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Operator's physical workload in simulated logging and timber bucking by harvester

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ABSTRACT: The aim is to conduct experimental measurements and analyses of physical and mental workload of harvester operators. Among other things, monitoring and analyses of work conditions and workload help reduce possible risks, injuries and long-term illnesses caused by occupational stress. The interim results of the presented ergonomic study describe and analyse the course of physical load upon performing selected work operations at the stage of timber harvesting in laboratory conditions at the harvester simulator. The authors study particularly the relations between independent variables (work operations) and dependent variables (pulse, respiration and muscle tension). The diagnostic system Biofeedback 2000$^{x\text{-}pert}$ is used for measuring and recording changes in dependent variables. Results presented in this study analyse the obtained differences in measurements of physical and mental load in operators in individual work operations. The null hypothesis about the non-existence of a difference between the working operations from the viewpoint of the monitored variables can be refused. Therefore we can accept the hypothesis stating that there is a significant difference between individual working operations.

Keywords: forest harvesting; biofeedback; ergonomics

The workload of operating personnel is defined as a psychosomatic response of a person to work in specific conditions (Procházková 2004). Therefore it can be generally understood as a response of the organism to a set of external conditions resulting from working activities. The conditions operate in the man-machine-environment system. The conditions make the person respond by a change of his/her psychophysiological functions. If the workload conditions reach a level that disturbs a feeling of working comfort we start speaking about stress (Bauer et al. 2006) that indicates the beginning of an excessive load of the organism. On the physiological level, both physical and mental workloads evoke responses in the organism which result in an increase in blood pressure, heart rate, cardiac output and skeletal muscle blood flow in addition to a decrease in renal and visceral blood flow (Wasmund et al. 2002; Zużewicz et al. 2013).

The physical workload can be defined as an activity involving primarily the activation of muscles in a manner characterized by muscle contraction. Based on the intensity of muscle contraction the physical workload may be classified as static (isometric) or dynamic (isotonic). Dynamic physical workload is characterized by muscle contraction

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followed by muscle relaxation. During the static physical workload the muscle does not change its length but the tension in it increases.

Static load is particularly inconvenient because the muscle is not moving and it quickly gets tired. Operators of multi-operation machines may encounter several types of static load, e.g. position (permanent sitting position), spatial limitation (lack of ability to move in a machine cab), holding (control levers) etc. Physical workload, however, means an increased load of not only the locomotive system but also of a complex of the cardiovascular and respiratory systems, which is reflected by metabolic processes and by thermoregulation of the organism. Chundela (2001) defined the physical workload of a person as a result of any activity that increases basal levels of the metabolism. The higher the metabolism, the more strenuous the work.

Experimental measurements in operating and laboratory conditions have shown that the muscle tension in the individual muscle regions responds to given stimulations and that it changes not only as a result of the load of the locomotive system but also as a result of the person's mental condition (Dvořák et al. 2008). In the case of a long-term physical workload the muscle regions are more strained, which results in decreased muscle performance and fatigue. The fatigue may be quantified by means of a biological feedback, specifically by a method called biofeedback.

The term biofeedback means a set of non-pharmacological methods that use special technical equipment to measure, record and evaluate various physiological indicators (Schwartz, Andrasik 2003). It is a natural therapeutic procedure that includes the measurement of personal physiological parameters, such as blood pressure (e.g. Chen et al. 1991; Jern et al. 1995; Trojan et al. 2003; Zengyuan, Joachim 2006; Aminoff 2008; Maikala, Bhambhani 2008; Morimoto et al. 2008; Farah et al. 2009; Babisch 2011; Carroll et al. 2012), pulse (e.g. Moran et al. 1998, 2001; Talbott et al. 1999; Fogari et al. 2001; Blomkvist et al. 2005; Zengyuan, Joachim 2006), breathing frequency, skin temperature, activity of sudoriferous glands (perspiration) and surface muscle tension (e.g. Bongers et al. 1993; Marras et al. 2000; Bongers et al. 2002). Electrodes connected to the client's skin measure the given parameters and they are further connected to a system of convertors and amplifiers that intensify the impulses and transform them into visual images or audio signals (Field 2009). When using the biofeedback method, both the client and the therapist can view the concerned indicators on a monitor which increases the awareness of the client's physical condition and thus an opportunity arises to practice – to a certain extent – ways to influence the indicators by the person's will and to learn to control them, at least partly – in the environment of wood harvesting. One of the modern diagnostic devices that facilitate the use of biofeedback for the collection of experimental data is Biofeedback 2000$^{x\text{-}pert}$ (Schuhfried Australia, Milton, Australia). The device enables the non-invasive use of various registration modules that employ surface electrodes to measure physiological parameters and then use wireless technology to send the data for processing. The main registration modules include the "respiration module" for monitoring of breathing frequency and lung capacity, the "EMG (electromyography) registration module" recording electric responses in muscle fibres during their contraction and the "multi module" recording and sending records about the body temperature, pulse and dermal electrovalence (Schwartz, Andrasik 2003). The measurements performed by now have shown that the respiration module is not convenient for the purposes of the experiment, particularly due to a major distortion of the measured values as a result of the demanding environment in which wood harvesting is performed, specifically difficult installation of a sensor on the operator's body and aggravated conditions for measuring in a machine cab. The main preconditions of correct recording and subsequent sending of data include the proper fixing of sensors of the registration modules on the operator's body. Incorrect installation may result in a significant distortion of the measured values (Mader et al. 2008a).

All the modules communicate with the parent station by means of wireless Bluetooth technology. The range of the wireless communication is ca. 15 meters (Mader et al. 2008b).

MATERIAL AND METHODS

The objective of the submitted comparative case study was to implement experimental measurements and to analyse selected relations between independent variables (individual working operations and working experience of the operator) and dependent variables (changes of the pulse, temperature and surface muscle tension). The study investigated physical workload for selected working operations during the stage of raw wood harvesting. The simulation of harvesting was performed in laboratory conditions on a simulator workstation of a

Fig. 1. Biofeedback 2000$^{x\text{-}pert}$

1 – multi module (temperature, blood volume pulse), 2 – EMG (electromyography) sensors

multi-operating machine – harvester. The measuring and data collection were performed with Biofeedback 2000$^{x\text{-}pert}$. The physical workload of the worker during individual operations was measured and monitored by means of indicators of surface muscle tension, pulse and temperature. The indicators were also measured when the worker was at rest during a working break.

The data were acquired by means of two registration modules (EMG and multi module) connected by wireless communication with Biofeedback 2000$^{x\text{-}pert}$ (Fig. 1). The multi module was used during the experimental measurement to record the body temperature and pulse, while both parameters were measured in the temple area. An elastic textile headband was used for the purpose with special fixtures to attach sensors and the registration module. The module was attached to the head vertex and the sensors were placed on the temples. It was essential to make sure that the sensors adhere directly to the operator's skin. It was particularly important to check that the sensors are not in contact with hair as this might have adversely influenced the measurement results.

When installing the EMG module and its sensors it is necessary to position the sensors precisely on the target muscle endings. The measurements involved the trapezius muscle (*musculus trapezius*), specifically the horizontal fasciculus attaching the shoulder blade to the central part of the spine line, and a spinal part of the deltoid muscle (*musculus deltoideus*), covering the shoulder joint from both sides (Fleischmann, Linc 1972). The simplest method to recognize the appropriate muscle fascicule to place the sensor turned out to be tactual exploration in a position with arms spread apart. The EMG module is equipped with two pairs of sensors of different colour and one separate reference sensor. The installation was bipolar, i.e. a pair of sensors of the same colour was placed on each side of the operator's back. The reference electrode was always installed on the neck at the point where the shoulder blade levator (*levator scapulae*) connects to the spine, which corresponds approximately to the fifth cervical vertebra (*vertebrae cervicales*, c5).

The length of the time interval of work on the multi-operation machine was 45 min. In the end one measurement was performed at rest, in the so called resting phase. It was during a 10-min working break and the measurement was conducted after the end of the operator's working activity. All activities of the operator and the attending personnel were digitally recorded and the resulting videos have been saved, including the installation of the sensors and modules.

Individual working operations in the course of raw wood harvesting with the multi-operation machine – harvester – were defined for the purposes of the experimental measurement as follows:

(*i*) operation: ride – drive from the moment the crane arm is stopped in a riding position until the wheels are stopped in a new position;

(*ii*) operation: felling – from the moment the wheels stop in a working position until a tree falls on the ground; provided that a falling tree remains suspended on the surrounding trees and the operator needs to make any manipulations with the felled tree, including cutting off its parts, then such activities are considered a part of the felling operation;

(*iii*) operation: sorting – includes manipulation with a felled tree after it hits the ground, including cross-cutting and placing of slash on piles; the operation ends once the crane arm moves into the riding position.

In order to process and to analyse the acquired data it was initially necessary to match the video recording with data recorded by Biofeedback 2000$^{x\text{-}pert}$ (Fig. 2). The application used by Biofeedback 2000$^{x\text{-}pert}$ makes it possible to export the data measured with the accuracy of one thousandth of a second. The digital recording from the video camera indicated time with the accuracy of one second from the time when the device started data measurements. Thanks to the available time data special editing software could be used to adapt the video recording and match it with the data exported from Biofeedback 2000$^{x\text{-}pert}$.

The adapted video recording was subsequently analysed and divided into individual working op-

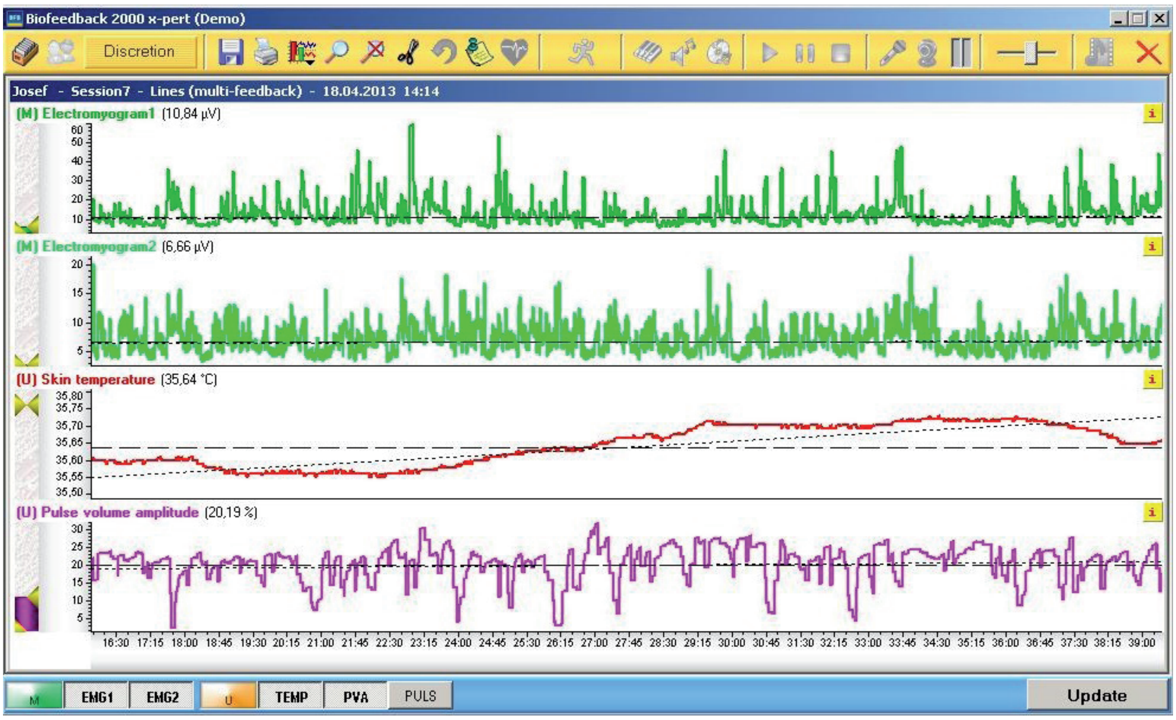

Fig. 2. Section of time series measurements of physiological functions

erations. It contained a continual recording ca. 45 min of working time. From the total of 45 min 15 min and 56 s of felling operation, 19 min and 30 s of sorting operation and 3 min and 56 s of riding operation were analysed with the accuracy of seconds. A separate video recording lasting 10 min was made for the resting phase.

Measurements of the physical workload of a student were performed on premises of a special classroom equipped with the simulator (Valmet, Svoboda nad Úpou, Czech Republic) of a multi-operation machine – harvester. While working on the simulator, the student was not disturbed by anyone and only the operators of Biofeedback 2000$^{x\text{-}pert}$ were present in the classroom. The measurement was performed under optimal conditions of the environment: the air temperature in the room was 22°C and the relative humidity was 60%.

RESULTS

The assumption of different demands of individual working operations in respect to the organism of an operator working on a simulator was formulated into a theoretical hypothesis stating that there is probably a difference between individual working operations, in terms of dependent variables (in this case temperature, pulse and surface muscle tension measured using a bipolar connection in two channels). Data for the analyses came from the measurement of one student who had no previous working experience, as described in detail in the methodology chapter.

Analytical measurements recorded 65,501 measured values for each of the physiological functions (surface muscle tension – EMG 1, surface muscle tension – EMG 2, blood volume pulse and skin temperature). Following an analytical reduction of extreme values, the number decreased to 63,004 (Table 1). The mean value of the surface muscle tension, which was measured on the trapezius muscles on both left and right sides of the body, was 8.09 and 8.89 µV, respectively, ranging from 3.06 to 51.73 and from 2.82 to 41.61 µV, respectively. The mean value of skin temperature was 35.6°C, ranging from 34.6 to 35.8°C. Blood volume pulse was the last analysed function which ranged from 30 to 87 beats in a min (b·min^{-1}), with the mean value of 47 b·min^{-1}.

During statistical processing the measured values were initially transformed into a z-score in order to determine more accurately the difference of the individual data from the average value.

Subsequently, a parametric analysis of variance was performed. In order to test the null hypothesis of non-existence of a significant difference between the two groups (always for two specific working operations), we used a test for two independent samples. Before each testing the null hypothesis of no difference in the variance of values of the evaluated variables in both groups was adopted based on Levene's test.

Table 1. Descriptive characteristics of the monitored variables after their transformation into z-score

z-Score	Operations	N	Mean	SD	SE	95% confidence interval for mean bound lower	upper
Surface muscle tension (EMG 1) (μV)	felling	25,566	0.133209	0.879985	0.005524	0.122422	0.143996
	sorting	31,365	–0.065823	1.145366	0.006467	–0.078499	–0.053147
	ride	6,073	–0.121130	0.704967	0.009046	–0.138864	–0.103396
	total	63,004	0.009610	1.012850	0.004035	0.001701	0.017519
Surface muscle tension (EMG 2) (μV)	felling	25,566	0.225426	0.918317	0.005743	0.214169	0.236683
	sorting	31,365	–0.275374	0.931984	0.005262	–0.285688	–0.265059
	ride	6,073	0.595296	1.257088	0.016131	0.563673	0.626919
	total	63,004	0.117671	1.009597	0.004022	0.003884	0.019651
Pulse (beats·min^{-1})	felling	25,566	0.018406	0.846210	0.005292	0.008033	0.028779
	sorting	31,365	0.594051	1.076960	0.006081	0.047486	0.071324
	ride	6,073	0.114996	1.010728	0.012970	0.089571	0.140422
	total	63,004	0.048127	0.983494	0.003918	0.040447	0.055807
Temperature (°C)	felling	25,566	0.184051	0.672255	0.004204	0.175812	0.192292
	sorting	31,365	0.133209	0.654234	0.003694	0.125969	0.140450
	ride	6,073	0.032622	0.906902	0.011637	0.009808	0.055436
	total	63,004	0.144145	0.691108	0.002753	0.138748	0.149541

EMG – electromyography, N – number of measured values, SD – standard deviation, SE – standard error

z-Score is a model based on relative indicators used in mathematical analyses. z-Score is the mathematical transformation of a numerical data set in such a way that the resulting numbers after transformation showed the mean 0 and variance 1. z-Score thus expresses how the given variable differs from the mean. Descriptive characteristics of the monitored variables after the transformation in the z-score for investigated operations are shown in Table 1. The table indicates that most work operations were related to sorting ("cross-cutting to length"), i.e. 31,365 times, while the "felling" work operation was measured 25,566 times and "vehicle drive" was measured 6,073 times.

Results of the variance analysis and subsequently of all t-tests for two independent samples, in this case always two working operations, are shown in Tables 2–5.

Table 2 presents results of the analysis of variance for all the three work operations listed above. The null hypothesis about the agreement of mean values may be rejected, as the resulting value is zero and therefore lower than the 0.05 level of significance, i.e. a statistically significant difference in the mean values of individual work operations with respect to all the physiological functions measured was proved.

Due to the fact that the null hypothesis was rejected, a more detailed evaluation using the t-test had to be conducted. In the course of individual work operations, slightly divergent values of individual physiological functions are measured – the mean values of the surface muscle tension range from 7.42 to 11.08 μV in relation to the given work operation; while the mean values of the skin temperature range from 35.5 to 35.6°C and the mean blood volume pulse ranges from 47.1 to 47.9 b·min^{-1}. The conducted t-test will therefore prove or disprove the statistically significant dependence of values of each physiological function with respect to the given work operation (felling, cross-cutting to length, harvester ride).

Prior to the analysis, Levene's test will be conducted. Tables 3–5 validate data homogeneity in individual classes through the null value.

Based on the outputs presented above, a statistically proven difference in the impact of all harvester-related work operations on the physiological functions of the human organism can be verified – in this case surface muscle tension, blood volume pulse and skin temperature.

As indicated by results of the analysis of variance, the null hypothesis about the non-existence of a difference between the working operations from the viewpoint of the monitored variables can be refused. Therefore we can accept the hypothesis stating that there is a significant difference between individual working operations. t-tests were used for a subsequent comparison of the individual operations, always for two independent samples. Also those tests have shown that there are significant differences between the values measured for all the investigated working operations.

Table 2. Analysis of variance for monitored operations

z-Score		Sum of squares	*df*	Mean square	*F*	Sig.
Surface muscle tension (EMG 1)	between	672.842	2	336.421	331.378	0
	within	63,959.778	63,001	1.015		
	total	64,632.620	63,003			
Surface muscle tension (EMG 2)	between	5,821.026	2	2,910.513	3,139.971	0
	within	58,397.114	63,001	0.927		
	total	64,218.140	63,003			
Pulse	between	53.728	2	26.864	27.797	0
	within	60,886.627	63,001	0.966		
	total	60,940.356	63,003			
Temperature	between	119.998	2	59.999	126.117	0
	within	29,972.117	63,001	0.476		
	total	30,092.115	63,003			

statistically significant at $\alpha \leq 0.05$, EMG – electromyography

DISCUSSION AND CONCLUSIONS

The method applying Biofeedback 2000$^{x\text{-}pert}$ in analyses of the physiological workload of harvester operators was designed and has been applied at the Faculty of Forestry and Wood Sciences in Prague since 2008 (Dvořák, Natov 2010; Dvořák et al. 2011). Biofeedback 2000$^{x\text{-}pert}$ has gradually been applied in physiological workload measurements in other forestry research facilities in Brno and Zvolen as well (e.g. Fiľo 2013; Jankovský et al. 2013) but its further application in forestry workload research abroad is not known. To date, physiological workload has been monitored by other "specialized" devices, such as ventilometers (Sláma 1983). Owing to the related physiological workload of operators and with respect to the latest developments in electronic diagnostic tools, these procedures prove to be unsuitable for contemporary research. Comparison of results with a number of other methods, including checklists, risk indices or monitoring techniques may be desirable. However, many of them draw on the subjective assessment of workload and operator's feelings of discomfort and as such their validity and reliability are frequently either not verified or are too low (Berryová 2009).

The research focuses primarily on muscle tension as harvester operators are subjected mainly to static workload (Gröger, Lewark 2002), whereby sitting may increase muscle tension in the neck, shoulders and back. Our research considers muscle tension a primary factor which may enable us to analyse workload in relation to selected working operations. The presented results reveal a difference in the physiological functions monitored in the course of individual studied work operations at the stage of timber harvesting simulated at a harvester simulator. A similar conclusion was made in preceding studies as well (Dvořák et al. 2008, 2011). On the other hand, Fiľo (2010) determined muscle tension, unlike others, as a non-detection predictor for analyses of work performance in time. With respect

Table 3. Statistically significant difference in the impact of felling and cross-cutting to lenght work operations

	Equal variances	Levene's test		*t*-Test for equality of means						
		F	Sig.	*t*	*df*	Sig. (2-tailed)	mean difference	std. error difference	95% confidence interval for mean	
Surface muscle tension (EMG 1)	assumed	283.096	0	22.830	56,929	0	0.199032	0.008718	0.181945	0.216119
	not assumed			23.437	56,735.408	0	0.199032	0.008492	0.182388	0.215677
Surface muscle tension (EMG 2)	assumed	45.752	0	64.194	56,929	0	0.500600	0.007801	0.485510	0.516091
	not assumed			64.290	54,944.020	0	0.500780	0.007790	0.485532	0.516068
Temperature	assumed	15.858	0	9.109	56,929	0	0.050842	0.005581	0.039903	0.061781
	not assumed			9.084	54,027.544	0	0.050842	0.005597	0.039872	0.061812
Pulse	assumed	496.747	0	–4.965	56,929	0	–0.409991	0.008258	–0.057185	–0.024813
	not assumed			–5.086	56,853.860	0	–0.040999	0.008061	–0.056800	–0.025199

statistically significant at $\alpha \leq 0.05$, EMG – electromyography

Table 4. Statistically significant difference between the cross-cutting to lenght and ride work operations

	Equal variances	Levene's test		*t*-Test for equality of means						
		F	Sig.	*t*	*df*	Sig. (2-tailed)	mean difference	std. error difference	95% confidence interval for mean	
Surface muscle tension (EMG 1)	assumed	479.800	0	3.632	37,436	0	0.553070	0.015227	0.025462	0.085152
	not assumed			4.974	13,197.565	0	0.055307	0.011120	0.033510	0.077104
Surface muscle tension (EMG 2)	assumed	1,166.080	0	–62.606	37,436	0	–0.870670	0.139071	–0.897928	–0.843412
	not assumed			–51.313	7,416.936	0	–0.870670	0.169678	–0.903932	–0.837408
Temperature	assumed	859.463	0	10.229	37,436	0	0.100588	0.009834	0.081313	0.119862
	not assumed			8.238	7,342.894	0	0.100588	0.122097	0.076653	0.124522
Pulse	assumed	1.738	0	–3.718	37,436	0	0.055591	0.014952	–0.084897	–0.026285
	not assumed			–3.881	8,951.312	0	–0.055591	0.014325	–0.083671	–0.027512

statistically significant at α ≤ 0.05, EMG – electromyography

to the fact mentioned earlier it is not possible to confront the results with corresponding forest management outputs on a larger scale. However, analyses conducted by Fiľo (2014) in forwarder operators confirm the increasing physiological workload in afternoon shifts, affected from 15–65% primarily by cabin type, terrain conditions, growing tiredness and changes in sun exposure. With respect to our analyses of harvester operators in relation to the production stage of work operations, a growing degree of physiological workload can be confirmed not only in relation to the type of working operation but also with increasing working time. This analysis thus corroborates the risk of decreasing work performance in relation to working time, as expressed in a performance curve (e.g. Doležal et al. 2012), where physiological workload undoubtedly affects performance as well.

Seen from the perspective of occupational hygiene it is therefore important to balance and alternate individual working operations in the course of a work shift and include breaks to calm down the monitored parameters. The presented study will be followed by further measurements with the objective to identify the relation between changes in individual variables and growing work experience of operators. The study has its limits (in this particular case we process values from a single operator measurements), yet the results obtained prove to be a source of inspiration for follow-up, more detailed analyses in the form of case studies as well for the innovation of analyses and maximum workload control, as defined by the government Decree No. 361/2007 Coll.

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Table 5. Statistically significant difference between the felling and ride work operations

	Equal variances	Levene's test		*t*-Test for equality of means						
		F	Sig.	*t*	*df*	Sig. (2-tailed)	mean difference	std. error difference	95% confidence interval for mean	
Surface muscle tension (EMG 1)	assumed	273.329	0	20.981	31,637	0	0.254339	0.012122	0.230579	0.278100
	not assumed			24.020	11,039.480	0	0.254339	0.010589	0.233583	0.275095
Surface muscle tension (EMG 2)	assumed	1,004.486	0	–26.110	31,637	0	–0.369870	0.014166	–0.397636	–0.342105
	not assumed			–21.601	7,679.679	0	–0.369870	0.017123	–0.403436	–0.336304
Temperature	assumed	670.046	0	14.668	31,637	0	0.151430	0.010324	0.131194	0.171665
	not assumed			12.238	7,729.250	0	0.151430	0.012374	0.127174	0.175685
Pulse	assumed	317.996	0	–7.688	31,637	0	–0.096590	0.012565	–0.121217	–0.071963
	not assumed			–6.895	8,208.330	0	–0.096590	0.014008	–0.124050	–0.069131

statistically significant at α ≤ 0.05, EMG – electromyography

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