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Occupational risks related to vibrations using a brush cutter for green area management

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Abstract

Introduction. Weed control is one of the most important issues in the maintenance sectors of both agriculture and green areas. Small tools are employed for controlling grass and other growths on steep verges and river banks. This leads the operators being exposed to many risks among which vibration is one. The purpose of this study is to measure and evaluate hand-arm vibration and to verify the daily exposure to which workers are often subjected while weeding.

Materials and method. Two cutting heads, a brush knife and a mowing head were compared. Both were mounted on the same cow-horn brush cutter. The vibration total value was expressed as the root-mean-square (rms) of three component values according to the axes X, Y and Z. The signal was frequency weighted using the weighting curve Wh, as described in the ISO 5349–1 (2001) standard. In addition, the daily vibration exposure was calculated and compared with the thresholds set by EU Directive 2002/44/EC (2005).

Results. The obtained results showed that the exposure action value (EAV) of 2.5 ms^{-2} was exceeded while using both cutting heads. The exposure limit value (ELV) using the brush knife also exceeded 5 ms^{-2}.

Conclusions. The results highlighted important aspects in terms of exposure values that should be considered with the view of preventing the risk of Hand-Arm Vibration Syndrome (HAVS) to which the operators who frequently use these tools are exposed. Specific measures should therefore be taken to protect the exposed workers.

Key words

vibration analysis, risk evaluation, work safety, brush cutter

INTRODUCTION

Weed control is one of the most important issues in the maintenance sectors of both agriculture and green areas. Several studies have been conducted to evaluate the effects of mechanical and physico-chemical methods used for this practice [1, 2, 3], as well as to quantify the various risks to which the operators are often exposed,such as vibrations, noise, physical fatigue, difficult postures and exposure to chemicals [4, 5].

In particular, small tools are employed for controlling grass and other growths on steep verges and river banks. This leads the operators being exposed to many risks, among which are vibration risks that do not occur immediately, but may provoke symptoms several years later. Among the most employed mechanical tools, brush cutters are widely used because of their affordability and easiness of use. However, they often provoke work injuries, either direct, such as serious injuries to the feet when the cutting head strikes the operator, or indirect ones that could weaken the nerves of the hand due to the prolonged exposure to vibrations generated mainly from the rotating engine and the cutting head [6, 7, 8]. Indeed, the professional brush cutters increase the risk of developing Hand-Arm Vibration Syndrome (HAVS) which includes circulatory, sensory and musculoskeletal disorders [9, 10]. The aim of the presented study was to measure and evaluate operators' exposure to hand-arm vibration through determination of the vibration amplitude and duration of exposure during green area management using a brush cutter.

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MATERIALS AND METHOD

A group of six operators aged 23–58 (average 43.3 years), weighing 58 – 115 kg (average 79.1 kg) and height from 164 – 182 cm (average 176.6 cm), were examined while carrying out their working duties consisting in the cleaning and maintenance of embankments and paths.

Brush cutters, as basic elements, usually have a single cylinder two-stroke engine and a cutting head, connected by a shaft that enables the operator to handle and control the tool. In order to assess vibration exposure during the trials, two cutting heads: a brush knife and a mowing head, were compared (Fig. 1).

Both were mounted on the same cow-horn brush cutter FS350 (STIHL, Germany), with 1.6 kW internal combustion engine weighing 7 kg, with a maximum engine speed of 12,500 rpm, an output shaft speed (cutting tool) of 8,930 rpm, and an idle speed of 2,800 rpm (Fig. 2).

For real time data acquisition, a portable analyzer HD2030 (Delta Ohm, Italy) was employed. This device is able to acquire simultaneously acceleration values and measure average acceleration values, as well as weighed values. The analyzer was integrated with the PCB triaxial accelerometer HDP356A02 (Piezotronics, USA) with 10 mV/g sensitivity,

Figure 1. The employed cutting heads used during trials: brush knife (left) and mowing head (right)

Figure 2. The brush cutter used during trials

secured by a screw on the HD2030AC4 adapter (Delta Ohm, Italy). This adapter was designed to be placed between the operator's hand and the tool handle, with the accelerometer placed in a central position between the middle finger and the ring finger. This also permits limiting the presence of the "DC-shift" in acceleration data. The accelerometer was previously calibrated using the portable multi-frequency and multi-level calibrator for vibration transducers HD2060 (Delta Ohm, Italy) using a frequency of 159.155 Hz, according to ISO 8041:2005 [11]. The accelerometer wire was additionally tied in order to avoid hindrance while carrying out the activity, as well as to avoid eventual noise in the withdrawn signal, as reported byAinsa et al. [12]. The accelerations were simultaneously measured along the three perpendicular axes *(X, Y, Z)*, according to the recommendations of the EN ISO/DIS 20643/A1 standard [13] as follows: the x-axis was perpendicular to the palm area, the y-axis parallel to the longitudinal axis of the grip, and the z-axis directed along the third metacarpal bone of the operator's hand. The signals were frequency weighted using the weighting curve *Wh* according to the ISO 5349–1 standard [14]. In order to obtain a stabilized signal, each test lasted two minutes [10]. Tests were repeated five times for each operator. During vibration analysis, the engine turned around 10,000 rpm, a lower speed than the maximum.

As suggested by Ko et al. [15], to measure vibration magnitude, it is useful to adopt the averages of frequency-weighted root-mean-square (rms) acceleration expressed in ms^{-2} (Eq. 1), according to ISO 5349–1 (2001):

$$a_{hw} = \sqrt{\sum_j (W_{hj} a_{hj})^2} \qquad \text{(Eq. 1)}$$

where a_{hw} is the frequency-weighted rms acceleration, W_{hj} is the weighted factor for the one-third octave band j, and a_{hj} is the rms acceleration for the one-third octave bande j.

Vibration analysis was performed using the vibration total value (a_{hv}), defined as the square root of the sum of the squares (rms) of the frequency-weighted accelerations a_{hwx}, a_{hwy} and a_{hwz} along the individual axes expressed in ms^{-2} (Eq. 2), according to ISO 5349-1 (2001):

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad \text{(Eq. 2)}$$

For an operator who carries out only one task or who uses one tool, daily exposure A(8) was measured considering the exposure level and duration expressed in ms^{-2} (Eq. 3), according to ISO 5349–1 (2001):

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \qquad \text{(Eq. 3)}$$

where a_{hv} represents the vibration total value (ms^{-2}), T is the duration of daily exposure to the total vibration value a_{hv} and T_0 refers to a reference period of eight hours. According to EU Directive 2002/44/EC[16], the limit values for daily vibration exposure A(8) regarding the hand-arm vibrations correspond to 2.5 ms^{-2} for the daily exposure action value (*EAV*), while it is equal to 5 ms^{-2} for the daily exposure limit value (*ELV*). Both values are referred to an eight-hour reference period. The software Noise Studio 8.29 (Delta Ohm, Italy) was used to post-process vibration analysis data. The acceleration values were processed using R 3.2.1(R Core Team, Austria) software package [17]. To compare data,an analysis of variance was carried out. The confidence interval was always 95%. When necessary, the post-processing Tukey test was applied.

RESULTS AND DISCUSSION

Low frequencies increase human perception to vibrations and are considered the most harmful, as reported by Hao et al. [18]. The one-third octave frequencies band analysis did not show any high acceleration values of low frequency in the vibration signals. The acceleration spectra of the three *X*, *Y* and *Z* axes, employing both cutting heads considering the average of the six operators, are illustrated in Fig. 3. The obtained results show that there are two well-distinguished peaks for both cutting heads in each of the three axes. In particular, for the

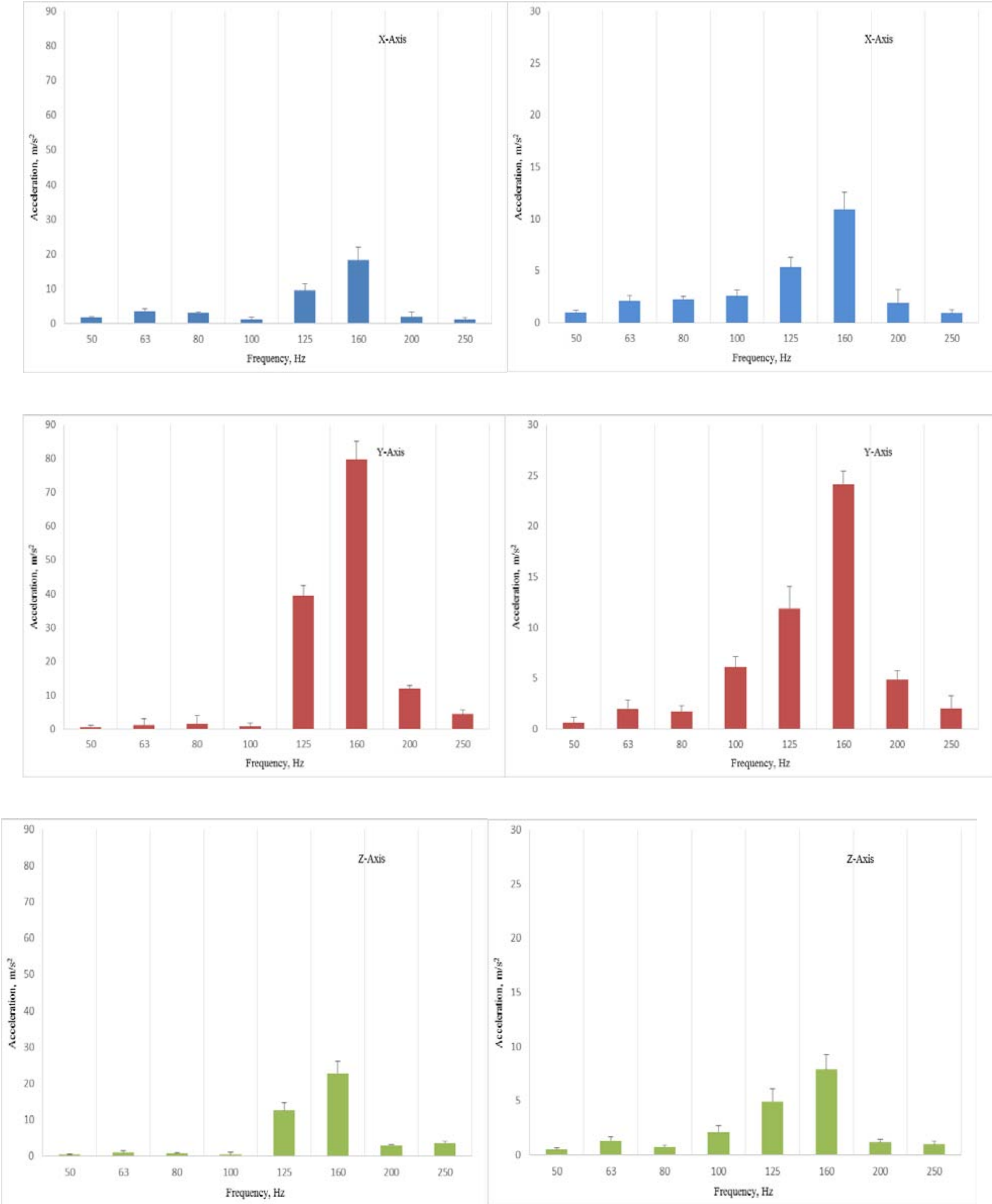

Figure 3. Input spectra in one-third octave band calculated as the average (±s.d.) of the six operators (left: brush knife; right: mowing head)

brush knife, the highest peaks of acceleration were recorded at a frequency of 160 Hz, with magnitudes of 79.9 ms^{-2} along the *Y* axis, followed by 22.8 ms^{-2} in the *Z* axis and 18.3 ms^{-2} in the *X* axis. The subsequent peaks, however, recorded at 125 Hz, corresponded to the acceleration values of 39.4 ms^{-2}, 12.6 ms^{-2} and 9.5 ms^{-2}, respectively, in *Y*, *Z* and *X* axes. For the mowing head, the acceleration magnitudes at the frequency of 165 Hz, corresponded to 24.10 ms^{-2} in *Y* axis, 7.88 ms^{-2} in *Z* axis and 10.9 ms^{-2} in *X* axis, while the subsequent peaks of acceleration, respectively, had the magnitudes of 11.9 ms^{-2}, 3.1 ms^{-2}, and 5.35 ms^{-2} in *Y*, *Z* and *X* axes. According to Hao et al. [18], the presence of these two peaks can be mainly attributed to the engine excitation from one hand, and to the rotation of the cutting head from the other hand.

The frequency-weighted rms acceleration analysis, calculated according to Eq. 1, for *X*, *Y* and *Z* axes, considering the average of the six operators, respectively, were 3.18 ms^{-2}, 9.36 ms^{-2} and 3.27 ms^{-2} for the brush knife, and 2.03 ms^{-2}, 3.35 ms^{-2} and1.76 ms^{-2} for the mowing head. The brush knife produced a higher acceleration for the vibration total value than the mowing head (Tab. 1). The obtained values are similar to those reported by Allsop et al. [19].

Table 1. Vibration total value a_{hv} of analyzed cutting head

	a_{hv} (ms^{-2})	SD
Mowing head	4.36[a]	0.98
Brush knife	10.56[b]	3.06

Values correspond to the average (±s.d.) of six operators
Data followed by different letters are significantly different ($P < 0.05$)

Considering an eight-hour working day, the exposure action value (*EAV*), i.e. 2.5 ms^{-2}, is reached after just 27 minutes using the brush knife, while the exposure limit value (*ELV*) corresponding to 5 ms^{-2}, is reached after one hour and 48 minutes. The daily vibration exposure A(8) using this tool is equal to 10.6 ms^{-2}, which provokes an unacceptable risk. Therefore, the exposure time must be reduced in order to avoid Hand-Arm Vibration Syndrome *(HAVS)*. Using the mowing head, the *EAV* is reached after two hours and 38 minutes, whereas the *ELV* is reached after 10 hours and 31 minutes, making the daily vibration exposure A(8) equal to 4.4 ms^{-2}. The obtained values suggest the implementation of specific measures, such as training and health monitoring in order to prevent the risks, even though these values were below 15 ms^{-2}, that corresponds to the BS EN ISO 11806 (2008) [20] fixed value for machines with engine displacement of less than 35 cc. This attainable vibration value does not represent the exposition limit perceived by a person, but expresses the machine emission value in certain trial conditions, according to ISO 7916 (1989) [21].

CONCLUSIONS

Vibrations, also associated with other factors, constitute a risk which increases occupational illnesses and accidents and decreases work productivity in agriculture [22]. The frequency analysis carried out in this study was useful for defining the vibration behaviour of two cutting heads of a brush cutter. The obtained results highlighted important aspects in terms of exposure values that should be considered with the view to prevent the risk of Hand-Arm Vibration Syndrome *(HAVS)* to which the operators who frequently use these tools are exposed. Indeed, during field activities, risks due to improper handling, such as the impact of the cutting head with the ground, often happen. Therefore, to guarantee operators' safety it is important to carry out regular controls and maintenance interventions, for example, regarding the correct attachment of the cutting head to avoid a centrifugal imbalance, as reported by Tudor [23]. Another important point is to consider the necessary preventive measures, i.e., operators should carry and handle the brush cutter in a correct way and adopt a correct posture while working, they must wear the necessary personal protective equipment, such as anti-vibration gloves, and should be aware of the correct functioning of the tool. It is also important to schedule work rotation and plan workers' training.

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