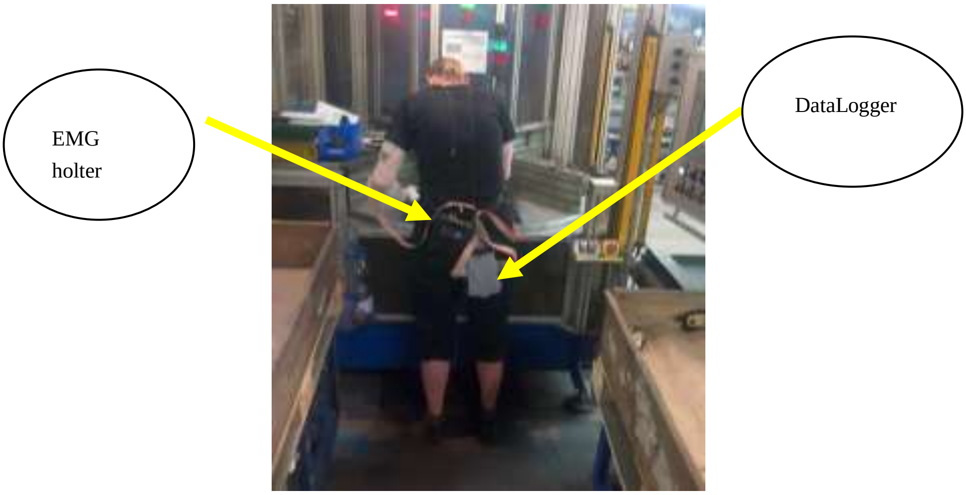
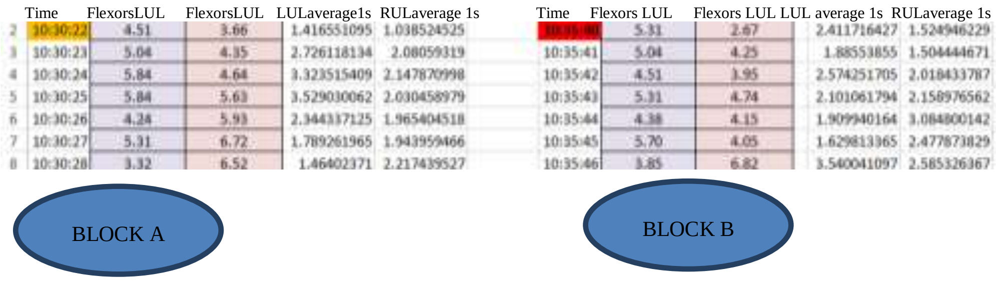


Figure 6
Measuring in factory: dependency between the EMG measurements and the muscle force recorded by datalogger: Operator in ITT holding Ostrava (own processing)

5.1 The Dependency Evaluation of Correlation Coefficient and the Sampling Frequency for Sample Measurements

In this chapter, the last illustration of the final data required for the input elevations is presented. The input data is the sampling frequency of 1 second (the EMG holter implicit configuration and the datalogger adjusted means). Then, the correlation analysis is done depending on the alteration of this sampling frequency (see Figure 7). In the Figure 8, the correlation coefficient dependencies on the sampling frequency (in seconds) are illustrated.



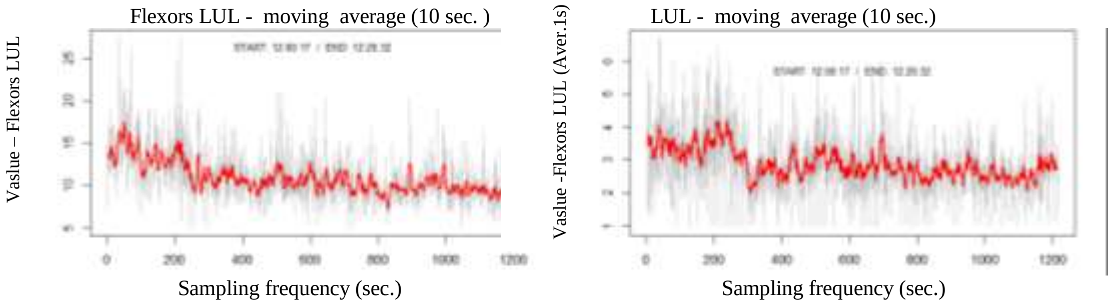
	Time	FlexorsLUL	FlexorsLUL	LULaverage1s	RULaverage 1s
2	10:30:22	4.51	3.66	1.416551095	1.038524525
3	10:30:23	5.04	4.35	2.726118134	2.08059319
4	10:30:24	5.84	4.64	3.323515409	2.147870998
5	10:30:25	5.84	5.63	3.529030062	2.030458979
6	10:30:26	4.24	5.93	2.344337125	1.965404518
7	10:30:27	5.31	6.72	1.789261965	1.943959466
8	10:30:28	3.32	6.52	1.46402371	2.217439527

BLOCK A

Time	Flexors LUL	Flexors LUL	LUL average 1s	RULaverage 1s
10:35:40	5.31	2.67	2.411716427	1.524946229
10:35:41	5.04	4.25	1.88553855	1.504444671
10:35:42	4.51	3.95	2.574251705	2.018433787
10:35:43	5.31	4.74	2.101061794	2.158976562
10:35:44	4.38	4.15	1.909940164	3.084800142
10:35:45	5.70	4.05	1.629813365	2.477873829
10:35:46	3.85	6.82	3.540041097	2.585326367

BLOCK B

Figure 7
The illustration of the input data from MS Excel for further processing in R software (own processing)

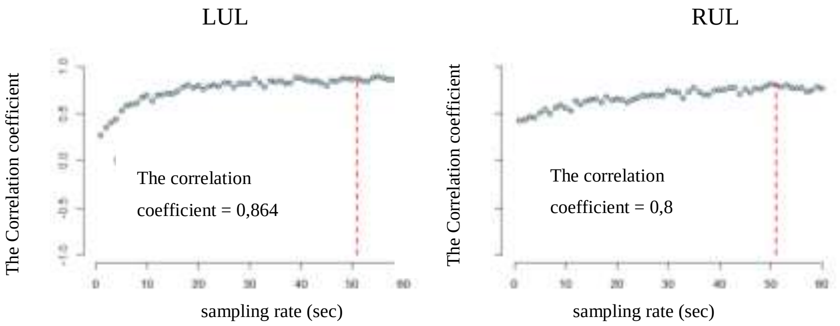


Average = 10.931 Standard deviation= 2936
Number of samples= 1216

Average = 2.874 Standard deviation= 0.97
Number of samples= 1216

Figure 8
The course of testing – 1st check-up – a graphical debugging of autocorrelation enables to find significant deviations (own processing)

The final analysis output is a graphical comparison of average muscle forces (the datalogger) and EMG values in accordance with legislation which sets occupational health rules.



Scatter diagram for the situation of optimum sampling rate: 51 (sec)

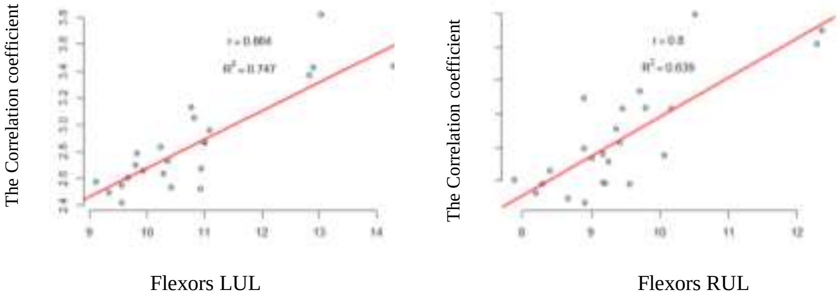


Figure 9

Finding an optimal sampling frequency; based on this, the dependency as being a linear regressive model is illustrated (own processing)

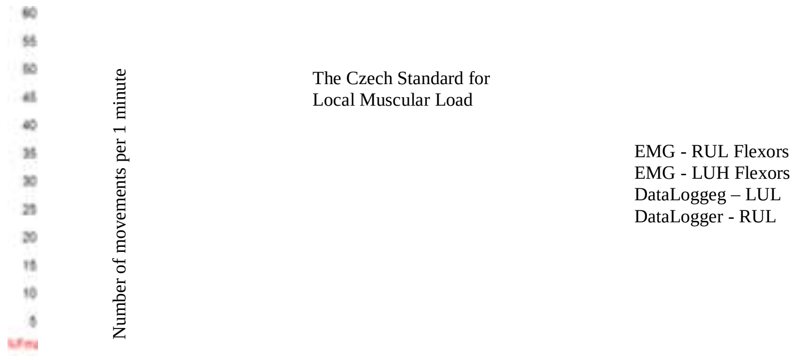


Figure 10

The data output of both devices evaluating a local muscular load for both upper limbs (own processing)

The Figure 10 shows that the EMG results confirm the work to be hard – the values exceeding the norm and breaking occupational health rules. The datalogger as well as the EMG device confirmed a higher muscle load of the right upper limb. For the reason of no similar limits for the load itself, the values can be compared visually only.

Conclusions

This datalogger was patented by The Industrial Property Office in the Czech Republic (IPO CZ) in 2017, under the group patent / application number PV / 2015-820 and it holds the security document code 306 627. IPI CZ is a central body of state administration of the Czech Republic acting in the field of industrial property protection. It is necessary define the limits of this new apparatus and methodology because this apparatus was patented only by The Industrial Property Office in Czech Republic. It means that its application is possible mainly in the Czech Republic and Slovak Republic, where the legislations are the same. Despite the high level of dependence resulting values measured (see Figures 7-10 and Table 1) by both devices (EMG vs. logger) the datalogger has no certification by The National Institute of Public Health (NIPH) is a health care establishment for basic preventive disciplines - hygiene, epidemiology, microbiology and occupational medicine of course in the ergonomics context as well.

The possibilities of a new datalogger were presented, mostly in laboratory conditions. However, this apparatus was tested at dozens production lines and workplaces as well. Our results have confirmed, that we can measure the load of all fingers individually. The load in the Table 1 (columns: LUL-datalogger, RUL-datalogger) is the sum of the load of all the fingers of the hand measured. The advantages of the new measuring principle are: more accurate measurements, higher frequency data reading, video analysis connected with the impulses of gloves, to scan the force directly at the tip of every finger excluding the effect of the operator distortion.

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