ForHeal Forestry Higher Education Advancement in Laos

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Occupational Safety and Health in Forestry

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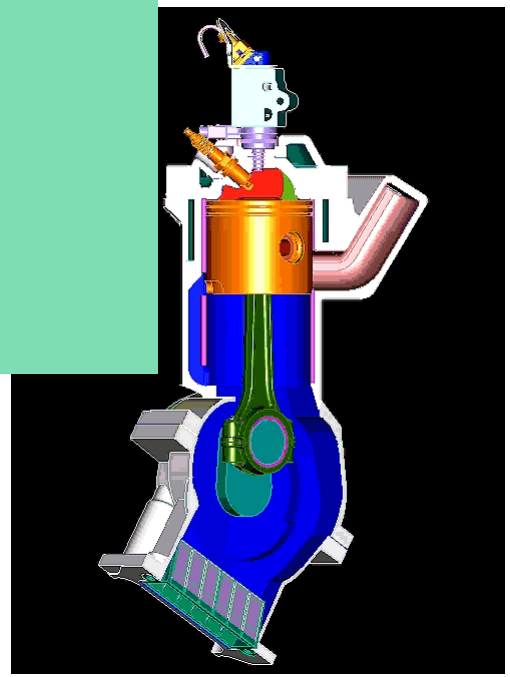
Safety

CHAINSAW OPERATOR VIBRATION EXPOSURE

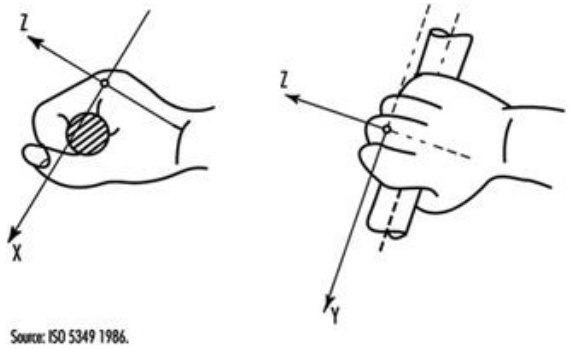
Exposure to hand-transmitted vibrations



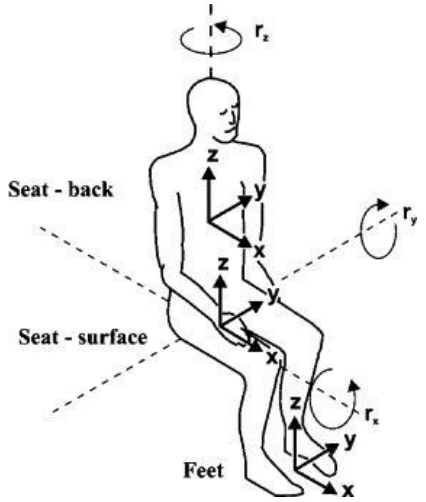
Vibration

- Oscillation motion of a body around an equilibrium point
- Oscillation motion: change of direction and acceleration and deceleration of a body at various points of the path
- Similar to noise in its nature: both are mechanical oscillations
- Can be a manifestation of the functional part of a system, its drive gear or both – chain saw

Exposure to hand-transmitted vibrations



Source: ISO 5349 1986.



- Vibrations in the environment are undesirable: human body is not adapted to them
- They are a hazard to the life of workers
- They decrease the productivity
- Depending on their direction, we know:
  - Vertical
  - Horizontal
- Depending on the place of transmission, we know:
  - Hand-arm transmitted vibrations
  - Whole-body vibrations
  - Locally transmitted vibrations

Effects of vibrations on human body

- Their effects depend on the place of transmission and their characteristics
- All vibrations can cause: loss of balance, blurred vision, inability to focus, premature fatigue

Whole-body vibrations

- Negative effects on spine
- Deteriorate intervertebrate discs
- Degenerate vertebrae
- Cause osteoarthritis
- Cause digestion problems
- Cause migrains
- Cause hemorhoids

Hand transmitted vibrations

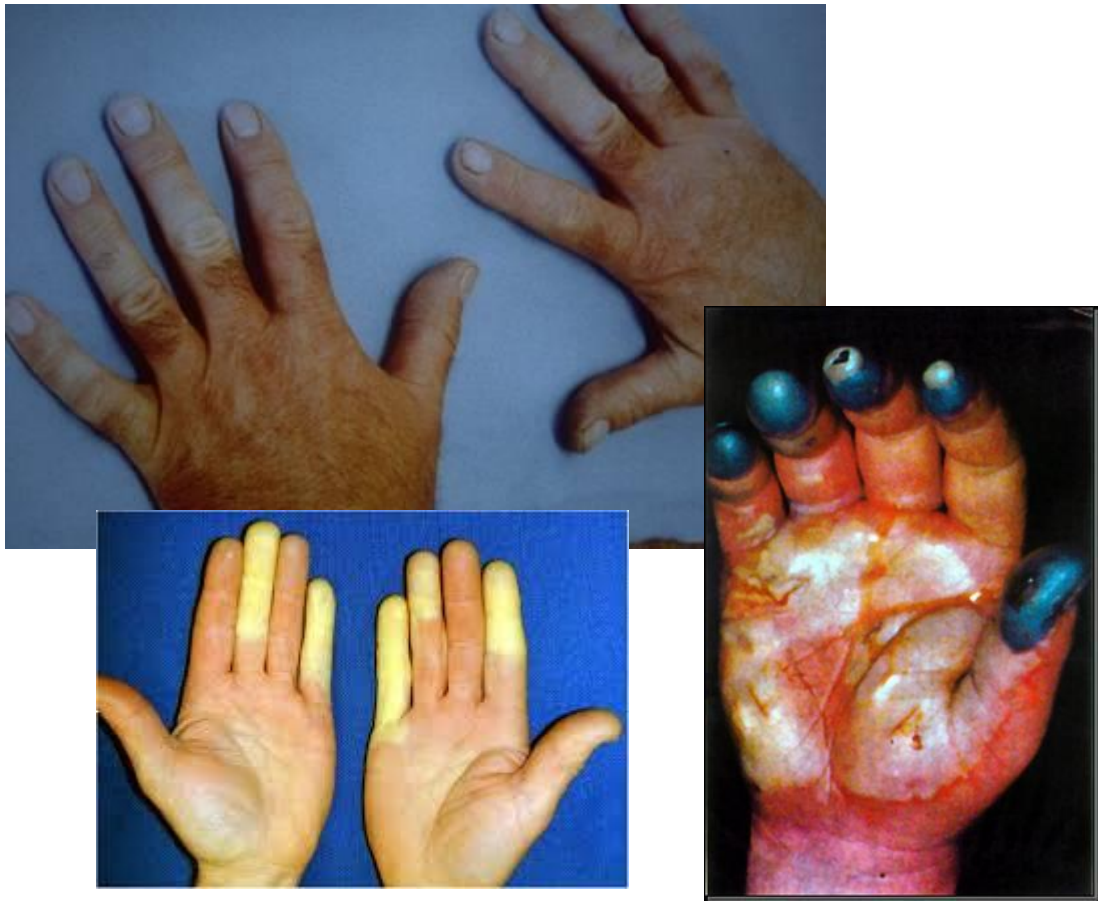
- Damage the vascular system
- Damage the peripheral nervous system
- Cause vasoneurosis
- Damage the nerves of the hand
- Cause muscle diseases
- Cause bone and tendon diseases

(mainly vibrations up to 50 Hz)

Legislation on vibrations in the EU

- Protection against vibrations is regulated by the Government regulation n. 272/2011 Sb. On health protection against undesirable effects of noise and vibrations
- GR set the limits for vibration exposure
- The exposure limit for hand transmitted vibrations is
  - $a_{hv,\,8h}=2.5\ m\ s^{-2}$

Vasoneurosis: whitefinger disease



- Vascular disease caused by vibrations
- At first, it affects the distal phalanges of the fingers
- Cold environment aids development
- Whitening persists until blood-vessels are expanded by heat
- The effects are
  - Loss of finger sensitivity
  - Tingling sensation in fingers
- After whitening, gradually fingers turn blue and gangrene sets in (very unlikely)

Vasoneurosis: Stockholm method of evaluation

Stage		Description
0	-	No whitening attacks
1	Light	Seldom attacks affecting the distal phalanges of one or more fingers
2	Moderate	Seldom attacks affecting the distal and intermediate phalanges (very rarely even proximal) of one or more fingers
3	Severe	Frequent attacks affecting all or most fingers
4	Very severe	Same to stage 3, with changes to the skin on proximal phalanges

Other diseases

- Damage of the nerves has similar symptoms as vasoneurosis
  - The cause of the symptoms is different: decreased ability of the nerves to transmit the impulse
- Muscular diseases
  - Connected mainly with grip – locked grip or insufficient grip
- Tendon inflammation

Hand-transmitted vibrations in motor-manual felling

Normalized acceleration of chain saw vibrations based on the species being cut (in $m\ s^{-2}$)

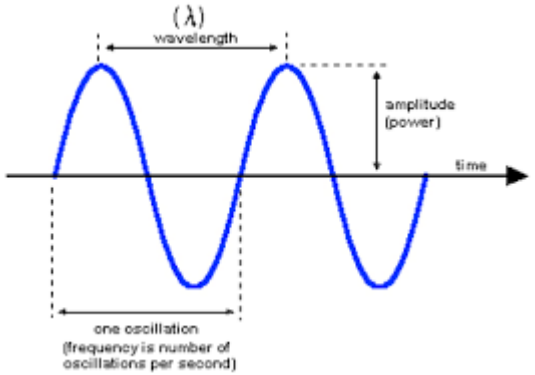
Species	Handle	Husqvarna 346 XP			Husqvarna 357 XP			Husqvarna 372 XP		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Poplar	Rear	4.0	3.7	4.4				3.5	3.2	3.7
	Front	4.9	4.4	5.9	5.9	5.5	6.4	4.1	3.6	4.4
Spruce	Rear	3.8	3.5	4.2	4.3	4.1	4.8	3.4	2.8	4.2
	Front	5.0	4.3	6.1	5.7	5.2	7.1	4.4	3.5	6.6
Beech	Rear	6.3	5.5	7.1	5.2	4.7	5.7	4.4	4.0	5.2
	Front	7.4	6.8	8.4	6.6	6.1	7.2	5.8	4.9	7.9

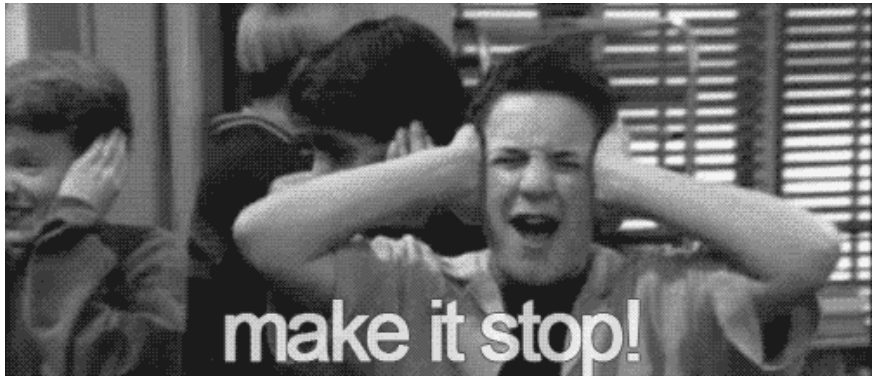
- Exposure of chain saw workers to vibrations exceeds the legislation limit considerably
- **How can they protect themselves against vibrations?**
  - Decrease the duration and level of exposure to vibrations
  - Follow strictly the appropriate work/rest regime
  - Use personal protective devices
  - Keep hands warm and dry

Safety

CHAINSAW OPERATOR NOISE EXPOSURE

Noise exposure





- Sound: mechanical oscillation of an elastic environment
- Expresses as the relative change of pressure in the environment, creates waves that compress and dilute the environment
- Noise is a subset of sound: unpleasant or obnoxious sound

Noise exposure

- Risk of hearing impairment is the function of total energy received by the hearing apparatus
  - Intensity of noise
  - The duration of the exposure
- Causes of noise:
  - Flow of gasses or liquids – molecule movement
  - Vibration of machine parts
  - Mutual friction of bodies
  - Mutual impact of bodies

Basic characteristics of noise

- **Acoustic pressure** (p) – mechanical waves, which causes the occurrence of oscillation of the pressure of the environment. **Human ear can sense acoustic pressure between 20–100 000 000*μPa***.
- **Level of acoustic pressure** (L) – decuple of the common logarithm of the ration of the acoustic pressure (p) and the reference value (p_0) (the smallest audible acoustic pressure of 20*μPa*)

$$L = 10 * \log(\frac{p}{p_0})^2 \ [dB]$$

- **Level of sound A** (L_A) – is the level of acoustic pressure corrected by the frequency weight filter A
- **Equivalent noise level A** (L_{Aeq}) – is the characteristic given by time distribution of the L_A :

$$L_{Aeq} = 10log\frac{1}{T}\int_{t1}^{t2}\left[\frac{p_A(t)}{p_0}\right]^2 dt \ [dB],$$

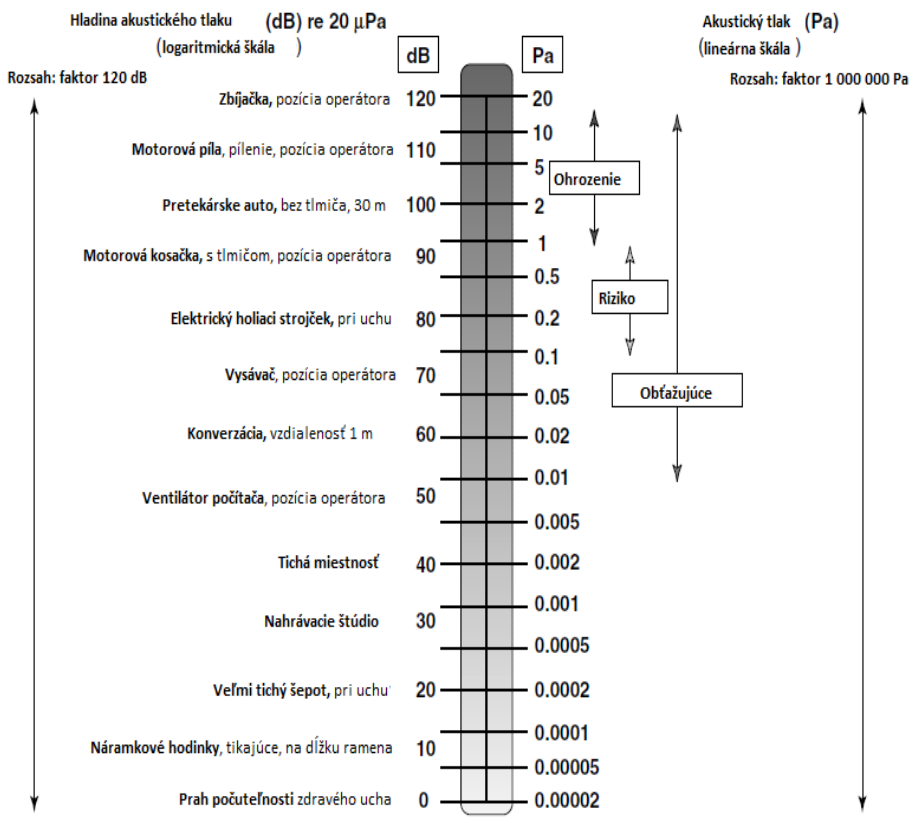
where

$p_A(t)$ – temporal function of the instantaneous acoustic pressure weighed by A filter [*Pa*],

T – duration of the integration, $T=t_2-t_1$,

P_0 – reference acoustic pressure of 20*μPa*

Decibel



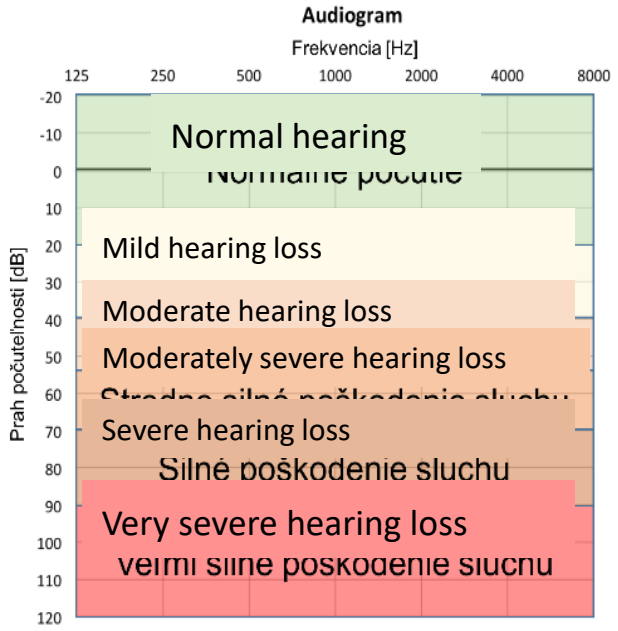
- The most common unit in acoustics is the decibel
- It is a logarithm of the ratio of one characteristic and a reference characteristic of the same type
- The range of 0-120dB includes the range of 1 000 000 Pa
- Increase of sound level by 6dB means the energy received by the ear doubles

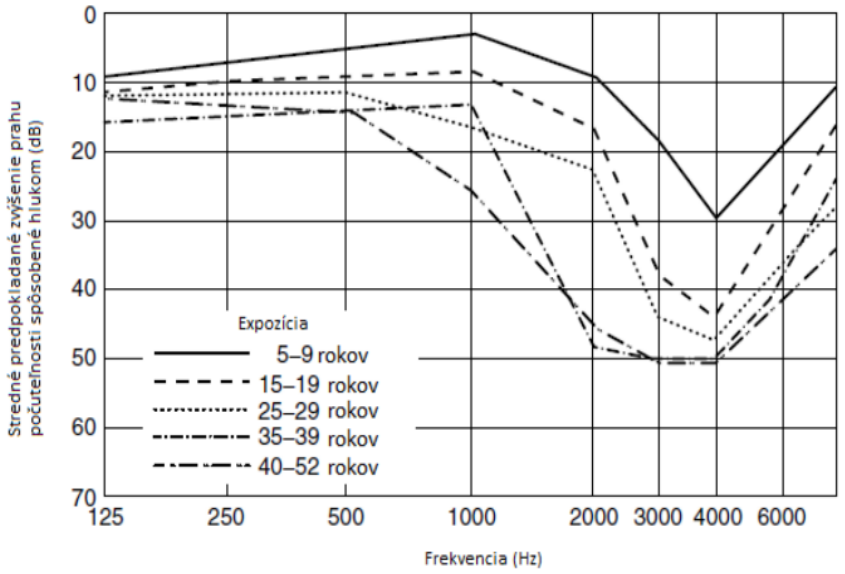
Effects of noise

- Long-term stimulation of the hearing apparatus causes its fatigue
- Temporary or permanent hearing threshold shift can occur
- At extreme noise levels, acoustical trauma can occur
- Deterioration of mental and physical performance
- Mental lability
- Decreased ability to focus (increased risk of accident)

Effects of noise

- Exposure to noise has cumulative effects
- Hearing threshold shift occurs gradually, frequently the problem is handled only when it is already late





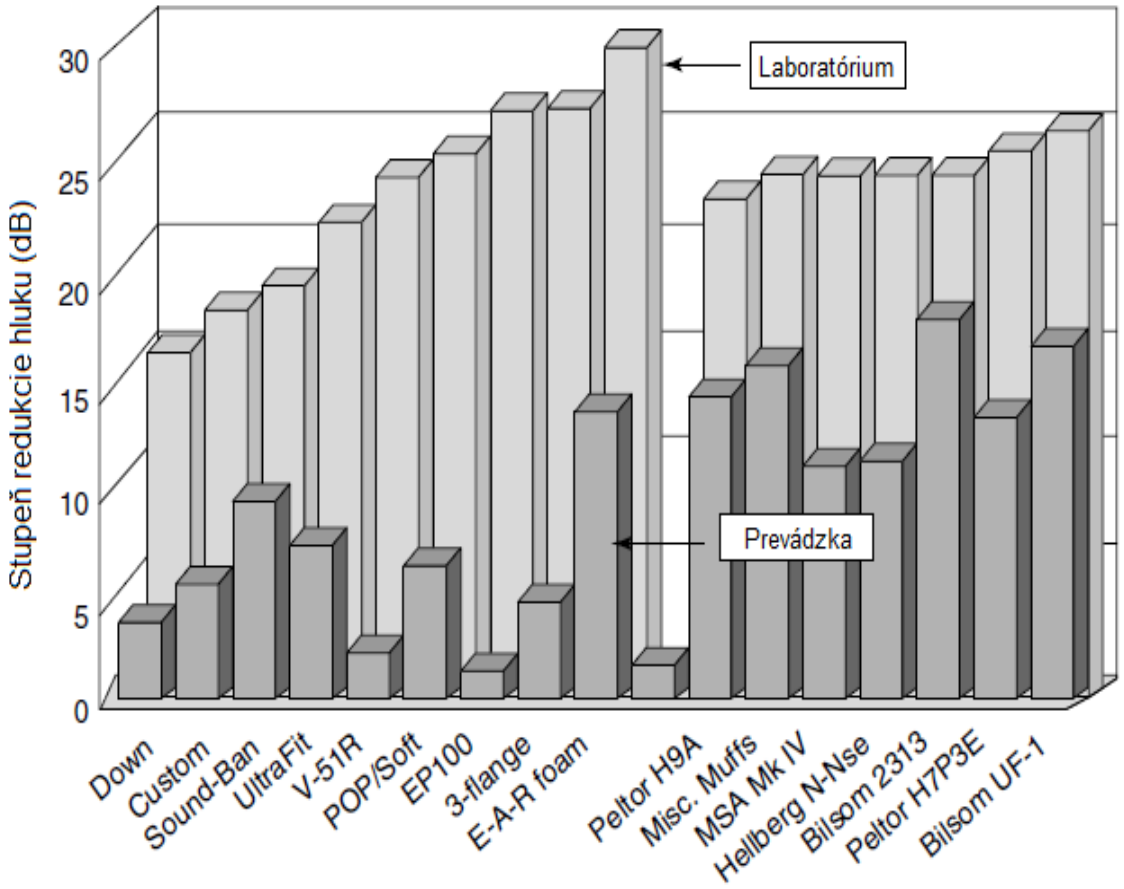
Legislation on noise in the EU

- Hearing protection is regulated by the Government regulation n. 272/2011 Sb. On health protection against undesirable effects of noise and vibrations
- GR set the limits to noise exposure
- Permissible exposure limit for steady and variable noise is $L_{Aeq,\ 8h}$=85 dB
- Permissible exposure limit for impulse noise is set by the peak noise level L_{Cpeak}=140 dB

Hearing protection

- Noise dampening working procedures help
- Select appropriate work tools with low noisiness
- Decrease the noise by technical means (shields, veils, covers, insulations, etc.)
- Change the work organization focused on limiting exposure
- Use hearing protection devices

Personal protective devices



- Using HPDs is the last instance in hearing protection
- The range of dampening varies a lot
- The employer is obligated to give hearing protection to its employees
- Protectors have to be designed in such way that they dampen the noise and at the same time enable hearing the warning signals

Safety

CHAINSAW OPERATOR ENERGY EXPENDITURE

Energy expenditure: motor-manual felling

- The extent of muscular strain correlates with changes of the circulatory and respiratory systems
- Energy expenditure can be observed by
  - The change of hear rate
  - Measuring the volume of exchanged air (ventilometry)
  - Analyzing the respiratory gasses (indirect calorimetry; the most precise method)

Heart output at muscle outputs

Muscle output	Heart rate [BPM]	Mean systolic volume [ml]	Mean minute output volume [l]	Minute lung ventilation [l]	Minute oxygen consumption [l]	Minute energy expenditure [kJ] (gross)
Rest (seated)	70	70	4.9	6–8	0.2–0.3	4.2–6.3
Small	75–95	85	7.0	9–15	0.4–0.8	6.7–16.7
Mild	96–115	105	11.0	16–22	0.9–1.2	17.2–25.1
Moderate	116–130	120	14.5	23–30	1.3–1.8	25.5–37.6
Large	131–150	140	19.5	31–40	1.9–2.4	38.1–50.2
Very large	>151	>150	>22.0	>41	>2.5	>50.7

Net energy expenditure

- The measure of loading of dynamic physical work
- Given by the limit of permanent output, cca 33% of the aerobic capacity $V_{O2,\ max}$
  - About 3.1 *l* min^{-1} for men and 2.05 *l* min^{-1} for women
  - It is the mean loading that a healthy person can manage per shift without greater fatigue or overloading

Energy expenditure: harvesting operations

Forest harvesting	Energy expenditure (net)					Heart rate			
	Min	Max	Mean			Min	Max	Mean	
								gross	net
	W			kJ min^{-1}	kcal min^{-1}	BPM			
Walking with a chain saw (summer)	224.3	301.3	260.7	15.6	3.7	106.7	115.0	109.7	33.0
Walking with a chain saw (winter)	269.3	407.0	344.7	20.5	4.9	116.3	129.0	122.0	44.7
Felling	195.0	356.0	271.0	16.2	3.9	108.0	128.0	114.0	38.0
Limbing	258.0	381.0	317.0	19.0	4.5	112.0	129.0	120.0	43.0
Measuring	189.0	277.0	219.0	13.1	3.1	106.0	112.0	109.0	32.0
Bucking	204.0	377.0	284.0	17.0	4.1	105.0	119.0	111.0	34.0
Carrying stackwood	314.0	475.0	373.0	22.4	5.4	111.0	142.0	127.0	49.0
Skidding with LKT 81, drive unloaded	100.0	162.0	144.0	8.6	2.1	78.0	88.0	84.0	14.0

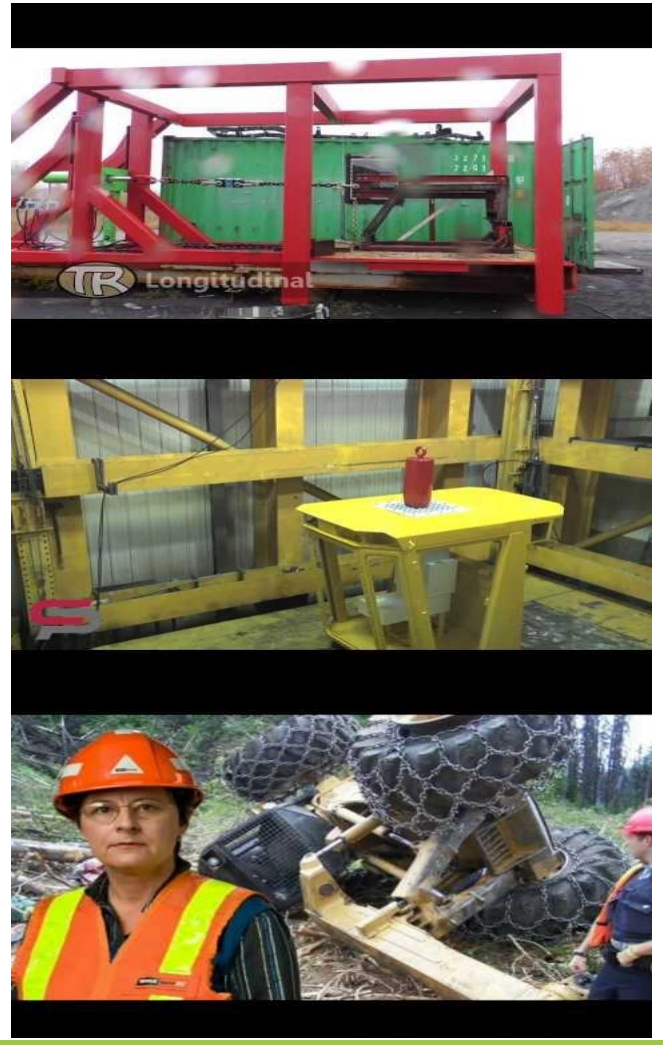
- Doplnit energeticky vydaj pre ine pracovne pozicie ako pilcik

U VÍCEOPERAČNÍCH TECHNOLOGIÍ

SAFETY AND HEALTH IN CTL TECHNOLOGIES

Machinery design requirements

- Cab
  - Suspension according to ISO 8797
  - Controls adjustable to operator physiology
  - Cab entry/exit designed according to anthropometric data
  - Cabs equipped with ROPS and FOPS systems (min. ISO 3471; 8082; 8083)
- Cabs equipped with first aid kit, fire extinguisher



Drive and operational systems

- Engine equipped with an immediate stop system
- Starter connected to the clutch or gear box, to prohibit starting with gear in
- Exhaust equipped with spark catcher (not applicable to turbo charged engines)
- Mininmum 20% of machine weight must load the steering axle

Machine operation and maintenance

- Operator must be a holder of all necessary certificates
- Operator must have seat belt on during machine operation
- Nobody besides the operator can be in the cab
- Before hydraulics systems maintenance
  - Make sure the system is shut down, pumps disengaged, system pressure released
- Mandatory PPE for harvester and forwarder operators
  - Safety boots
  - Closely fitting clothes
  - Safety helmet
  - Noise protectors – over ear

Mechanized harvesting and timber handling

- Reserve harvest for terrains that ensure machine stability
- Work organization
  - Recommend using other than standard shifts
  - Rotation of employee activities, optimization of shift duration, etc.
  - Helps mental overexertion, muscle problems, etc.
- If possible, refrain from lateral slopes
- Functional parts of the machines must be in safe position before drive
- Pile processed timber so that chance of spontaneous movement is minimized
- Park on level surfaces, with park gear and brake engaged

Timber forwarding

- Load should be of similar length
- Do not work in slopes greater than 35%
- Minimize drive in lateral slopes
- Loading adjusted to local conditions
- Check brake function and engage differential lock before steep downhill drive

Ergonomics in forestry

- Understanding of human behavior and interactions with socio-technical systems and their application when designing the work environment
- Need to apply ergonomic processes in forestry
- Forestry – dangerous sector
  - Work in exterior
  - Rough terrains
  - By dangerous tools
  - Fatal accident risk 2x higher than in construction industry

Work environment

- Set of all conditions in which work is done
- Factors are varied in character; divided to:
  - Physical
  - Chemical
  - Biological
  - Psychosocial
  - Economic
- Some factors cannot be influenced in forestry
- Synergies of multiple factors occur
- In forestry, evaluation and adjustment of mainly:
  - Vibro-acoustic component of the work environment

MODELS OF COMPLEX LOADING BY THE WORK ENVIRONMENT

Research goals

- Construction of a mathematical model for prediction of complex loading by the work environment
  - Select factors that explain the relationship between the worker and work environment,
  - Select a mathematical model suitable for such evaluations of the work environment,
  - Measure data with sufficient quality for statistical evaluation,
  - Construct a model, verify it for suitability in teaching and practice

Selection of independent variables

Factors of the work environment

Personal traits of the operators

Factors of the work environment

- Whole-body vibrations
  - X_1 Normalized accel. of vibration $a_{wbv,\ 8h,\ a}$ ($m.s^{-2}$)
- Noise exposure
  - X_2 Equivalent noise pressure level $L_{eq,\ a}$ (dBA)
  - X_3 Peak noise pressure level $L_{CPk,\ c}$ (dBC)
- Microclimate
  - X_4 Operativní teplota v kabině stroje t_o (°C)
- Illumination in the cab
  - X_5 mean illuminance in the cab E_{mean} (lx)
- Mental loading
  - X_6 Meister questionnaire

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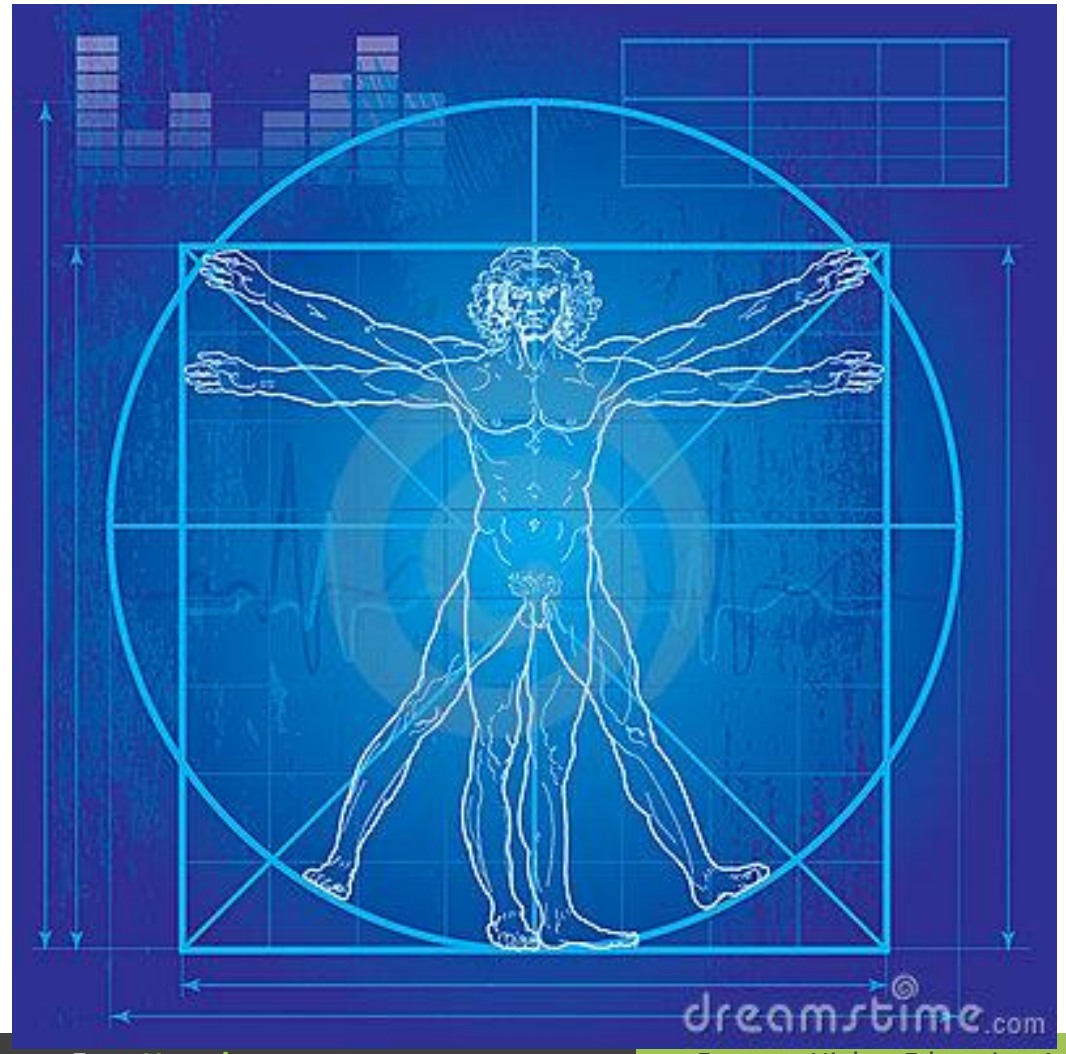
Personal traits of the operators



- X_7 Age (y)
- X_8 Weight (kg)
- X_9 Height (cm)
- X_{10} Experience (y)

Selection of the response variable

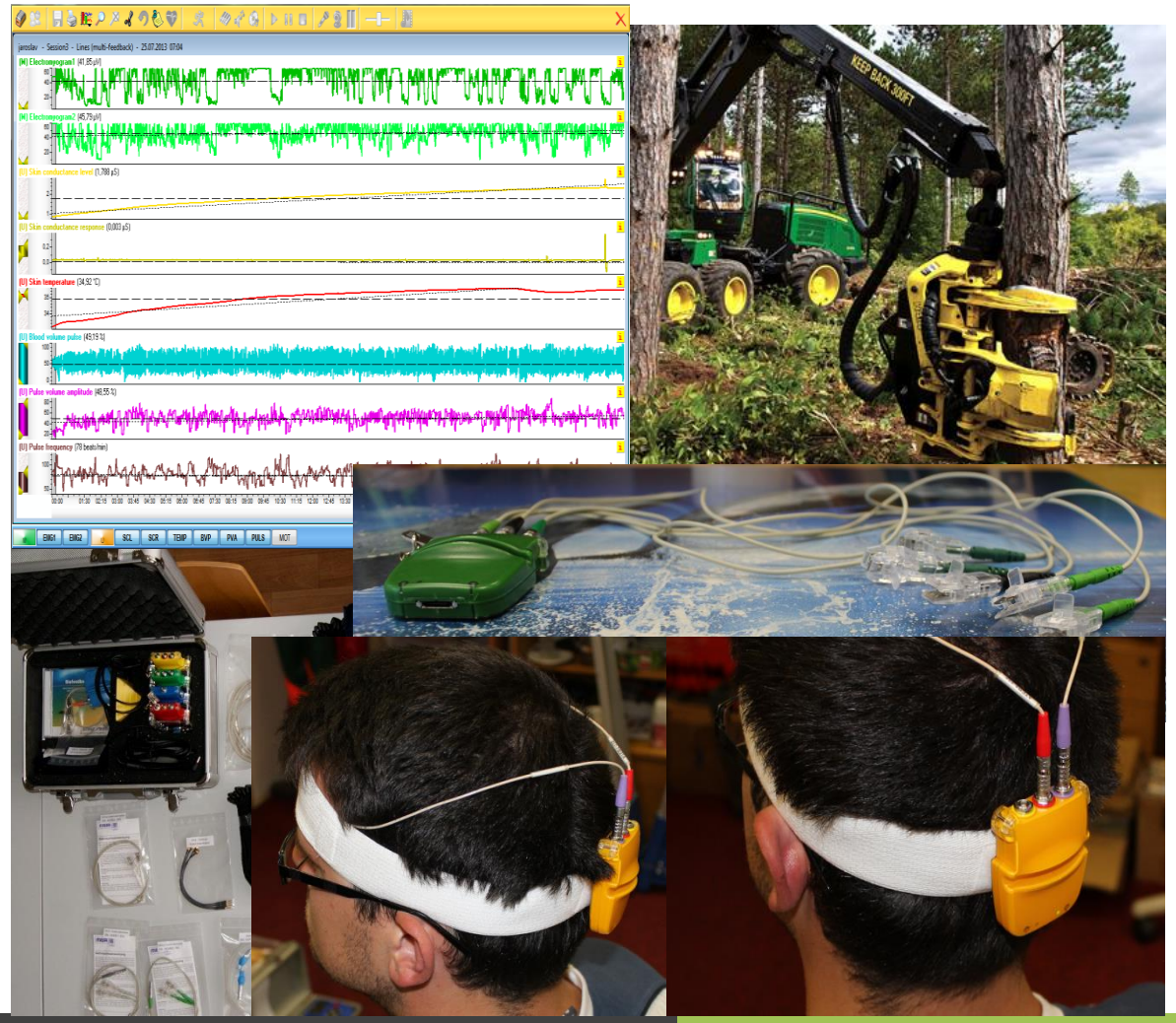
Requirements

Variable selected

Requirements – response variable

- Reacts to all independent variables
- Changes reflect the degree of health risk
- Measurable
- Method of risk evaluation available

Response variable



- Binary variable “Work risk“
- Based on the heart rate of the workers
- Evaluation of “Work Risk” according to GR 542/2007 Z.z.

Measurements

Method

Measurement method

- Measurement at full operation of the machines
- Data collection throughout the shift
- Three measurement procedures
  - Continuous
    - Noise
  - Sampling
    - Heart rate
    - Whole-body vibrations
    - Microclimatic conditions
    - Illumination
  - Questionnaire survey
    - Mental loading
    - Personal traits of the operators

Data processing and measurement outcomes

Heart rate

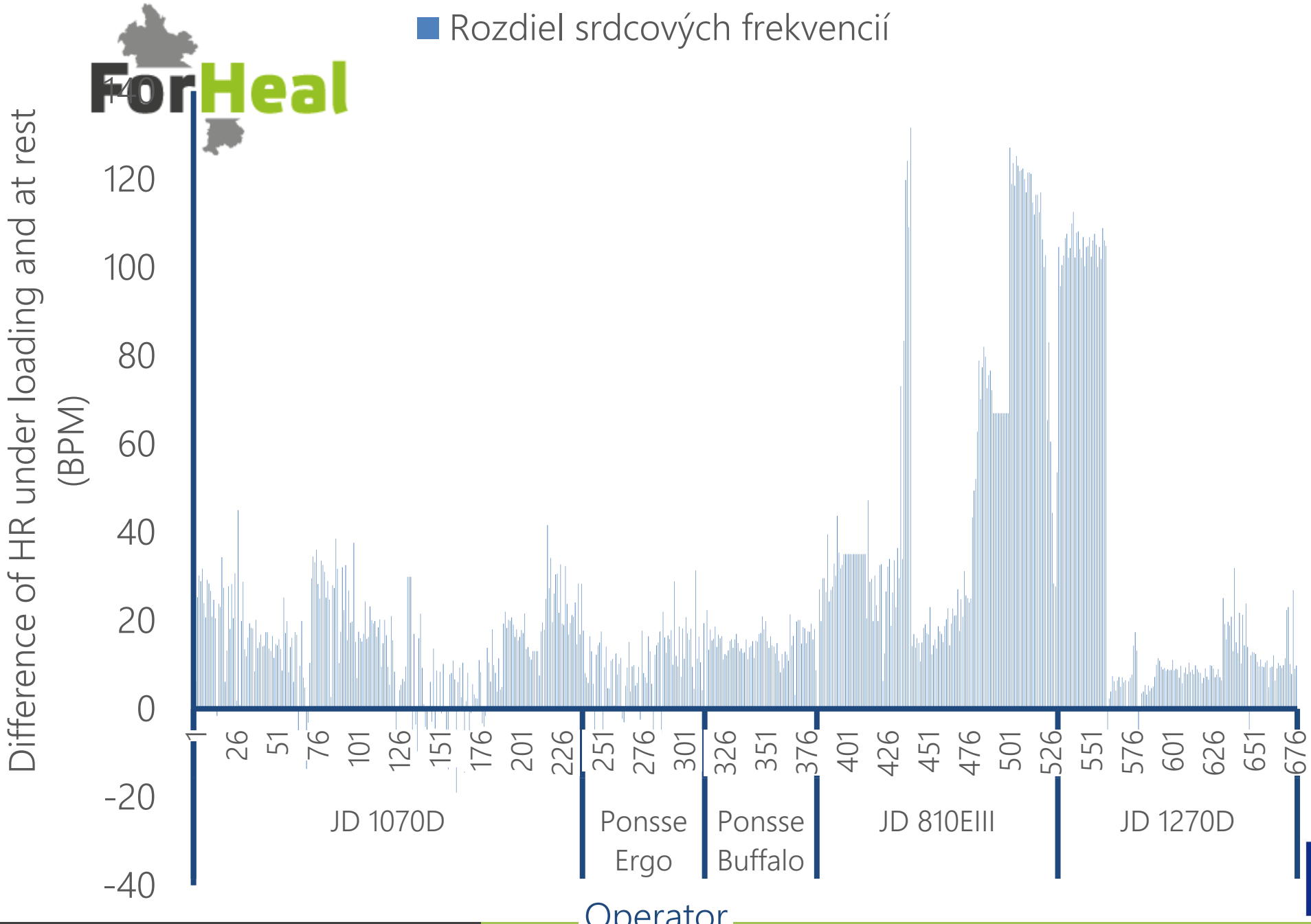
Vibrations

Noise

Microclimate

Illumination

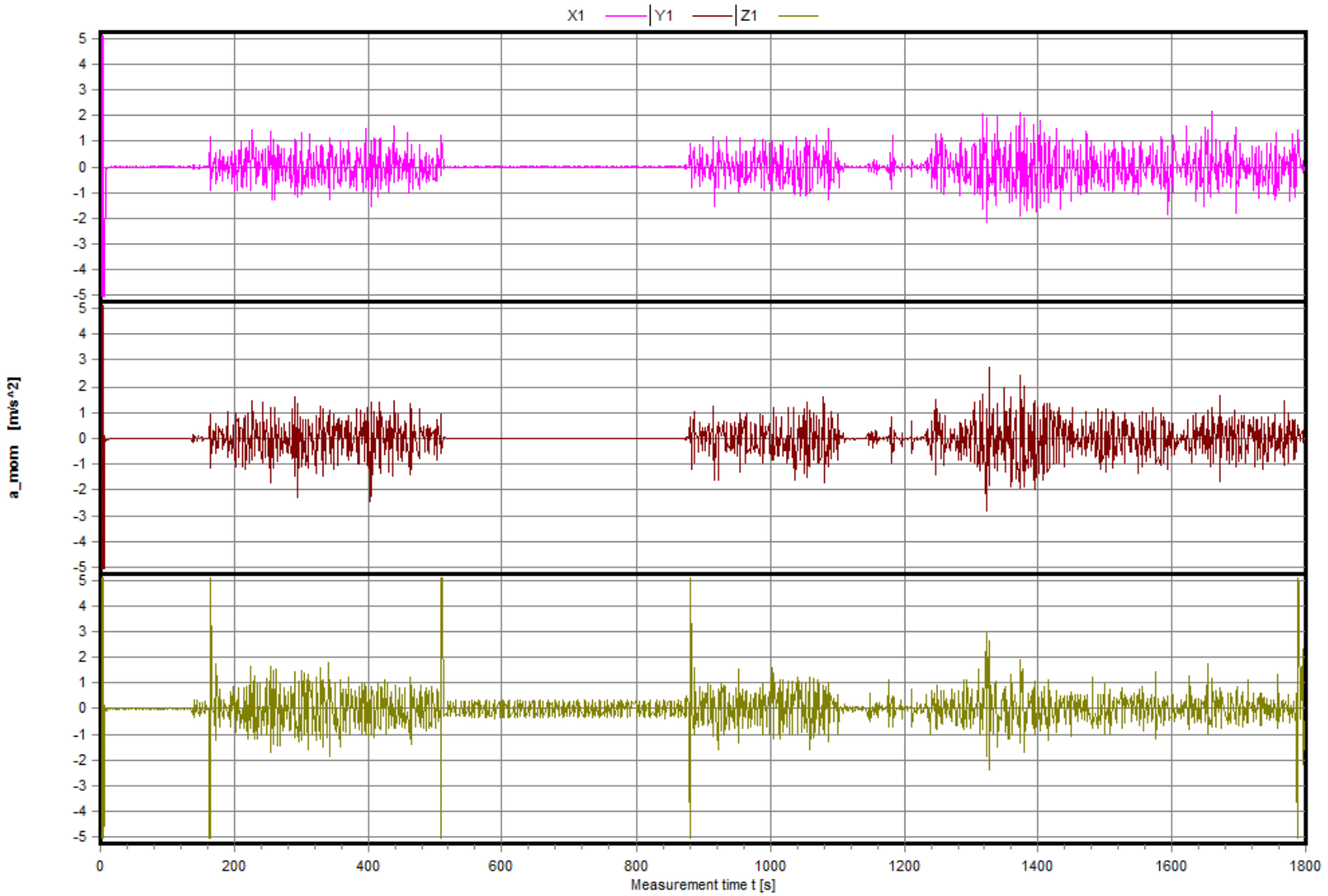
Mental loading



Heart rates of the operators

Values sorted according to operator ID

Peak values measured for operators of JD 1270D a JD 810 ECOIII



Whole-body vibrations

Total

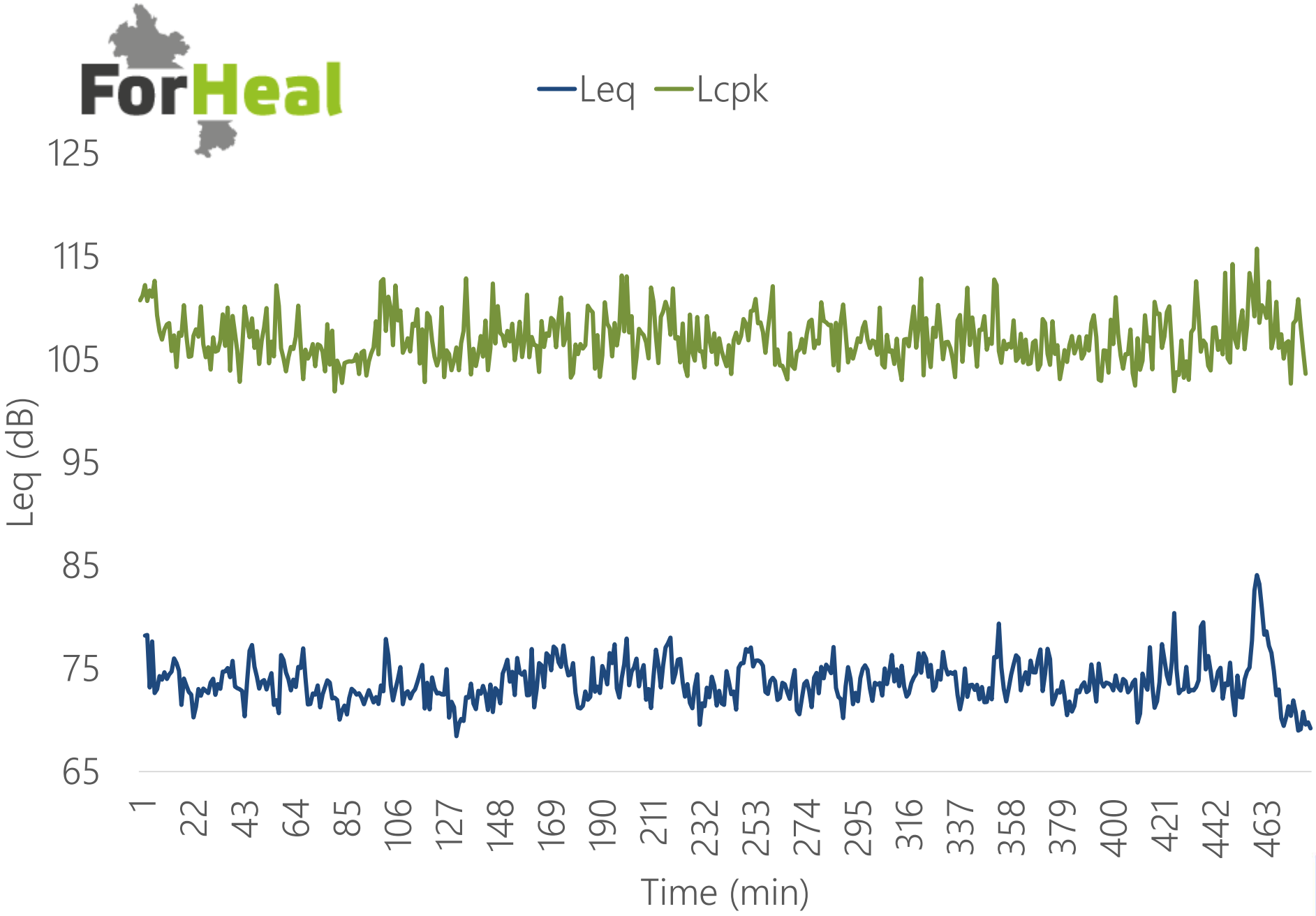
0,52 $m.s^{-2}$

Harvesters

0,48 $m.s^{-2}$

Forwarders

0,61 $m.s^{-2}$



Noise

Total

$L_{AEX, 8h}$ 77.79 dB

L_{CPk} 131.34 dB

Harvesters

$L_{AEX, 8h}$ 77.29 dB

L_{CPk} 130.33 dB

Forwarders

$L_{AEX, 8h}$ 78.94 dB

L_{CPk} 133.70 dB

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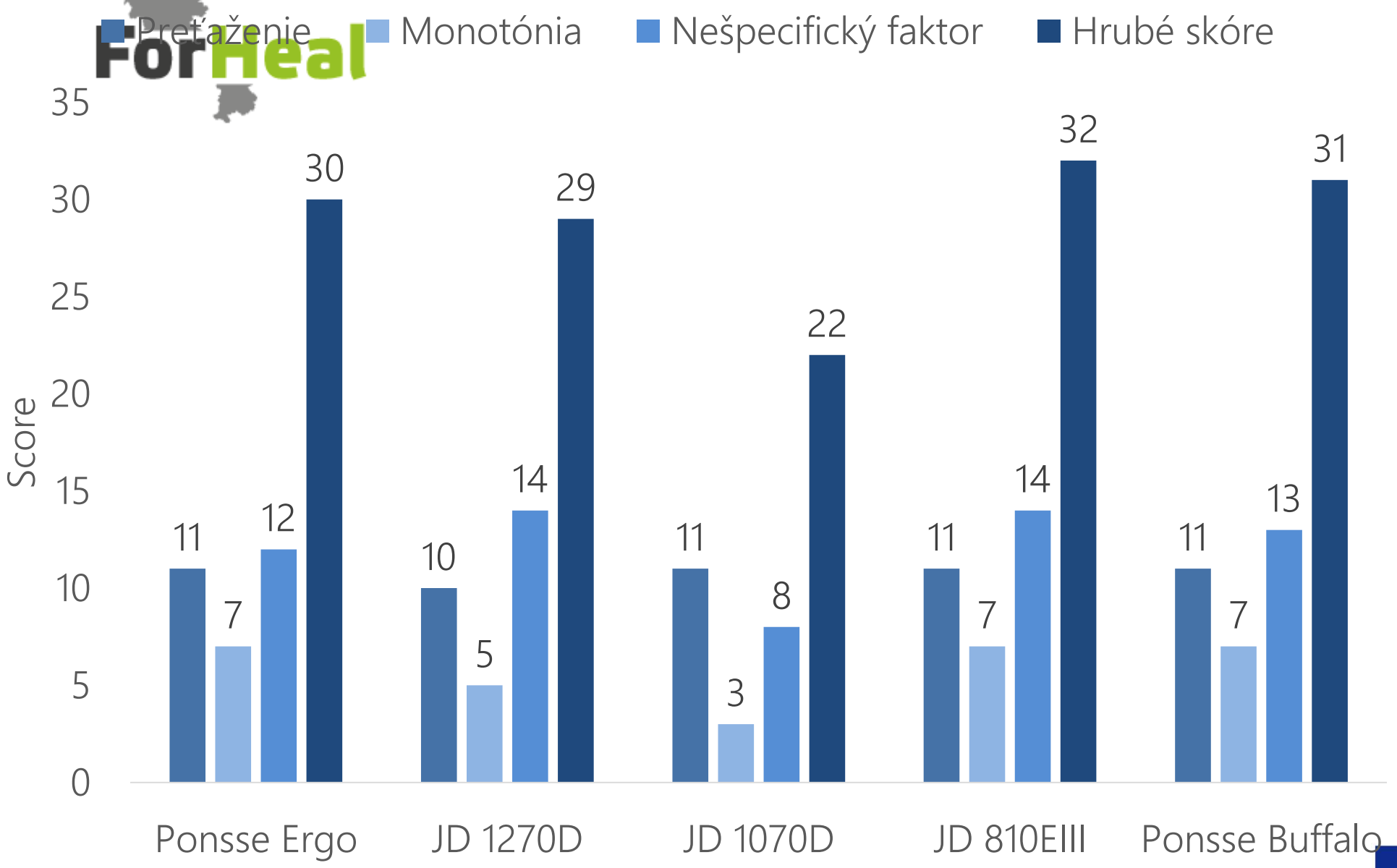
Season	Shift part	E_{mean} (lx)	t_O (°C)
Spring	Start	223	14
	Mid	879	17
	End	45	16
Summer	Start	2886	19
	Mid	2486	26
	End	3301	28
Fall	Start	465	15
	Mid	10114	19
	End	795	20

Microclimate and illumination

Depend on part of shift

Depend on season



Mental loading

Critical median reached for:

- Time stress
- High responsibility
- Problems and conflicts
- Nervousness
- Salience
- Exhaustion
- Long-term bearability

Model construction

Forward stepwise analysis

Multiple regression and correlation analysis

Model equation

Forward stepwise multiple regression

Variable	Step	Multiple R	Mult. R^2	Change R^2	F for integr. eradication	p	Integrated variables
x_8	1	0,412239	0,169941	0,169941	138,3998	0,000000	1
x_1	2	0,507839	0,257900	0,087959	80,0061	0,000000	2
x_5	3	0,526194	0,276880	0,018980	17,6905	0,000030	3
x_2	4	0,537048	0,288421	0,011541	10,9152	0,001004	4
x_6	5	0,544584	0,296572	0,008151	7,7867	0,005413	5
x_4	6	0,566445	0,320860	0,024288	23,9970	0,000001	6

Statistically significant values are bold

- Sample n 678 cases
- Six independent variables integrated into the model

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Multiple regression

$R = 0.57\ R^2 = 0.32$ Upr. $R^2 = 0.31\ F = 52.836\ p < 0.0000\ S_x = 0.35835$

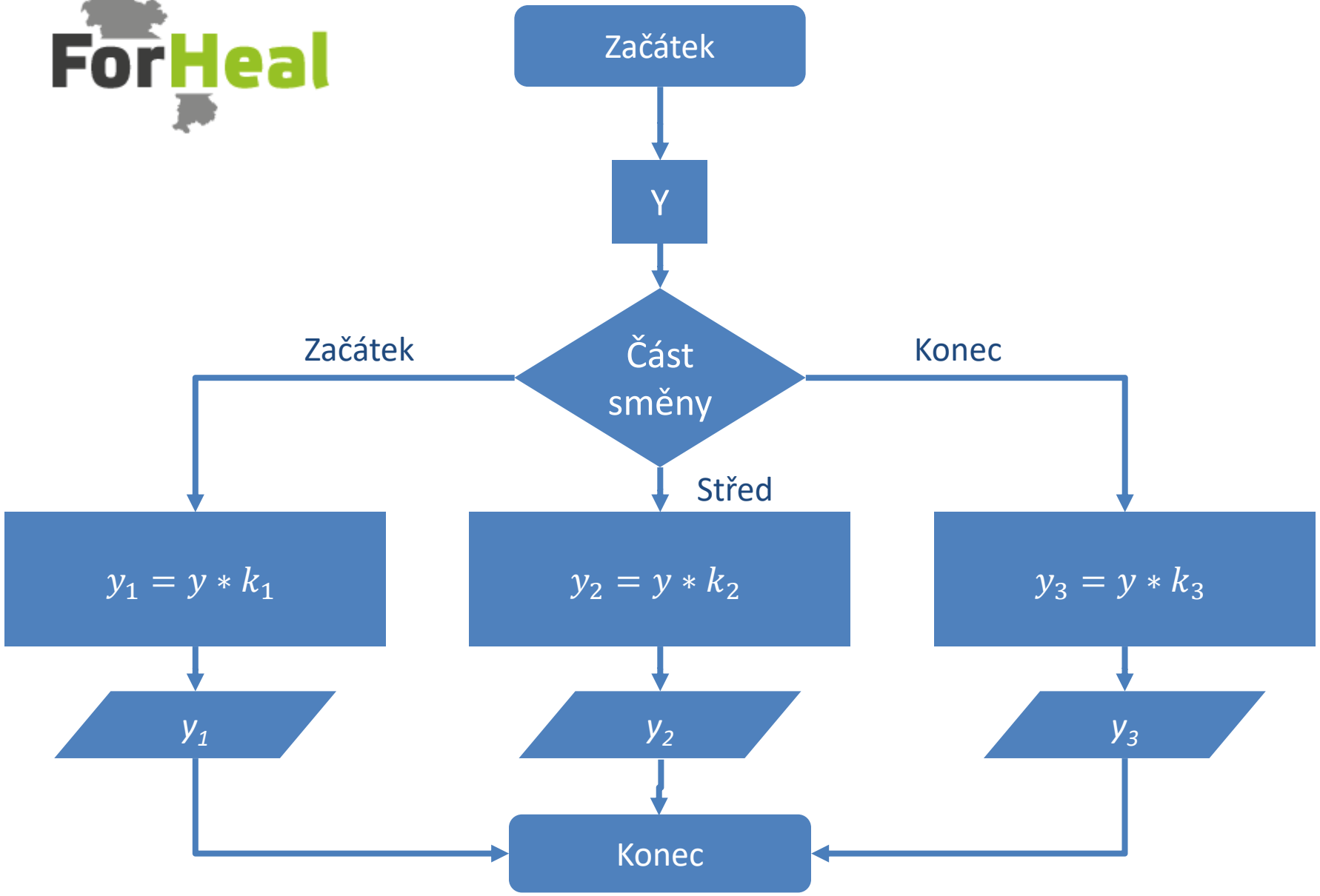
Variable	Beta	Mean Beta dev.	B	Mean B dev.	t (671)	p
intercept			-1,47563	0,225469	-6,5447	0,000000
x_8	0,249274	0,043212	0,00772	0,001338	5,76863	0,000000
x_1	0,215898	0,033738	0,57822	0,090358	6,39922	0,000000
x_5	-0,152023	0,032748	-0,00002	0,000003	-4,64226	0,000004
x_2	0,096786	0,032857	0,00636	0,002160	2,94569	0,003334
x_6	0,231390	0,043613	0,02392	0,004509	5,30552	0,000000
x_4	-0,231711	0,047301	-0,02193	0,004476	-4,89868	0,000001

Statisticky významné hodnoty jsou označeny tučným písmem

Model prediction equation

$$y = 1.47563 + 0.57822x_1 + 0.00636x_2 - 0.02193x_4 - 0.00002x_5 + 0.02392x_6 + 0.00772x_8$$

y – dependent variable,
x_1 – norm. whole-body vibrations acceleration ($m.s^{-2}$),
x_2 – equivalent noise pressure level (dBA),
x_4 – temperature in the cab (°C)
x_5 – mean illumination of the cab (lx),
x_6 – Meister questionnaire output,
x_8 – weight of the operator (kg).



Algoritmization of the model for part of shift

Part of shift significantly affected y

Model Algoritmization through coefficients

k_1 = 1.26

k_2 = 0.69

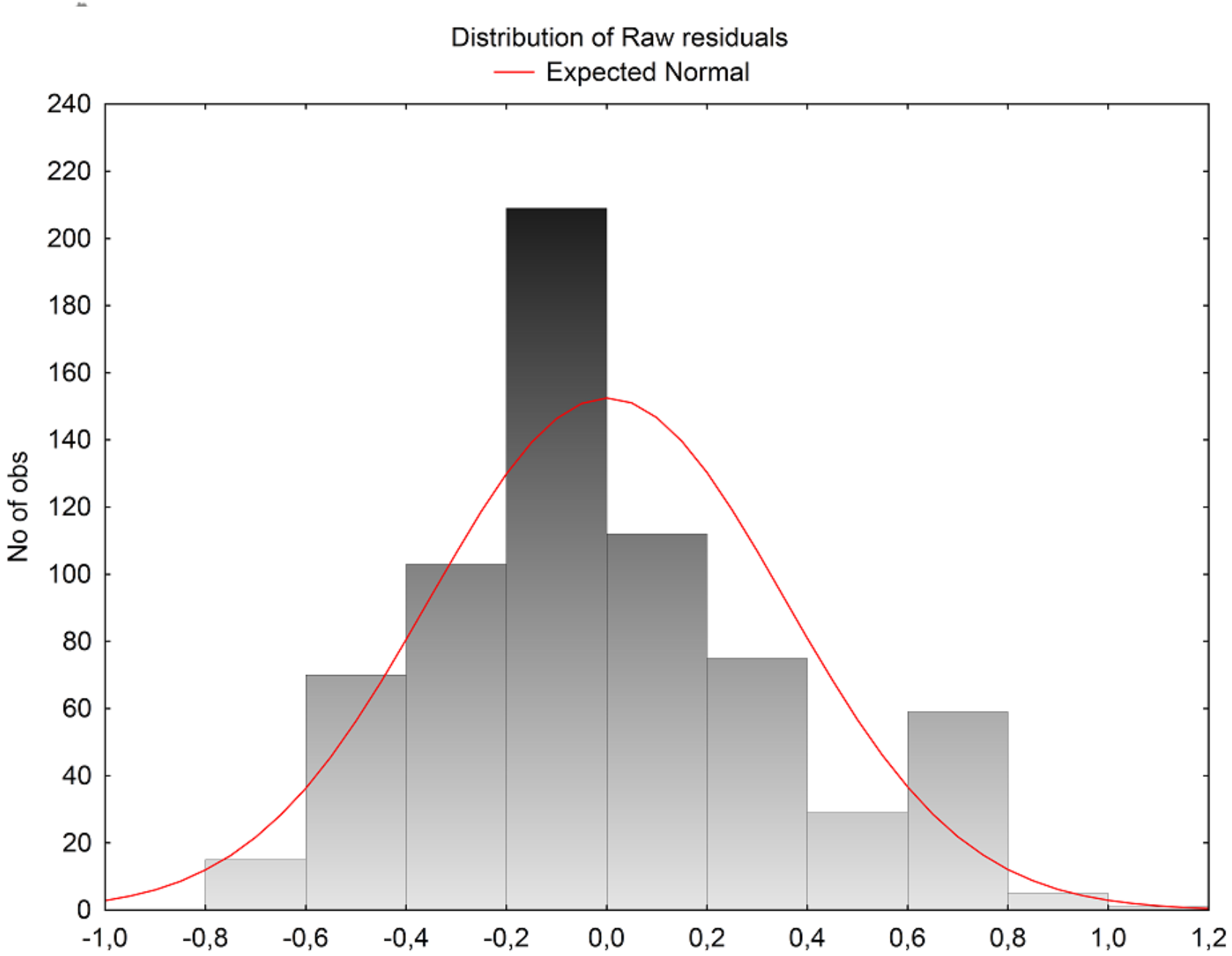
k_3 = 0.97

ANOVA of the model

Effect	SS	Degree of freedom	Mean Squares	F	p
Model	**40.7090**	**6**	**6.784827**	**52.83564**	**0.00**
Rezidual	86.1657	671	0.128414		
Sum	126.8746				

Significant values are bold

- Model explained a significant part of the variability of y



Residuals distribution

Residuals distribution is normal

Minor abnormality in the 0.6 – 0.8 interval.

End of Day 3

THANK YOU FOR YOUR ATTENTION