# Vibration and noise caused by lawn maintenance machines in association with risk to health

P. Tint, G. Tarmas, T. Koppel, K. Reinhold and S. Kalle

Tallinn University of Technology, Ehitajate 5, EE19086 Tallinn, Estonia; e-mail: piia.tint@tseba.ttu.ee

**Abstract.** The aim of this study was to compare vibration and noise characteristics caused by different types of lawn maintenance machines in association with the risk factors to workers' health. In the present study, the method connecting vibration hazard, health damages and risk levels is presented. Three types of agriculture machines were investigated: all-terrain vehicles (ATV), simple lawn-mowers, ride-on mowers. These machines are used not only in occupational settings, but also by the inhabitants for cutting grass. The gardeners and maintenance workers of the municipal authorities use them daily, sometimes 8 hours a day. The protective equipment against noise is used in occupational settings, but hardly by the public. Noise was evaluated using a Sound Level Meter (TES 1358) following the standard ISO 9612:2009. Vibration was determined as acceleration, velocity and amplitude – measured using a Vibration Dosimeter & Analyser (SV 100) following the standards ISO 2631-4, EVS-EN 5349-2. The risk to the health is assessed by the original flexible risk assessment method worked out in TTU. On the basis of this flexible model the scheme for connecting the local and whole-body vibration hazards and possible health damages was worked out. The results showed that there are differences in the noise and vibration generated by the ATV, lawn-mowers and ride-on mowers. The safest was ride-on mower (local vibration below 1.15 m $(s^2)^{-1}$). Lawn-mowers gave high vibration levels (over 3 m $(s^2)^{-1}$). The personal protective equipment (PPE) has to be worn by all users of the investigated machines. The noise spectral content by these three types of machines is presented and it is different. This enables to choose the right type of ear-muffs by the frequency of noise. The PPE against vibration is also available.

**Key words:** noise, vibration, agriculture machines.

## Introduction

Machines for grass cutting are widely used by workers in agriculture, gardening, landscaping, grounds keeping as well as by public. The main health hazards while maintaining the lawn using gasoline powered machines are noise and vibration. Both may impair human health irreversibly. Occupational health and safety requirements exist for workplaces affected by noise and vibration, but for public users there is no legislation concerning the potential health hazards for local vibration.

The lawn-maintenance industry grows in suburban areas; it has become a new and significant source of environmental noise and occupational noise exposure. Most lawn-maintenance workers spend from 8–10 h per day exposed to A-weighted sound levels greater than 85 dB, and it appears that few employees wear hearing protection. Sound levels were measured and monitored at the operator's ear and measured at a distance of 10 ft from the following equipment: lawn mowers, gas and electric edgers, gas and electric trimmers, electric lowers, and electric hedge trimmer. A-weighted sound levels at the operator's ear ranged from 82 to 102 dB (Lepley et al., 1994).

The aim of the study was to connect the local vibration hazard, the health damages and preventive measures. Additionally, frequency analysis of noise was conducted. Three types of agriculture machine were investigated: all-terrain vehicles (ATV), simple lawn-mowers (gasoline-powered push mowers), ride-on mowers (tractor type). These machines are used not only in occupational setting, but also by large amount of Estonian inhabitants during warm seasons for cutting the grass at least twice a week.

The study includes of the following activities:

1. To connect risk levels and health complaints, the simple/flexible risk assessment method which was worked out by the authors in 2002 (Fig. 1, Reinhold et al., 2009) is used. The method is based on two-step model that could be enlarged to a six-step model, and uses (no/yes) or (corresponds to the norms/does not correspond to the norms) principle. In this study, the five-step flexible risk assessment method is used. The motivation to use five risk levels is derived from BS 8800:2004 standard, which also recommends five risk levels and is therefore familiar and easy to understand to employers and occupational health and safety specialists.

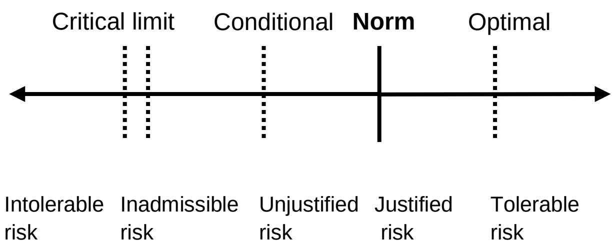


**Fig. 1.** Five-step flexible risk assessment method.

2. The criteria for risk levels of occupational hazards were obtained from regulative norms, standards, directives or scientific literature. Literature scan focused on the impact of noise and vibration on workers' health.

3. To perform the measurements of occupational hazards, standard methods were used:

- ISO 9612:2009 Acoustics – Guidelines for the measurement and assessment of exposure to noise in a working environment' (for noise)
- ISO 2631-4:2001. Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration (vibration)
- EVS-EN 5349-2:2001. Mechanical vibration. Measurements and evaluation of human exposure to hand-transmitted vibration (vibration).

Noise, measured as equivalent continuous A-weighted sound pressure level ($L_{eq}$(A)), was evaluated under normal operating conditions using a hand-held Type II Sound Level Meter (TES 1358). Vibration was determined with 3 physical characteristics – vibration acceleration, velocity and amplitude – measured using a hand-held Vibration Dosimeter & Analyser (SV 100). The aim of the study was to measure the noise and vibration levels from the lawn-maintenance machines and assess the health risk associated with them.

## Study sample

The gardeners and maintenance workers of the municipal authorities use the lawn maintenance machines daily in summer, sometimes 8 hours a day. The protective equipment against noise is used in occupational settings, but hardly by public. Many patrons are unaware of the potential danger of sustaining permanent hearing loss (caused by noise) or Raynaud's syndrome (caused by hand-arm vibration) and other various health problems those two hazards pose.

The ATV-s (2), simple lawn-mowers (2) and ride-on mowers (1) were investigated in a village in West-Estonia. Noise was measured following the standard method ISO 9612. Additionally, the frequency analysis of noise was conducted. Vibration was measured according to the standards ISO 2631 and EVS-EN 5349-2.

## Measurement of noise

The results of noise measurements at various frequencies were used to identify the specific frequencies with especially high intensity (Franklin, 2006). These are useful to develop control measures and select appropriate ear protection. Moreover, it gives an indication about the noise levels in most hearing-damaging frequencies (0.5…2 kHz – the speech frequencies) which are the main concern in selecting the workers' hearing apparatus and serve as basis in estimating numerically the risk of noise-induced hearing impairment/handicap if no risk control measures are applied or the worker misuses them.

According to the measurements, lower frequencies do not pose a concern in previously studied industries (Fig. 2), but is a concern for simple lawn mowers. Knowing the prevailing damaging frequencies helps to decide which ear protection should be used. A hearing protector device can reduce the exposure significantly. The nominal attenuation, recommended by the manufacturers, varies from 11 dB to 35 dB, depending on the hearing protector device and the frequency contents of the noise.

Regulations limiting noise exposures of industrial workers have been instituted in many countries. In Estonia, the current threshold level value for 8-h noise exposure is 85 dB(A). To reduce noise levels, engineering control methods and administrative measures are used. If the engineering and administrative controls are not feasible or not in effect and a noise level less than 85 dB(A) is not achieved, personal hearing protection devices should be offered to the workers. These devices are easily implemented, low-cost methods of minimizing hearing loss from continuous exposure to high-intensity noise (Mohammadi, 2008). The hearing damages from excessive noise are usually generated when the noise exceeds permanently 85 dB(A) and the workers reject or misuse personal hearing protection. For effective noise-induced hearing loss prevention, it is important to reckon the spectral content of noise as the personal protective equipment is often designed according to the frequency of the noise.

The connections between the risk levels due to noise and stages of health complaints determined using the flexible risk assessment method are presented in Reinhold & Tint 'Hazards profile in manufacturing: determination of risk levels towards enhancing workplace safety' (2009).

## Measurement of vibration

Vibration in agriculture is the important health problems causing hazard (Lines, 1987; Marsili, 2002).

The measurable units characterizing vibration are: v, w, A.
The velocity of the vibration (v, measured in $mm \cdot s^{-1}$) can be calculated by the formula:

$$v = 2\pi A f \quad (1)$$

where A is the amplitude and f is the frequency of vibration.

The acceleration (w, measured in $mm \cdot s^{-2}$) might be taken in 3 axes: x, y, z. In the current study the acceleration is given as r.m.s. (the mean value).

The acceleration of the vibration is calculated by the equation:

$$w = 4\pi^2 A f^2 \quad (2)$$

The assessment of the vibration exposure level transmitted to the hand-arm system is mainly based on the determination of the value of daily exposure standardised to an eight hour reference period, A (8) ($m \cdot s^{-2}$), estimated on the base of the root of the sum of the squares (A (w) sum) of the root mean square value of the frequency-weighted accelerations, calculated on the three orthogonal axes x, y, z, in agreement with the standard ISO 5349. The equation to calculate A (8) is the following:

$$A(8) = A_{(w)sum}(Te/8)^{1/2} \quad (3)$$

where: Te is the total daily vibration exposure (hours);

$$A_{(w)sum} = \left(a_{wx}^2 + a_{wy}^2 + a_{wz}^2\right)^{1/2} \quad (4)$$

$a_{wx}$ $a_{wy}$ $a_{wz}$ are r.m.s. values of frequency-weighted acceleration ($m \cdot s^{-2}$) on the x, y, z axes (Monarca, 2008).

Constant exposure to vibration has been known to cause serious health problems such as back pain, carpal tunnel syndrome, and vascular disorders. Vibration related injury is especially prevalent in occupations that require outdoor work, such as forestry, farming, transportation, shipping, and construction. There are two classifications for vibration exposure: whole-body vibration and hand and arm vibration. These two types of vibration have different sources, affect different areas of the body, and produce different symptoms. Whole-body vibration is vibration transmitted to the entire body via the seat or the feet, or both, often through driving or riding in motor vehicles. Hand and arm vibration, on the other hand, is limited to the hands and arms and usually results from the use of power hand tools, but also from vehicle controls (lawn-mowers). Occupational health effects of vibration result from extended periods of contact between a worker and the vibrating surface. What are the possible health effects of chronic whole-body vibration and hand and arm vibration exposure? Whole-body vibration: back pain hand and arm vibration: decreased grip strength, decreased hand sensation and dexterity, finger blanching or 'white fingers', carpal tunnel syndrome (Futatsuka, 1998; Kawanabe et al., 2007; Monarca et al., 2008). Currently, there are no legal standards that limit exposures to local vibration during leisure time in Estonia, only whole-body vibration is regulated.

The farm mechanization has been widespread and developing rapidly, in particular riding farm machines are increasingly used in different countries. There is no information available on the actual situation regarding whole-body vibration on the seats of these farm machines from the standpoint of labour protection. Measurement and evaluation of whole-body vibration was performed on the seats of popular riding agricultural machineries. Whole-body vibration on the seats of combine harvesters and wheel tractors exceeded exposure limits and the fatigue-decreased proficiency boundary limit of 8 hours and also shortened the reduced comfort boundary limits of ISO 2631. Some combines, tractors and excavators had only less than one hour exposure duration as compared with the ISO 2631-1 standard. On the other hand a questionnaire was also performed on the subject of agricultural machine operators. Any specific injury or other effects, i.e. low back injuries were not found among the group of operators as compared with those in non-operator farmers. It seems to be difficult to find out the health effects of whole-body vibration itself, because there may be a lot of causes, i.e. working posture, operating heavy materials, in farm working conditions.

## Analyse of risk to health

Hand-arm vibration syndrome is also known as Reynaud's phenomenon of occupational origin. Vibration is just one cause of Raynaud-s phenomenon. Other causes are connective tissue diseases, tissue injury, diseases of blood vessels in the fingers, exposure to vinyl chloride, and the use of certain drugs. The resulting reduced blood flow can produce white fingers in cold environments (Bovenzi, 2005).

The whole-body vibration can cause fatigue, insomnia, stomach problems, headache and 'shakiness' shortly after or during exposure. Studies show that whole-body vibration can increase heart rate, oxygen and respiratory rate, and can produce changes in blood and urine.

Riders of all-terrain vehicles (quad bikes) are exposed to very high levels of WBV. The risk of injury from riding quad bikes is unclear because the posture and muscle tone of the rider (whether seated or standing) is very different to that of a driver seated in a conventional agricultural machine. Even so, the exposure action and limit values of the vibration regulations still apply – both at the seat and at the footrests. The common practice of standing on the footrests with bent knees, for example when crossing rough ground, appears likely to reduce the transmission of vibration into the driver's back and so reduces the risk of causing back pain compared to sitting in the saddle.

The whole body vibration (WBV) might be an effective modality to enhance physical performance. Sometimes vibration also has a positive effect: in a study in sports science the comparison of the immediate effect of various whole body vibration accelerations on counter movement jump height, the duration of any effect, and differences between men and women were carried out. The results suggest that WBV might be a useful modality as applied during the pre-competition warm-up (Bazett-Jones, 2008).

The connections between the risk levels, vibration levels (local and whole-body) and the possible health damages are given in the Fig. 2. The considerations base on exposure limits and scientific literature. The results of measurements of vibration and the Estonian exposure limits at work and leisure time are given in Table 1.

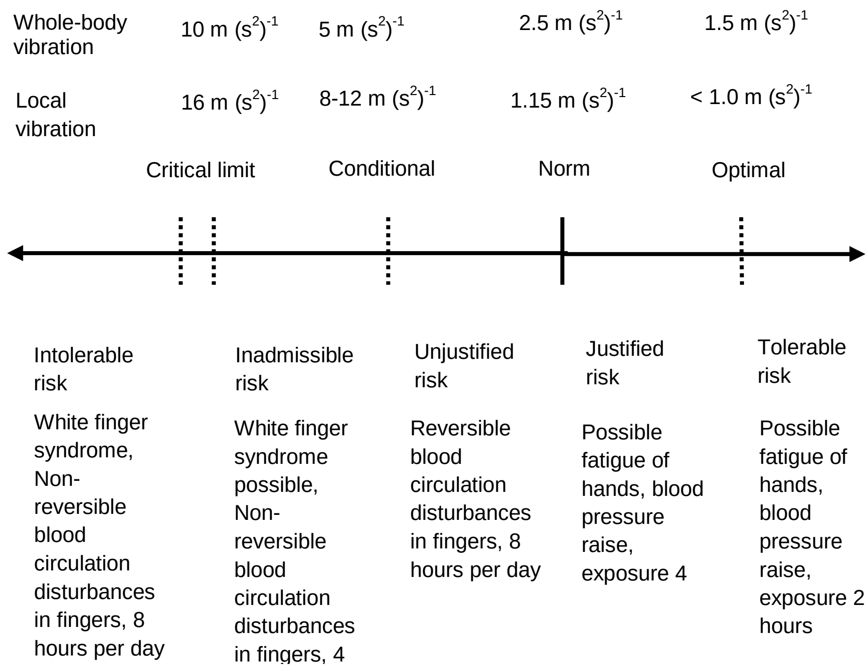


**Fig. 2.** Five-step flexible risk assessment method implemented in local and whole-body vibration.

## Results

The results show that there are differences in the noise and vibration generated by the ATV, lawn-mowers and ride-on mowers. The safest was ride-on mower (local vibration under 1.15 m $(s^2)^{-1}$, the limit for whole-body vibration). The ATV and particularly lawn-mowers gave higher vibration levels (over 2 m $(s^2)^{-1}$). The noise and vibration of ATV users are also over the limits regulating the public use of these machines. ATV-s are used for towing the materials (wood etc.) with wheelbarrows. The personal protective equipment (PPE) has to be used by all users of investigated machines. The noise spectral content by these three types of machines is presented (Fig. 3) and it is different. This enables to choose the right type of ear-muffs by the frequency of noise. The PPE against vibration is also available. Fig. 4 shows the comparison of noise level of industrial and gardening machines. The results of measurements of noise in manufacturing (Fig. 4, Reinhold, 2009) were drawn from case studies 5 in wood processing industry, 5 in textile and clothing industry, 3 in printing and plastic industries and 2 cases from mechanical industries. The noise was the most obvious health hazard in the four different industries (mechanical, wood, printing and textile) and the spectrum of noise was different in these investigated enterprises (Fig.4). The noise levels in clothing industry were much lower than in other 4 industries. Comparing these results to the lawn maintenance machines' noise it is obvious that in lower frequencies (like 31.5 Hz or 63 Hz)

The noise level is 20–30 dB(A) higher, so they are more hazardous that the machines used in manufacturing.

**Table 1.** The vibration on the seats of ATV and ride-on mower, on the handgrip of the lawn mover

| The machine | Vibration amplitude A, mm | Vibration velocity v, mm $s^{-1}$ | Vibration acceleration w, m $(s^2)^{-1}$ | Vibration acceleration w, m $(s^2)^{-1}$ |
|---|---|---|---|---|
| ATV1 | 0.049 | 6.8 | 0.94 | 0.94 |
| ATV2 | 0.080 | 8.9 | 0.99 | 0.99 |
| Ride-on mower | 0.050 | 2.3 | 0.11 | 0.11 |
| Simple lawn- mower 1 | 0.130 | 22.0 | 3.72 | 3.72 |
| Simple lawn-mower 2 | 0.117 | 18.0 | 2.76 | 2.76 |

Daily exposure action value–, local vibration, 2.5 m $(s^2)^{-1}$
Daily exposure action value whole body vibration, 0.5 m $(s^2)^{-1}$
Daily exposure limit value local– 5.0 m $(s^2)^{-1}$
Daily exposure limit value– 1.15 m $(s^2)^{-1}$
Exposure limits for whole body vibration in dwellings and buildings for public use, 0.0126 m $(s^2)^{-1}$

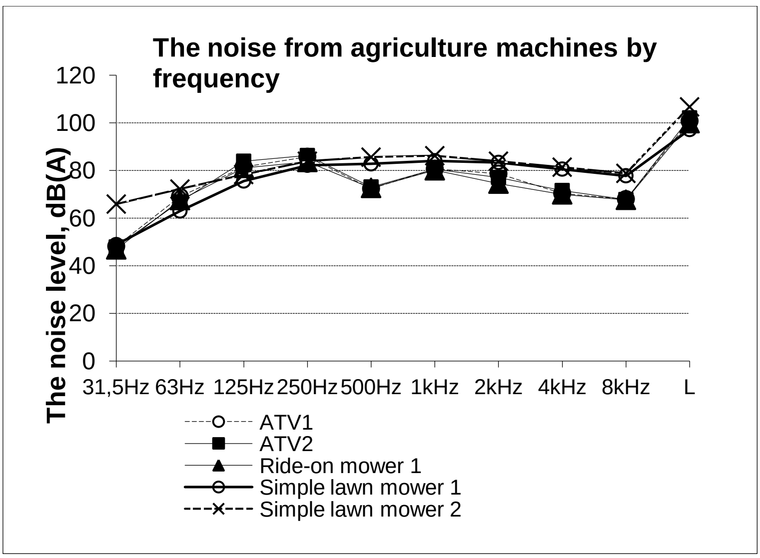


**Fig. 3.** Noise level from different machines by frequency.

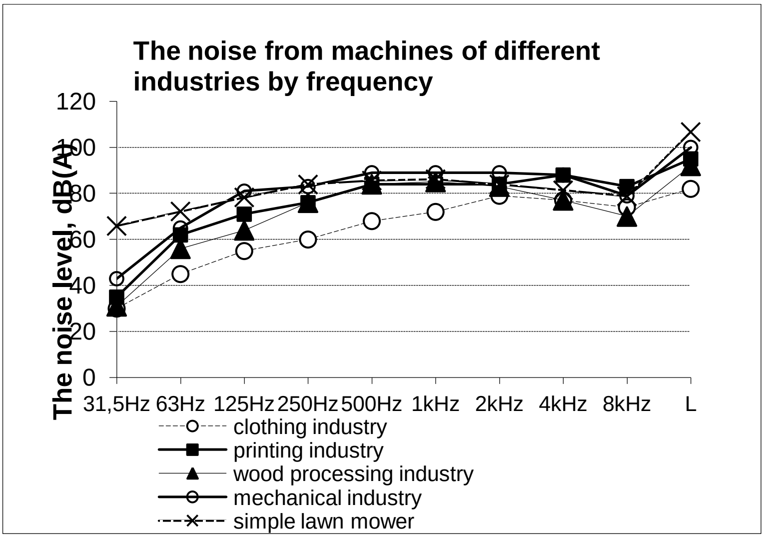


**Fig. 4.** Noise from agricultural machines by frequency (Reinhold, 2009).

## Discussion

### Protection from noise and vibration influence

There are many ways for employers and workers which can help to reduce workers' exposure to vibration. WBV exercise was performed on a Galileo machine (Novotec, Pforzheim, Germany) at an intensity of 12–20 Hz, for duration of 4 minutes, once every week. The mean age of the participants was 72.0 years (range, 59–86 years). This study showed the beneficial effect of WBV exercise in addition to muscle strengthening, balance, and walking exercises in improving the walking ability in the elderly. WBV exercise was safe and well tolerated in the elderly (Kawanabe et al., 2007).

Whole-body vibration levels can often be reduced by using vibration isolation and by installing suspension systems between the operator and the vibrating source. The seat of a machine will probably need replacing several times during the life of the machine (ATV, ride-on mower).

Hand and arm vibration may be more difficult to control, but the proper selection and maintenance of tools can dramatically decrease vibration exposure. Vibration levels associated with power hand tools depend on tool properties, including size, weight, method of propulsion, handle location, and the tool drive mechanism. Primary prevention through eliminating excessive vibration and shocks can be accomplished through better ergonomic tool designs.

Administrative controls can be very important. In high-risk situations, job rotation, rest periods, and reduction in the intensity and duration of exposure can help reduce the risk of adverse health effects. All workers should be advised of the potential vibration hazard and receive training on the necessity of regular tool maintenance and be taught to grip the tools as lightly as possible within the bounds of safety. The ear protection is provided by Peltor™ (Peltor, 2012). Early prevention through exposure monitoring and through the early reporting of initial signs and symptoms of vibration exposure can dramatically reduce chronic health effects.

## Conclusions

The results showed that there are differences in the noise and vibration generated by the ATV, lawn-mowers and ride-on mowers. The safest was ride-on mower (local vibration below 1.15 m $(s^2)^{-1}$). Lawn-mowers gave high vibration levels (over 3 m $(s^2)^{-1}$). The personal protective equipment (PPE) has to be worn by all users of the investigated machines. The noise spectral content by these three types of machines is presented and it is different. This enables to choose the right type of ear-muffs by the frequency of noise. The PPE against vibration is also available.

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