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Objective and subjective assessment of selected factors of the work environment of forest harvesters and forwarders

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ABSTRACT: This article was aimed at assessment of selected factors of the work environment, which influenced the operators of harvesters and forwarders. The selection of the work environment factors was based on a thorough literature survey. From the survey exposure to whole-body vibrations, noise (equivalent and peak), microclimatic conditions and mental load were selected for detailed observations. The measurements were conducted according to international standards and assessed according to European or national legislation. Subjective assessment of the effects of the work environment was conducted through a structured interview. The exposure to whole-body vibrations was 0.5 $m \cdot s^{-2}$. The equivalent noise exposure was 78 dB, peak noise exposure was 130 dB. The average temperature inside the machine cabs was 17.9°C and average airflow velocity was 0.06 $m \cdot s^{-2}$. Mental load was high according to the Meister questionnaire, three operators considered the load inadequate, two considered it adequate. Subjective assessment showed that operators considered other factors to be light or no load.

Keywords: noise exposure; whole-body vibrations; microclimate; mental load

Work environment is a set of all conditions in which workers carry out their work. It consists of all workers and factors present at the workplace, or of those who have to do with the work and influence the health or comfort of workers. The worker is exposed to many harmful factors which interact and their joint effect can be synergistic or complementary (Schwartz et al. 2013).

Operators of multi-operational machinery carry out their tasks in ergonomically designed cabs capable of partial attenuation of noise and vibrations caused by the machine movement, driving gear, and working parts of the machine. Cabs are also equipped with air conditioning and glare reducing windows. Some factors (e.g. electromagnetic, ionising radiation, various chemical factors, or energy expenditure) do not apply to the jobs of multi-operational machinery operators. Their assessment would only consume time with no significant effect on the overall outcome of the assessment. The nature of work in mechanized logging partially shifted from physical to mental after employment of multi-operational machinery. The need for muscular activity decreased and the need to stay concentrated and alert through long periods grew in importance. Harvester operators have to be able to process a lot of information, react quickly, and retain their concentration in monotonous, repetitive operations (Axelsson, Pontén 1990; Poschen 1993; Gellerstedt 1997; Gellestedt et al. 1999; Tsioras 2012). Operating the machines is quite demanding. According to Gellerstedt (2002), 4,000 control inputs per hour have to be carried out by the operator, due to the lack of automatic functions of the boom and harvester head. Despite the ergonomic design of the cabs, the operators of mobile machinery are exposed mainly to noise (Hansson 1990; Axelsson 1998; Marsili et al. 1998; Nieuwenhuis, Lyons 2002; Messingerová et al. 2005; Sümer 2006; Beuk et al. 2007; Gerasimov, Sokolov 2009; Aybek et al. 2010; Bilski 2013), whole-body vibrations (Boileau, Rakheja 1990; Burdorf, Swuste 1993; Magnusson et al. 1993; Hansson 1995; Huston et al. 1999; Hinz et al. 2002; Paddan, Griffin 2002; Hostens, Ramon 2003; Chen et al. 2003; Sherwin et al. 2004a,b;

Deprez et al. 2005; Kolich et al. 2005; Tiemessen et al. 2007; Li et al. 2008; Gerasimov, Sokolov 2009), microclimatic conditions – mostly temperature, and airflow velocity inside the cab (Gao, Niu 2004; Kaynakli, Kilic 2005; Huang et al. 2006; Mezrhab, Bouzidi 2006; Cengiz, Babalik 2007; Farzaneh, Tootoonchi 2008; Kim et al. 2009; Zhang et al. 2009a,b; Alahmer et al. 2011), and severe mental and sensory load (Axelsson, Pontén 1990; Poschen 1993; Gellerstedt 1997; Axelsson 1998; Yamada 1998; Gellerstedt 2002; Lewark 2005; Ovaskainen 2009). The operators of multi-operational machinery have to work in awkward postures during their work and are in risk of repetitive strain injuries (Grieco 1986; Gellerstedt 1997, 2002; Andreoni et al. 2002; Gerasimov, Sokolov 2009).

The aim of this article is to select key factors of the work environment influencing the operators and assess these factors through objective and subjective methods. The combination of objective and subjective assessment allows a complex view on the state of the work environment. Objective assessment describes the intensity with which the factors manifest themselves, and subjective assessment describes the intensity of reactions of the operators to the factors influencing them.

MATERIAL AND METHODS

In this study, harvesters and forwarders operating in Slovakia and Czech Republic were used. Data was collected on a John Deere 1070D harvester (John Deere Forestry Oy, Joensuu, Finland) (operator No. 1), middle class; a John Deere 1270D harvester (John Deere Forestry Oy, Joensuu, Finland) (operator No. 2), high performance class; and Ponsse Ergo 6W harvester (Ponsse Plc, Vieremä, Finland) (operator No. 3), high performance class. Data was also collected on a John Deere 810D ECOIII forwarder (John Deere Forestry Oy, Joensuu, Finland) (operator No. 4), and Ponsse Buffalo 6W forwarder (Ponsse Plc, Vieremä, Finland) (operator No. 5). Table 1 shows basic characteristics of the machine operators. Table 2 shows the conditions in which the operators worked. To decide which factors affect the quality of the work environment to the greatest extent, a thorough literature review (mentioned in the introduction) was conducted. Based on this review, operator's exposure to whole-body vibrations, exposure to noise, microclimatic conditions, and mental load were selected as factors for further research.

Objective measurements of factors of the work environment. The measurements of exposure to whole-body vibrations were conducted according to the standard STN ISO 2631-1:1999. We assessed the data according to current European legislation (Directive 2007/30/EC). The duration of one measurement was 30 min. To ensure a representative sample three measurements were carried out during one shift – at the beginning of the shift, in the middle of the shift (before the lunch break), and at the end of the shift (before the end of work). Equivalent acceleration of whole-body vibrations ($a_{eq,\,T}$) was measured. This served for the computation of normalized acceleration of whole-body vibrations ($a_{wbv,\,8h,\,a}$).

The noise exposure was measured according to STN ISO 9612:2010. The data was assessed according to current European legislation (Directive 2007/30/EC, 2007/30/EC). These measurements were continuous and lasted for the whole shift during every measurement day. Exposure to equivalent noise (L_{aeq}) was measured, which served for computation of normalized noise exposure ($L_{AEX,\,8h,\,a}$). Exposure to peak noise (L_{Cpk}) was measured in a similar manner.

Table 1. Characteristics of the CTL machine (male) operators

Operator ID	Machine	Age (yr)	Experience (yr)	Qualification	Height (cm)	Weight (kg)	Work organization
1	John Deere 1070D	44	8	John Deere training, certificate for work with hydraulic manipulator	168	91	12 h shift, 7 workdays, 7 rest days
2	John Deere 1270D	48	8	John Deere training, certificate for work with hydraulic manipulator	190	105	12 h shift, 7 workdays, 7 rest days
3	Ponsse Ergo 6W	54	5.5	Ponsse training	173	80	12 h shift, 6 workdays, 6 rest days
4	John Deere 810ECOII	33	8	John Deere training, certificate for work with hydraulic manipulator	185	112	12 h shift, 7 workdays, 7 rest days
5	Ponsse Buffalo 6W	35	6	Ponsse training	170	67	12 h shift, 3 workdays, 3 rest days

Table 2. Characteristics of the conditions in which the machines were employed

Operator ID	Weather	Terrain		Stand				
	temp. (°C)	slope (%)	soil type	stand No.	age (yr)	harvest type	volume (m^3)	
							avg. stem	harvest
1	10	25	cambisol	303	60	thinning	SM 0.01	448.38
2	14	0	podsol	57	90	incidental	BO 0.01	303.89
3	25	12	cambisol	805J13	110	regeneration	SM 0.95; SMC 1.90; BO 1.76	393
4	16	0	podsol	57	90	incidental	BO 0.01	303.89
5	27	12	cambisol	805J13	110	regeneration	SM 0.95; SMC 1.90; BO 1.76	393

SM – *Picea abies*, BO – *Pinus sylvestris*, SMC – *Larix decidua*

The exposure to heat and cold, and exposure to airflow velocity were measured according to current Slovak legislation (544/2007 Coll.), as there is no internationally acknowledged legislation for assessment of thise factors. Before each measurement, if there was a perceivable difference between temperature in the cab and outside, the device was placed inside the cab in order to avoid inaccuracies in the measurements. After the device warmed up (or cooled down) to the approximate ambient temperature inside the machine's cab, the measurements started. During one shift, three measurements were carried out (the same procedure as with the measurements of whole-body vibrations was applied). Because the measurement device was too bulky to be stored inside the machine cabs during actual work, microclimatic conditions were measured during short breaks when the operator was outside the cab of the machine. The measurement interval was five minutes. Such a short interval was chosen because longer intervals would interfere with the work of the machine operators and therefore with other measurements conducted simultaneously. When the measurements ended, the globe temperature probe was stored inside the cab, so that it would not have to be acclimated again. Operational temperature inside the cabs (t_o) and airflow velocity (v_a) were measured.

The mental load of the operators was measured through the Meister questionnaire (Meister 1975). The questionnaire is a basic screening tool for mental load assessment. The questionnaire has three parts – overloading, monotony, and nonspecific factor. The gross score ranges from 10 to 50 points (the higher the score, the higher the mental load). The outcome of the questionnaire depends on sex and age of the inquired person. The questionnaire divides mental load into three categories: favourable load – the subjective state of the operator and his mental health are not likely to be affected by work; adequate load – the employer can expect regular changes in productivity and subjective well-being of the employees; inadequate load – occupational health risks cannot be ruled out (Meister 1975).

Subjective assessment of the work environment. The subjective assessment of the work environment was carried out through a structured interview with the operators. At the start of the interview, the operators were inquired about their short personal history (whether they overcame a serious illness or had an accident that could cause some symptoms also related to exposure to noise, vibrations, etc.). Then the subjective assessment of the environment itself started. The interview was divided into three main parts, which were in accordance with the measured factors, with the exception of mental load assessment, because a subjective survey of this factor was already conducted through the Meister questionnaire. Then follow-up questions were asked. This served to discover whether an operator already had symptoms of overexposure to a particular factor (e.g. noise – whether they had tinnitus, or had trouble communicating in noisy or quiet rooms, etc.). After the follow-up questions, the operators were inquired whether individual factors were present during their free time (e.g. noise – whether they worked with noisy appliances outside of work, how long the exposure lasted, etc.).

Instrumentation. The exposure to whole-body vibrations was measured with a vibration analyser (Norsonic, NOR 136 model), equipped with a triaxial accelerometer unit (Norsonic, NOR 1286). The device was calibrated with a field calibrator (MMF, VC20). The Norsonic NOR Vibratest software was used for the assessment of data. The placement of the accelerometer unit on the operator's seat can be seen in Fig. 1c.

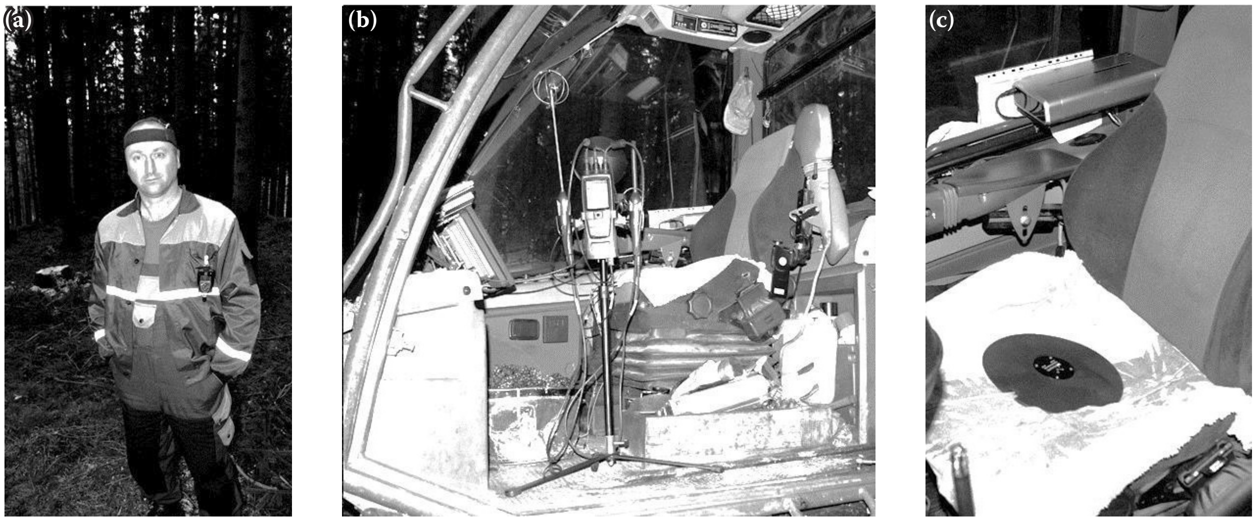

Fig. 1. Position of the noise dosimeter on operator's clothing (a); fully assembled Testo 480 microclimate measurement device placed inside the machine cab prior to the measurement (b); after the measurement, the device was partially disassembled and stored inside the cab to prevent inaccurate temperature measurements; position of the accelerometer for measuring whole-body vibrations on the operator's seat (c)

A noise dosimeter (Quest Edge, type eg4) was used for measurements of noise exposure. It was calibrated with a field calibrator (Quest, QC-10) before and after every measurement. The placement of the noise dosimeter on the operator's clothing can be seen in Fig. 1a.

For measurements of microclimatic conditions, an integrated measurement device (Testo, 480) was used. It was equipped with a globe temperature probe, humidity and temperature probe, and airflow probe. The placement of the Testo 480 device inside the harvester cab can be seen in Fig. 1b.

RESULTS AND DISCUSSION

Whole-body vibrations

The average exposure to whole-body vibrations was $0.5\ m\cdot s^{-2}$. The exposure of harvester operators was $0.5\ m\cdot s^{-2}$. Whole-body vibrations generated by forwarders were higher ($0.6\ m\cdot s^{-2}$) than those of harvesters (Table 3). According to ROTTENSTEINER et al. (2013), driving through forest stands causes higher vibration than other operations of the machine in chipping operations. This could also cause higher vibration of the forwarders in our case, as their share of driving through forest stands is higher than that of harvesters.

Operator No. 3 did not consider whole-body vibrations to be any load for him and did not suffer from any health problems linked to this factor. Operator No. 1 considered them a light load and did not suffer from any health problems linked to them. Operator No. 4 considered them also a light load, but suffered from back pain, which could be caused by whole-body vibrations, but also by the working posture (sitting for most of the work shift). Operator No. 2 considered them a moderate load, suffered from kinesis. Operator No. 5 considered them a severe load for him, suffered from numbness of fingers and arms, and finger pain. He also mentioned stiffness of wrists. These disorders are linked to hand-arm vibrations, instead

Table 3. Results of measurements of particular factors of the work environment for each machine used in the research

Factor	Time period	Operator ID				
		1	2	3	4	5
$L_{AEX,\ 8h}$ (dBA)	–	77	80	75	81	75
L_{CPk} (dBC)	–	129	137	131	137	127
$a_{wbv,\ 8h,\ a}$ ($m\cdot s^{-2}$)	–	0.5	0.5	0.4	0.6	0.7
t_o (°C)	start	12.6	15.1	16.6	13.4	21.3
	middle	15.1	20.5	16.4	17.3	23.0
	end	17.4	16.8	28.9	22.3	28.2
	overall	14.3	17.6	22.7	17.7	24.2
v_a ($m\cdot s^{-1}$)	start	0.12	0.00	0.02	0.00	0.05
	middle	0.10	0.18	0.04	0.01	0.01
	end	0.04	0.06	0.00	0.10	0.00
	overall	0.10	0.09	0.02	0.04	0.02

$L_{AEX,\ 8h}$ – normalized noise exposure, L_{CPk} – peak noise, $a_{wbv,\ 8h,\ a}$ – normalized acceleration of whole-body vibrations, t_o – operative temperature, v_a – airflow velocity of whole-body vibrations. Stiffness of wrists is often a sign of overloading hands and shoulders with machine controls. Operator No. 5 worked with a chain saw as a member of a logging squad prior to his work as a CTL machine operator.

The exposure to whole-body vibrations exceeded the action value (0.5 m·s^{-2}) set by legislation (416/2005 Coll.). Normalized acceleration of whole-body vibrations did not reach or exceed the limit value (1.15 m·s^{-2}). Human body is not adjusted to vibrations. Their harmful effects are various, be it loss of balance at work, coronary diseases or diseases of the nervous system. Whole-body vibrations have severe negative effects on the spine, can harm the intervertebral disks, degenerate the vertebrae, and cause osteoarthritis. They are frequently associated with abdominal pain, digestive problems, haemorrhoids, migraines, etc. (DUPUIS, ZERLETT 1986; HULSTOF, VAN ZANTEN 1987; GRIFFIN 2006).

Noise exposure

The overall exposure of the operators to equivalent noise was 78 dB. The average exposure of harvester operators was 77 dB, and 79 dB was the average exposure of forwarder operators. The exposure of operators to peak noise was 131 dB. The average peak noise exposure of harvester operators was 130 dB. The average exposure of forwarder operators to peak noise was 134 dB. Similar to whole-body vibrations, the exposure of multi-operational machine operators was not considered high. The average exposure to equivalent noise was about 2 dB lower than the lower action value set down by legislation of the Government of the Slovak Republic (115/2006 Coll., 555/2006 Coll.). During two shifts, the exposure to peak noise exceeded the higher action value – once during measurements with operator No. 2 and once during measurements with operator No. 4, on one occasion the exposure to peak noise during a shift reached exactly the lower action value on said forwarder (Table 3).

Three operators considered noise to be a light load, but two of them suffered from disorders linked with noise exposure – one from tinnitus and the other from head pain. All of them are exposed to excessive noise in their free time, caused by timber processing. Operator No. 2 considered noise to be no load for him, but he suffered from tinnitus, sensation of pressure in the head and had trouble communicating in noisy environments or over the telephone. As he was a forestry worker through all of his professional life, working with chain saws and other noisy tools, the health problems could be linked to his previous occupations, but the worsening of disorders during his occupation as an operator of harvester could not be ruled out. Operator No. 5 considered noise a moderate load, did not suffer from any problems linked to noise exposure.

Noise directly affects the auditory system; indirectly it affects various other body systems. Prolonged periods of noise exposure cause deterioration of mental and physical capacity, emotional instability, irritability, decreased ability to concentrate, impaired reaction time and reaction quality, and premature fatigue (MOHAMMADI 2008; HNILICA et al. 2013). Noise is the most frequent source of work related accidents and occupational diseases (FERNÁNDEZ et al. 2009). Hearing loss is seldom immediate (this can be caused by noise of more than 130 dB) but it can cause either temporary or permanent hearing threshold shift (MELNICK 1991).

Microclimatic conditions

According to our findings, the operative temperature inside the cabs depended on the time of day, despite the fact that the cabs were air-conditioned. The average temperature at the start of the shift was 15.2°C, in the middle of the shift it was 19.9°C, and at the end of the shift it was 19.2°C. Another important factor was the season of logging. The average temperature in spring was 15.1°C, in summer it was 23.4°C, and in the autumn it was 17.7°C. The overall average temperature inside the cabs was 17.9°C.

The airflow velocity inside the cabs depended on the setting of the air conditioning system. The average airflow velocity was 0.06 m·s^{-1}. At the start of the shift it was 0.02 m·s^{-1}, in the middle it was 0.08 m·s^{-1}, and at the end of the shift it was 0.06 m·s^{-1}. When looking at the season of logging, the average airflow velocity inside the cabs during spring was 0.08 m·s^{-1}, during summer it was 0.02 m·s^{-1}, and in the autumn it was 0.08 m·s^{-1}.

Four operators considered microclimatic conditions mostly suitable, without any particular comments on what would have to change for them to be fully satisfied with the state of the microclimate. Operator No. 3 considered microclimatic conditions mostly unsuitable, commenting that the air conditioning blew too cold and dry air, causing dried mucous membranes and pain in his joints.

The operative temperature inside the cabs of machines was inside the interval of optimal temperatures in most cases. The operative temperature inside the cabs in autumn was outside the optimal temperature interval set down by Slovak legislation (544/2007 Coll.). The legislation states that optimal temperature in the warm season (outside temperature above 13°C on two consecutive days) is in the interval of 20–24°C; the permissible operative temperature interval is 17–26°C. The operators were exposed to cold at the start of the shift and they preferred it, because the airflow velocity was not high at the beginning of the shift (which would be the outcome of turning on the air conditioning). From the measurements of the airflow velocity, it is obvious that the operators switched on the air conditioning mostly in the middle and at the end of the shifts, when the temperature reached higher values (Table 3). Unsuitable operative temperature leads to decreased physical and mental capacity, and negatively affects the human immune system (Olesen 1995). Workers have to spend more energy to retain homeostasis and therefore the muscles and other tissues cannot deliver optimal performance. Mental performance of workers also decreases at high temperatures (Parsons 1995).

Mental load

The survey on mental load showed that all of the operators consider their work to be overloading (Table 4). The median score was 11 out of 15 possible points for this factor (72% of the maximal score). The operators did not consider their work monotonous; the median score for this part of the questionnaire was 6 out of 15 points (38% of the maximal score). Forwarder operators considered their work more repetitive and less exciting. Non-specific factor had the highest absolute score of 13 points out of 20, but the relative strength of the factor was 61% of the maximal score. Individual questions were aimed at various aspects of the operator's perception of the work. Table 4 shows detailed results of the survey. According to the assessment manual, three operators consider their occupational mental load to be inadequate and two consider it adequate. A study from Gardell (1982) showed that monotonous work affects the personal life of employees by general passivity. Another study by Allen et al. (2000) pointed to the fact that conflict between work and personal life is caused by dissatisfaction with work, burnout and depressions. A poor design of the work process (duration of the work-shift, etc.) interferes with the personal life of employees and reflects in their health (Ala-Mursula et al. 2004; Jansen et al. 2004).

CONCLUSIONS

Preliminary data from a small statistical sample consisting of three harvester operators and two forwarder operators was presented in this article. The duration of the investigation was 10 work shifts. We plan to expand the statistical sample by including more operators and machines, working in more controlled conditions such as harvest type, terrain type, season, etc.

Operators of the multi-operational machinery usually worked in suitable conditions overall. Whole-body vibrations transmitted through

Table 4. Assessment of mental load through the Meister questionnaire. Exceeding the critical median means negative work perception, values lower than the critical median mean positive work perception. The scale ranges from five (the operator agrees totally that the subject of the question is present during his work) to one (the operator does not see the subject of the question as a problem)

No.	Question	Factor	Critical median	Result harvesters	Result forwarders	Result overall
1	time stress	overloading	3	4	3	3
2	little satisfaction	monotony	2.5	2	2.5	2
3	high responsibility	overloading	3	5	4	5
4	tedious work	monotony	2.5	1	2.5	2
5	problems and conflicts	overloading	2.5	2	4	3
6	monotony	monotony	2.5	1	2	2
7	nervousness	non-specific	3	3	3.5	3
8	satiation	non-specific	3	2	4.5	4
9	exhaustion	non-specific	3	4	2.5	3
10	long-term bearing capacity	non-specific	2.5	3	3	3

the seat of the cab were below the limit values set down by international or national legislation and the operators considered them a light load mostly. The machines provided a reasonable level of noise attenuation, although when the operators stepped out of the cabs and inspected the drive unit of the machines, the peak noise levels reached high values. However, these were rare occasions, considering the age (6–10 years old) of the machines. Airflow velocity was under the legislation limits and we considered it as satisfactory, exchanging air in the cabs sufficiently, and simultaneously preventing disorders caused by high airflow. The only factor of the work environment considered precarious was the mental load of the operators. Both employers organized work into 12-h shifts. Lesy SR, GOE made the operators work biweekly and Lesy CR, GOE differentiated between harvester operators (six days work, six days leisure) and forwarder operators (three days work, three days leisure). Having to work for 12 h in such a demanding job as they did was not mentally safe for the employees and there was a considerable threat of burnout syndrome occurring later in their life.

Ergonomic research traditionally evaluates the work environment as if the risk factors were isolated. Assessment of CTL machines focuses mostly on the mental load the work poses on the operators, which indeed is the predominant risk factor (we concluded this as well), but omits the effects of other factors influencing the well-being of the operators. Noisy cabs or inadequate microclimate (as stated by the operators in this study) can add to (or even multiply) the effects of the predominant factor (mental loading) and the joint effects of these factors can shorten the time to develop or increase the severity of occupational diseases connected with exposure to any risk factor present at the workplace. The need for a complex assessment of the work environment is apparent and it is up to the scientific community to develop new kind of limits that would take into account the complex of factors.

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