HARMFUL FACTORS IN THE WORKPLACES OF TRACTOR DRIVERS

Ričardas Butkus, **Gediminas Vasiliauskas**
Aleksandras Stulginskis University, Lithuania
ricardas.butkus@asu.lt; gediminas.vasiliauskas@asu.lt

Abstract
Results of various studies show that the most prevailing risk factors on workers of agricultural sector are noise and vibration. These hazards are especially important in transportation and most field works. Results from previous studies show that vibro-acoustic environment in tractors operated in Lithuania usually cannot be attributed as acceptable, but technical solutions implemented by manufacturers had definitely positive influence on working conditions. Noise level reduced from 90 dB(A) (tractors of 1980 – 1990 years of manufacture) to 73 dB(A) (tractors manufactured from year 2000). As renewal of tractors is not sufficient, there is still a large number of old machinery i.e. noise levels might be as high as 92 dB(A) which allows to work safely only one hour per day without personal protection. It was found that values of whole body vibration (WBV) during ploughing operation might be as high as 1.5 $m \cdot s^{-2}$ which excess the vibration limit value of 1.15 $m \cdot s^{-2}$, while hand-arm vibration (HAV) did not exceed the vibration action value of 2.5 $m \cdot s^{-2}$. Significant effect of tyre pressure was noticed on vibration values measured on driver's seat. Vibration acceleration values may be reduced to safe 0.5 $m \cdot s^{-2}$ by selecting appropriate tyre pressure.
Key words: Tractor, noise, vibration, noise exposure, vibration exposure.

Introduction

Agriculture is attributed to one of the most risky economic activity sectors. Large number of occupational injuries and diseases are diagnosed to operators of tractors and combine harvesters in various countries. The most common risk factors in tractor cabs are noise, vibration and dust. According to the results obtained by Spirgys and Vilkevičius, 70% of work accidents occur because of incorrect operators' actions or inappropriate work organization. More than 70% of all occupational diseases are diagnosed to the operators of various mobile machinery, which are usually caused by high levels of noise and vibration (Spirgys *et al*., 2008). Research findings provided by Melemez & Tunay (2010) show that noise and vibration levels at tractor cabs are mostly influenced by a tractor type, exploitation duration and operating conditions. Technical solutions used for cab noise insulation and vibro-isolation as well as tyre pressure and soil conditions are also influencing factors. Construction of tractor cab depends mostly on technology, which means that modern machinery offers better working conditions (Melemez & Tunay, 2010). Futasuka provides the results of 10 tea plucking machines and their WBV effects on workers in Japan. 68.6% of these workers have complaints manifesting as stiff shoulders syndrome, while 31.4% are complaining about backache (Futasuka *et al*., 1998).

Research results provided by Strelkauskis, Merkevičius & Butkus (2012), reveal the fact that WBV might be 1.38 times higher for used machinery in comparison to modern tractors when driving on gravel road at speed of 7.5 $km \cdot h^{-1}$. Similar results were also presented in the study of Starkus & Butkus (2010) and Butkus & Vasiliauskas (2013), where they found that noise levels in cabs of old tractors might exceed the exposure action values. Their results also revealed that noise levels might be as high as 95 dB(A) in tractors, manufactured around 1980. Such machinery constitutes approx. 50% of tractors operated in Lithuania.

The EU Directive 2003/10/EC regulates the minimum health and safety requirements to workers arising from noise. Limit values and exposure action values in respect of the daily noise exposure levels ($L_{EX,\,8h}$) and peak sound pressures (p_{peak}) are fixed at:

a) peak sound pressure (p_{peak}): maximum value of the C-weighted instantaneous noise pressure;

b) daily noise exposure level ($L_{EX,8h}$) for a nominal eight-hour working day as defined by ISO 1999:2004;

c) weekly noise exposure level as a time-weighted average of the daily exposure levels for 5 working days.

The exposure limit values and exposure action values in respect of the daily noise exposure levels and peak sound pressure ($L_{C,peak}$) are fixed at:

- ***Exposure limit values***: $L_{EX,8h}$ = 87 dB(A), p_{peak} = 200 Pa, $L_{C,peak}$ = 140 dB(C);
- ***Upper exposure action values***: $L_{EX,8h}$ = 85 dB(A), p_{peak} = 140 Pa, $L_{C,peak}$ = 137 dB(C);
- ***Lower exposure action values***: $L_{EX,8h}$ = 80 dB(A), p_{peak} = 120 Pa, $L_{C,peak}$ =135 dB(C).

Vibration exposure values according to EU Directive 2002/44/EC (Directive 2002/44/EC, 2002) are as follows:

Hand arm vibration:

- ***Exposure limit value*** (ELV) calculated for 8 hours: $A(8) \leq 5$ $m \cdot s^{-2}$;
- ***Exposure action value*** (EAV) $A(8) \leq 2.5$ $m \cdot s^{-2}$.

Whole body vibration:

- **ELV:** 1.15 $m\ s^{-2}$ or vibration dose of 21 $m \cdot s^{-1.75}$;
- **EAV**: 0.5 $m\ s^{-2}$ or vibration dose of 9.1 $m \cdot s^{-1.75}$.

Aim of the work was to investigate noise and vibration levels in agricultural tractors and to determine exposure levels and provide safe work recommendations.

Materials and Methods

Results obtained in this study were gathered by several stages. Tendencies of noise level were derived from 30 agricultural tractors, while vibration values were collected from 10 tractors. All tractors were manufactured over the time period 1980 – 2013. Detailed measurements of noise and vibration were carried out in five wheeled tractors (three of them were made over 2006 – 2012 period and two – 1988 – 1999) which were: Massey Ferguson 6480 (manufactured in 2008, 1900 moto hrs.), Claas Atles 926 RZ (2006, 2100 hrs.), Belarus 920.4 (2012, 860 hrs.), T–150K V8 (1988, 6860 hrs.) and New Holland 8870 (1999, 9200 hrs.).

Noise level measurements and exposure calculations were carried out according to the requirements of international standard ISO 9612. Noise level measurements in tractor cabs were done by using first class sound pressure level meter DELTA OHM HD-2010. Parameters, such as continuous equivalent A-weighted sound pressure level ($L_{A,eq}$), equivalent C-weighted sound pressure ($L_{C,eq}$) and peak C-weighted sound pressure level ($L_{C,peak}$) were measured. Measurements were carried out in the tractors' cabs when all doors and windows were closed. Position of the measurement microphone was at the driver's ear level approx. 100 mm from the ear. Tractor crankshaft rotation frequency was 1500 – 1800 min^{-1} and the driving speed was 7.5 $km \cdot h^{-1}$. Noise and vibration measurements were carried out on asphalt paving, while detailed analysis and noise exposure calculations were done from the measurement results which were carried out on gravel paving and ploughing operations. Duration of noise level measurements was at least 60 s and the measurements were repeated three times. Results of noise levels are presented as arithmetic average and standard deviation. Noise exposure was calculated as follows:

$$L_{EX.8h} = L_{Aeq.Te} + 10\lg(T_e/T_0),\ \text{dB(A)} \quad (1)$$

where: $L_{Aeq.Te}$ – equivalent A-weighted sound pressure level over exposure duration T_e;
T_0 – reference duration of 8 hrs.

According to the lower exposure value of 80 dB(A), duration of particular operation was calculated during the work shift.

Vibration measurements in tractor cabs were carried out according to the requirements of ISO 5349 and ISO 2631-1. Human vibration meter *Bruel & Kjaer* (B&K) type 4447 was used to perform the measurements.

Hand-arm vibration was measured on the steering wheel. Accelerometer B&K type 4524 was placed between the wheel and hand and fixed as required by ISO 5349. Weighted average acceleration values of x, y and z axis and total vibration acceleration value a_h were measured.

WBV measurements at driver‘s seat were performed by using the seat-pad with built in triaxial accelerometer B&K type 4524. Vibration acceleration a_w and vibration dose value for eight working hours were calculated VDV(8). Vibration exposure value $A(8)$ was calculated as follows:

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{i=1}^{n} a_{wi}^2 T_i}, \quad (2)$$

where: a_{wi} – frequency weighted acceleration average (RMS) during *i–th* operation;
T_i – duration of *i–th* operation in seconds;
T_0 – work-shift duration in seconds (28 800s).

Calculations were also performed according to equation (2) in order to find the duration which should not be exceeded in order to have the $A(8)$ value lower than vibration action value of 0.5 $m \cdot s^{-2}$.

Whole body vibration measurements were also carried out under the same working conditions but different tyre pressures. Tractors New Holland 8870 and Belarus 920.4 were used for these measurements. Tyre pressures were reduced from 2.6 bar to 0.8 bar in steps of 0.3 bar (7 cases in total). Measurements were carried out on uneven gravel road and repeated three times. Parameter VDV(8) was used to assess the WBV and calculated as follows:

$$VDV(8) = \sqrt[4]{\frac{\sum a_{wi,eq,8h}^4\ T_i}{8}},\ \text{m} \cdot \text{s}^{-1.75} \quad (3)$$

where: a_{wi} – frequency weighted acceleration average (RMS) during *i–th* operation;
T_i – duration of *i*–th operation in seconds;
T_0 – work-shift duration in seconds (28 800s).

Vibration dose was used as estimate of vibration as it is more sensitive to the peaks in the acceleration levels.

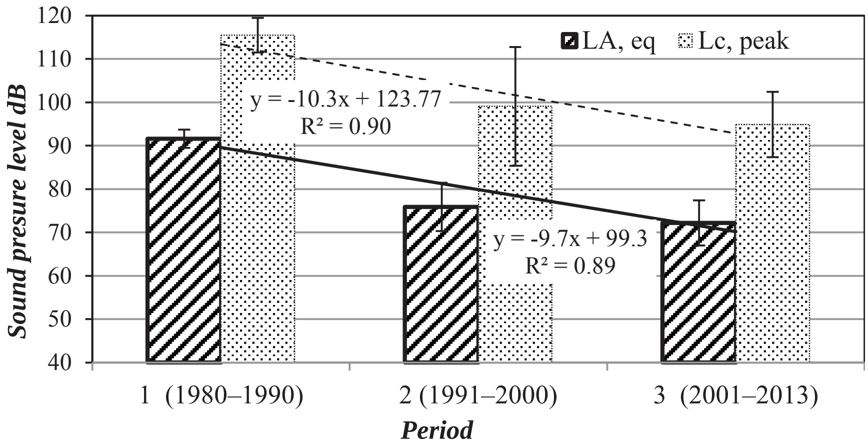

Figure 1. Tendencies of $L_{A,eq}$ and $L_{C,peak}$ sound pressure levels according to manufacturing year.

Results and Discussion

Equivalent A-weighted sound pressure ($L_{A,eq}$) and C-weighted peak ($L_{C,peak}$) levels of 30 tractors were divided into three categories by manufacturing year. Tendencies in noise levels are shown in Figure 1.

As shown in Figure 1, technical modernization and manufacturing quality had significant influence on noise levels which reduced from 92 dB(A) (manufacturing period of 1980 – 1990) to 73 dB(A) (manufacturing period of 1991 – 2000). These results were obtained by using the methodology,which complies with the requirements of EU Directive 2009/76/EC.

Measured noise levels $L_{A,eq}$ and $L_{C,peak}$ are presented in Figure 2 for ploughing and transportation (on gravel paving). Maximum A-weighted SPL registered in tractors was as high as 92.3 dB(A) in transport and 89.7 dB(A) when ploughing. This means that 8 hour exposure would exceed the exposure limit value of 87 dB(A). Lowest noise levels were found 74.2 dB(A) in transport operations and 71.5 dB(A) in ploughing. Considering the fact, that $L_{EX,8h}$ should not exceed 80 dB(A) it is recommended to shorten work duration or to use hearing protection. Exposure durations to reach the exposure of 80 dB(A) for five different tractors are presented in Table 1.

Average WBV and HAV acceleration values are shown in Figure 3.

Hand-arm vibration acceleration values changed from 0.81 $m \cdot s^{-2}$ to 2.28 $m \cdot s^{-2}$ and did not exceed the action value of 2.5 $m \cdot s^{-2}$. Maximum WBV acceleration value was 1.4 $m \cdot s^{-2}$, while it was slightly lower in other cabs. Special attention must be given to if the work duration is full work shift, i.e. 8 hours. This would exceed the vibration action value of 0.5 $m \cdot s^{-2}$ and in 2 tractors would exceed vibration limit value of 1.15 $m \cdot s^{-2}$ and in one tractor exposure level close to 1.15 $m \cdot s^{-2}$. Values of vibration exposure are presented in Table 1 and these results show that noise exposure action value of 80 dB(A) or vibration action value of 0.5 $m \cdot s^{-2}$ is reached over 1 or 2 hours of operation when used old tractors are exploited.

Noise exposure might be reduced to acceptable level by using personal protection, meanwhile reduction of vibration and its effects on operators is complicated. One of the most effective and practicable

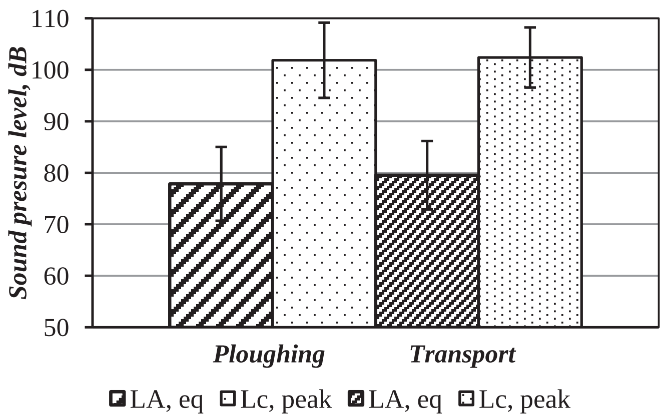

Figure 2. $L_{A,eq}$ and $L_{C,peak}$ noise levels in tractor cabs for ploughing and transportation.

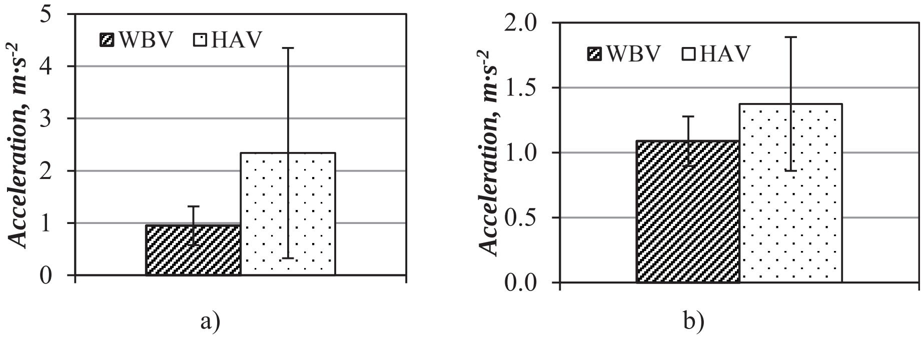

Figure 3. Average values of WBV and HAV in tractor cabs when driving on gravel road (a) and ploughing (b).

Table 1

Durations to reach exposure lower value of noise and action value of vibration ($L_{A, eq}$ / a_w) in ploughing

Tractor	1	2	3	4	5
$L_{A, eq}$ / a_w	74 / 1.12	72 / 0.96	72 / 1.25	90 / 0.99	83 / 1.48
t, H:MM	>8:00 / 1:30	>8:00 / 2:10	>8:00 / 1:18	0:48 / 2:00	4:00 / 0:55

solutions might be tyre pressure reduction. Vibration acceleration values and time history (passing the same distance and time of 40 s) of acceleration values at different tyre pressures (2.6 and 0.8 bar) are presented in Figure 5.

As seen in Figures 4 and 5, tyre pressure decrease has a significant effect on vibration values, which might decrease by 0.5 m·s^{-2} when comparing the case 1 (2.6 bar) and 7 (0.8 bar). Vibration dose VDV(8) analysis show similar results, as vibration dose reduced from 43.8 m·s$^{-1.75}$ to 25.1 m·s$^{-1.75}$ and from 28.5 m·s$^{-1.75}$ to 19.0 m·s$^{-1.75}$ respectively for different test objects.

Results presented in this study clearly show the necessity to perform risk assessment arising from noise and vibration in the workplaces of machine operators. Farmers should also consider either the use of personal protection or any organizational changes in order to reduce the negative effects of noise and vibration in agriculture.

Conclusions

1. Results of noise measurement in tractor cabs of different manufacturing year revealed that technical development of tractor cabs had a significant effect on noise level, which decreased

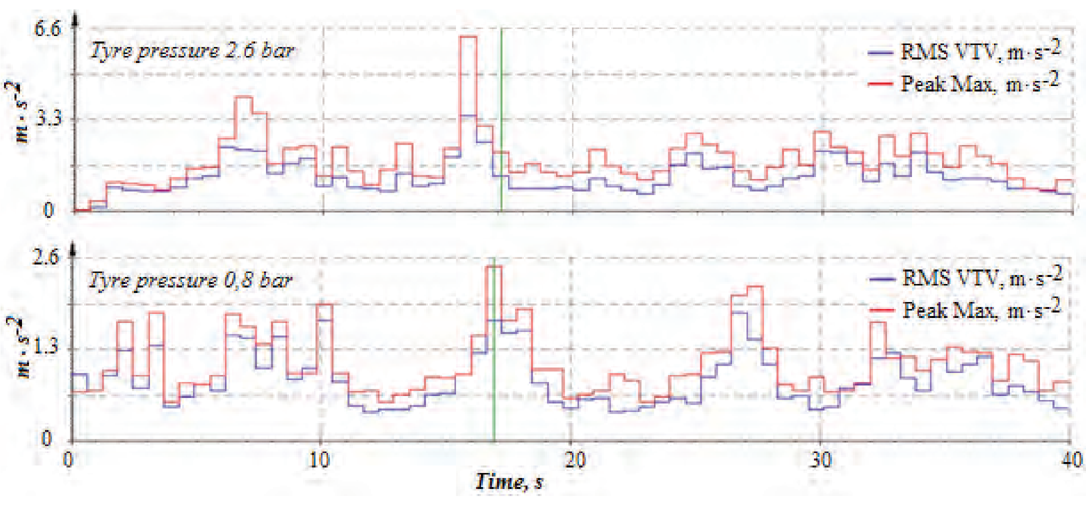

Figure 4. Time history of whole body vibration acceleration values at different tyre pressures (*peak Max* is the above curve in all cases).

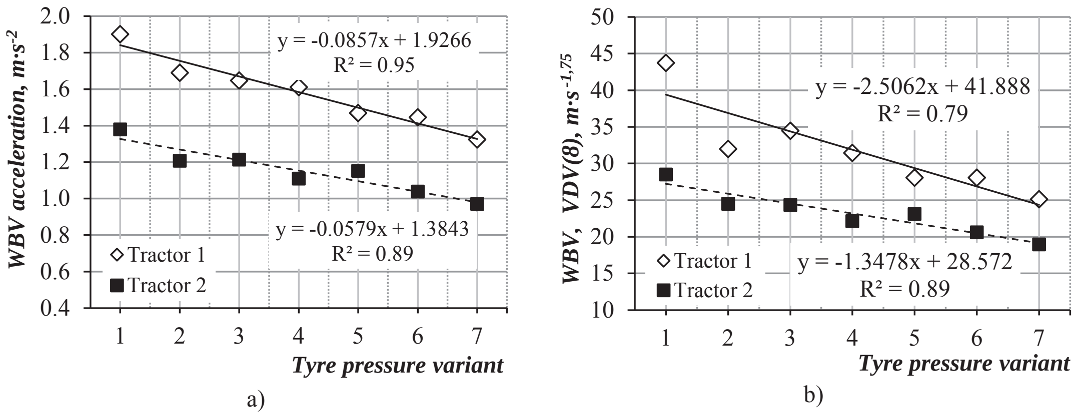

Figure 5. Dependence of *WBV* acceleration (a) and dose (b) to tyre pressure.

from 90 dB(A) (manufacturing year 1980 – 1990) to 73 dB(A) for newer machinery (the year 2000 and later).

2. Noise measurement results carried out in the cabs of tractors Massey Ferguson 6480, Claas Atles 926 RZ, T–150K, Belarus 920.4 and New Holland 8870 during ploughing and transportation operations show that noise levels were in the range from 71.5 dB(A) to 92.3 dB(A). Safe working conditions with exposure value of less than 80 dB(A) are satisfying when working duration is 30 min (when $L_{A,eq}$=92 dB(A)) and 4 hrs. (when $L_{A,eq}$=83 dB(A)).
3. Results of whole body vibration measurements during ploughing operations show that vibration acceleration values varied from 0.96 m·s^{-2} to 1.48 m·s^{-2}, which means that action value of 0.5 m·s^{-2} was exceeded in all tractors when work shift duration is 8 hours. Exposure limit value of 1.15 m·s^{-2} was exceeded in two tractors. Hand-arm vibration action value was not exceeded in any case.
4. Tyre pressure decrease from 2.6 to 0.8 bar significantly influence whole body vibration, which was reduced on average by 0.5 m·s^{-2} while vibration dose value was reduced by one third.

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