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Angela Calvo, Roberto Deboli, Christian Preti, Antonino De Maria

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Angela Calvo[1,2], Roberto Deboli[2], Christian Preti[2], Antonino De Maria[3]

[1]DISAFA (Department of Agricultural, Forest and Food Sciences and Technologies), Largo P.Braccini 2, 10095 Grugliasco, Turin, Italy

[2]IMAMOTER Institute for Agricultural and Earth-moving Machines of C.N.R (Italian National Research Council), Strada delle Cacce 73, 10135 Turin, Italy;

[3]ASSPO – Olive Oil Association, vicolo Don Vercellis 2, 10090 Vialfrè (Turin), Italy

Correspondance: Angela Calvo, Largo P. Braccini, 2 10095 Grugliasco (Turin), Italy

Tel. +39 011 6708592 Fax. +39 011 6708591; e-mail: angela.calvo@unito.it

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Contributions: the authors contributed equally

Abstract

The electric hand held olive harvesters have a low weight (about 2 kg) and cause the fruit pick up by means of impacts produced by their vibrational tools: for this reason they transmit elevated vibration doses to the operator's hand arm system during the work. In this paper electric beaters of different manufacturers and different models were considered, to analyse their vibrational behaviour in field, during the olive harvesting campaign in a site located in Northern Italy. One operator did the tests, to avoid the operator's uncertainty on the obtained results.

All the five examined beaters gave high acceleration values (in a range from 10 to 26 ms^{-2}), but the most restricting data were the daily vibration exposures, calculated considering the real working duration time acquired in field, almost ranged between 10 and 18 ms^{-2}. Also the operator posture during the work (with the arms over the shoulders) may set health problems, related to upper limb disorders, other than the already known musculoskeletal, nervous and vascular pathologies.

1. Introduction

The hand held olive harvesters are operator brought machines (driven by little internal combustion - i.c. -, pneumatic or electric engines) used to pick up the olives. The hand held harvesters studied in this work have an electric engine and are called beaters: they have an oscillating head with carbon fibre sticks and the harvesting is obtained by direct impact of sticks on olives or by vibration transmitted to the pliant branches. There are different types of hand held olive harvesters (combs, flaps and hooks, Figure 1).

Figure 1 here

The hand held olive harvesters have a low weight (from 2 to 15 kg) and the electric are the lightest (about 2 kg): the lightness of these machines, together with the high tangential velocity of the sticks tips, as well as the pole material, diameter and length (Manetto et al. 2012), are the main cause of the elevated vibration levels to the operator's hand arm system.

The prolonged use of hand held vibrating power tools can lead to the hand arm vibration syndrome (HAVS) that can interest the musculoskeletal, nervous and vascular peripheral structures of the upper limb. Epidemiologic aspects of the relationship between exposure and response have been studied since many years (Pyykkö, 1986; Gemne, 1997; Bovenzi, 1998; Bovenzi *et al.*, 2000; Punnet and Wegman, 2004; Bovenzi, 2005) and therefore a European Directive (2002/44EC) provided to the assessment of the vibration exposures at the workplace in order to guarantee the health and safety protection of workers.

In this Directive the daily vibration exposure *A(8)* (derived from the magnitude of the a_{hv} vibration total value measured and from the daily exposure duration) is the core element for the employers: greater are a_{hv} and the exposure times, greater is the risk and therefore employers need to consider actions to reduce the workers' risk. Other important concepts are the exposure action value (EAV) and the exposure limit value (ELV). The EAV is a daily amount of vibration exposure above which employers are required to take action to control the employees exposure: for hand-arm vibration the EAV has a daily value of 2.5 ms^{-2}. The ELV is the maximum amount of vibration to which an employee may be exposed to on any single day. For hand-arm vibration the ELV amount is 5 ms^{-2}. Employees should never be exposed to higher values.

If a machine produce a vibration total value equal to 12 ms^{-2} (root mean square - r.m.s. -), therefore it cannot be used more than 20 minutes/day to not reach the EAV and 1 hour and 23 minutes to stay under the ELV.

This is the theory, difficult to apply in some practical situations in many agroforestry tasks, as the olive harvesting with hand held harvesters.

Deboli and Calvo (2008) measured values from 20 up to 71 ms^{-2} on the front hand position of a hook beater during the work. Çakmak *et al.* (2011) obtained vibration total values variable from 2.2 and 42.9 ms^{-2} (including the idling state) in flap type olive harvesters. Referring to the same harvesters, Manetto *et al.* (2012) obtained different values in laboratory and in field: in fact, the vibration values increased from 16.3 ms^{-2} (in laboratory) to 19.6 ms^{-2} (in field).

Deboli *et al.* (2014) in field obtained vibration values between 11.6 to 17.2 ms^{-2} using a comb type harvester equipped with combs of different diameters (combs with a lower diameter vibrated more).

Other tests were performed with different olive harvesters both in field and in laboratory (Monarca *et al.*, 2007b, Pascuzzi *et al.*, 2009, Cerruto *et al.*, 2010, Aiello *et al.*, 2012, Saraçoğlu *et al.*, 2011), but it is evident that a great data variability exist.

In general, there is great potential for vibration levels to vary between materials, operators, tools, working conditions and a combination of all these factors (Cerruto *et al.*, 2012; Heaton and Hewitt, 2011). It is quite hard to specify the HAV related risk with an acceptable uncertainty: the best procedure for assessing it, is through direct measurement on the specific worker in the real working conditions, using the actual tool (Moschioni *et al.*, 2011).

In this work, electric beaters of different manufacturers and different models were considered, to analyze their vibrational behavior in field, during the olive harvesting campaign in one site located in Northern Italy. The choice of the electric beaters was due to the operators, that prefer these models for their easy use and manoeuvrability, because in this region olive orchards have small surfaces and are mostly located in sloped terrains.

Considering the operators, they skill and experience also play a role (Heaton and Hewitt, 2011; EN ISO 20643: 2008).

The EN ISO 20643: 2008 requires that measurements must be done with at least three operators, except if it can be shown that the vibration is not affected by operator characteristics: in this last case it is acceptable to perform measurements with one operator only. Also the methodology for EN ISO 28927-x series of standards requires three operators, but all these standards refer to laboratory tests to calculate vibration emission of hand-held and hand-guided machinery (the EN ISO 20643) or of specific machine types (ISO 28927-x series).

Aim of this work was not to evaluate electric beaters in laboratory, but to analyze their vibrational behaviour in field, with the same skilled operator, experienced in the use of the tool and able to operate the machine properly.

Some Authors (Pascuzzi *et al.*, 2007; Vergara *et al.*, 2008; Costa *et al.*, 2013) observed that hand-arm vibration are in many cases operator dependent, because the most skilled ones have an attitude to ‘follow’ the machine, while others (especially inexperienced people) tend to tighten the tool. Another aspect is the beater lightness (around 2 kg mass): some operators, while harvesting the olives, address the beater head among the branches, and when the sticks are into the foliage they loosen the hand grip force.

Moreover, the electric beaters do not have specific handles and each operator may prefer to grip the pole in different points: as requested by the EN ISO 20643:2008, the measurements must be carried out as close as possible to a point on the grip surface half-way along the length of the grips or at such places where an operator normally holds the machine during the operation. Different are the grip points, different may result the acceleration data, because the pole warps under mechanical vibration and the hand could grasp in a node (a point on the pole that is with zero deflection).

At the beginning three operators were considered, as required by the standards but, since field tests and not laboratory tests were performed, it was then decided to use as unique skilled operator, who was the olive picker accustomed to the beaters use in field: his gestural expressiveness during the harvesting was filmed and therefore discussed. The main target of the work was indeed to compare the acceleration global values of the beaters and, therefore, the allowed exposure times.

Another parameter influencing the vibration exposure, other than the magnitude of the total vibration value, is the duration of the exposure (Palmer *et al.*, 2000). Daily exposure duration is the total time for which the hands are exposed to vibration during the working day. It is very important to base estimates of total daily exposure duration on appropriate representative samples for the various operating conditions. For this reason the real utilization times of the analysed beaters in the different operative conditions were acquired.

2. Materials and methods

2.1 Field site and cultivar

The fields test were carried out during the olive harvesting campaign in the site of Carpe (SV), 430 meters above sea level, Northern Italy, in a private olive tree grove of *Olea Europea*, variety Leccino, with a tree age around 15 years old. The coordinates of the olive orchard are: 44°7'39"N and 8°12'19''E.

2.2 The electric beaters

The five tested olive harvesters were of three different manufacturers and of different models (from now on, the first letter indicates the manufacturer, while the second letter denotes the model). In Table 1 there are the harvesters characteristics, while in Figure 2 there are the analyzed machines (the C1 model is omitted, because it has the same structure of C2). These machines do not have handles, but a pole over which the operator may move the hands to guide the machine. In this work the words front and rear handles are avoided and the front and the rear hand positions over the beater pole are used.

Table 1 here

All the measurements were carried out when the beaters were switched on and hold by the operator without working (idling state) and during the olive harvesting (full load state). In the idling state the pole was 45° bend.

Figure 2 here

2.3 Operators

Three operators (Table 2) were initially involved: they were all skilled in the use of the hand held olive harvesting machines and they all used the C2 machine, but at the end only the operator #1 was involved in the tests.

Table 2 here

2.4 Hand arm vibration measure

2.4.1 Measurement chain

Two tri-axial accelerometers ICP (Integrate Current Preamplifier) by PCB (SEN020 model, 1 mV/g sensitivity, 10 g mass) were oriented according to the EN ISO 20643 standard and secured to the harvester pole by means of metal supports wrapped with metallic screw clamp to reduce the uncertainty of hand-arm vibration measurements.

The output signals from the accelerometers were processed in real time through a NI (National Instruments) 9402 (six channels), while the software Sound and Vibration Assistant (National Instruments) was used to post-process the data. The measurement chain was previously calibrated. The position of the front accelerometer was identified according to operator's anthropometric characteristics: this position however was noticed useless because the operator during the field acquisitions moved the left hand along the pole for better balancing the beater. The position of the rear accelerometer was fixed in correspondence of the power switch. Axes directions are in Figure 3.

Three series of five consecutive tests were carried out for each examined beater, both at front and at the rear hand position (EN ISO 20643, 9.1).

Figure 3 here

2.4.2 Measurement of the vibration total value (a_{hv}) and of the equivalent vibration total value ($a_{hv,eq}$)

The accelerations were simultaneously measured along the three perpendicular axes (a_x, a_y, a_z) following the recommendations of the EN ISO 20643/A1 standard and the signals from the accelerometers were frequency weighted using the weighting curve *Wh* (ISO 5349-1 standard). To obtain a stabilized signal, the acquisition time for each test was at least two minutes.

The vibration total value (a_{hv}) was calculated as the square root of the sum of the squares (r.m.s.) of the frequency-weighted accelerations a_{hwx}, a_{hwy} and a_{hwz} along the axes (Eq. 1).

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \qquad (1)$$

The vibration total values were acquired for each beater and for each hand position (front and rear).

Both the idling and the full load condition were examined: the equivalent vibration total value $a_{hv,eq}$ was then calculated, following the CEN/TR 15350:2013 indications. The $a_{hv,eq}$ is the time-averaged sum of the vibration total values of the various machinery operating modes (in this case 2: idling and full load), called a_{hvi}, during their associated exposure durations T_i (Eq. 2):

$$a_{hv,eq} = \sqrt{\frac{1}{T}\sum_{i=1}^{2} a_{hvi}^2 T_i} \qquad (2)$$

In this study, a_{hvi} were registered at the front and at the rear hand position, but only the highest value was used in the equation 2 (EN ISO 20643, 6.2).

T is the total exposure duration, namely the time when the hand is gripping the pole: T is therefore the sum of the individual exposure durations T_i within the entire work cycle considered (idling and full load).

If each vibration total value a_{hvi} for the corresponding operation mode may be correctly evaluated, increasing the acquisition time and correctly following the standard procedure, difficulties may be encountered in the associated exposure durations T_i (Griffin, 2004; Gerhardsson *et al.* 2005). For the purposes of carrying out a reliable risk assessment, results from the study of McCallig *et al.* (2010) indicate that direct measurements of worker exposure time are recommended.

Vice versa, the time sequences of the operating modes as used for measurement of the vibration emission for flap type fruit harvesters are indicated in Table D.2 of the CEN/TR 15350 as 1/7 in idling condition and 6/7 in nominal maximum speed condition (full load). Since the equation 2 is not affected by the total exposure duration T, but by its splitting percentages, whatever is the T value, it can be used to calculate the equivalent vibration total value, maintaining the weights for each working condition.

2.4.3 The daily vibration exposure calculation

The daily vibration exposure (formerly *A(8)*) is derived from both the magnitude of the vibration and the daily exposure duration (Eq. 3):

$$A(8) = a_{hv,eq}\sqrt{\frac{T}{T_0}} \qquad (3)$$

where:

$a_{hv,eq}$: equivalent vibration total value

T: total exposure duration (hours)

T_0: reference time (8 hours)

In the calculation of *A(8)*, different results are obtained if the accelerations measured or the exposure times to the vibration source are different.

The CEN/TR 15350 standard indicates 3 hours per day the typical daily exposure time when using fruit or olive harvesters (flap and hook types) but only in the case they have an i.c. engine: none information is available for the electric olive harvesters. During the olive harvesting the beaters are really used until 5 hours per day for one month and more. Manetto *et al.* (2012) used a 4h exposure time, considering a 7h working day, whereas the 3 residual hours were used for the positioning of the nets and for the final product recovery. The same T value was assumed by Aiello *et al.* (2010).

In the present work 4 hours and thirty minutes of beaters use was the registered average time during the olive harvesting.

For these reasons the *A(8)* was calculated in two possible scenarios of T, the CEN/TR 15350 standard T_s (3 hours) and the work site T_w (4.5 hours) to let a comparison between the two situations.

2.4.4 The operator behaviour

During the harvesting, the operator behaviour was also considered, using a camera (PJ530 Handycam, Sony). The video were then analysed and studied to better understand the operator posture and its attitude to manage the beater during the work.

2.4.5 Data analysis

All the acquired data were organized into spreadsheets and then processed using the IBM SPSS Statistics 20 software package. To verify the variance homogeneity the Levene's test was used.

3. Results and discussion

3.1 Comparison among the operators

Differences were obtained at the idling and at the full load (work) conditions over both the hand positions of the three operators (Table 3). The obtained vibration total values had different trends for each operator. The operator #1 registered the highest acceleration data in the full load condition (more than 25 ms^{-2} at the front hand position and 23 ms^{-2} at the rear). In the idling tests, the operator #2 had the highest value at the front hand position (more than 18 ms^{-2}), while the operator #3 detected the highest rear hand acceleration value (more than 13 ms^{-2}). The ANOVA test never revealed likeness among the three operators, while the post-hoc Dunnett's test coupled the operators in different way, in function of the operative condition and of the hand position (Table 3).

The differences obtained are due to the different operator's behavior conducting the beater. Considering also the lack of handles in these machines and the personal attitude of each operator to grasp the pole at different rod points and with a different clutch (as observed by the video), because the aim of the work was to calculate the vibration daily exposure using different models of electric hand held olive beaters, to avoid the operator uncertainty an unique skilled operator was considered.

Table 3 here

3.2 The vibration total value (a_{hv})

3.2.1 Idling state

The A1 and B1 harvesters registered the lowest acceleration values, both at the front and at the rear hand positions, while the B2 harvester had the highest accelerations (around 19 ms^{-2} at both the hand positions). The vibration differences among the beaters are due to the different machines balance, related to structural parameters. The Kruskal-Wallis non parametric test (used because the variance homogeneity was not verified) on front and rear a_{hv} data confirmed the previous differences among the shakers. The Dunnet's multiple comparison procedure then revealed a unique likeness between the A1 and B1 beaters at the rear hand position (Table 4).

Table 4 here

3.2.2 Full load condition

Full load acceleration data reached extreme values higher than 35 ms^{-2} at the front hand position and 28 ms^{-2} at the rear, with different data variability among the models.

Considering the averages of the vibration total values, at the front hand position they were between 10 and 30 ms^{-2} at the front hand position and between 5 and 23 ms^{-2} at the rear. The Kruskal-Wallis non parametric test on a_{hv} confirmed the discussed differences among the shakers and the Dunnet's multiple comparison procedure revealed only one likeness between the B1 and the B2 at the front hand position (probably linked also to a high data variability, as confirmed by the SD, Table 5).

Table 5 here

3.3 The equivalent vibration total value ($a_{hv,eq}$)

From this moment on, only the highest a_{hv} vibration total value, corresponding to the front hand position, was used to calculate the equivalent vibration total value $a_{hv,eq}$ for each beater. These values, Table 6, have the same trend of the previously calculated a_{hv} data for the front hand position, with a little difference in the B2 shaker which shows an $a_{hv,eq}$ average value very similar to the full load: the explanation is its high acceleration value in the idling condition. For this reason the Dunnett multiple comparison procedure for mean differences did not reveal likeness among the B1 and the B2 shakers, as previously observed: one likeness was accomplished between the beaters B2 and C2.

Table 6 here

In Figure 4 the box plot shows the median and the quartiles (25^{th} and 75^{th} at the box borders) of the $a_{hv,eq}$ values, which are quite variable, as already observed in Table 6. Only the A1 beater shows homogeneous measures around 10 ms^{-2}.

Figure 4 here

3.4 The daily vibration exposure *A(8)*

Concerning the daily vibration exposure *A(8)*, even the most favourable scenario with the lowest exposure duration (3 hours) gives acceptable results for any beater (Table 7): all data are higher than 5 ms^{-2}, the exposure limit value. In this context, the machine cannot formally be used for the expected time. The situation is obviously worse in the real field investigated, where these machines are used for 4.5 hours.

These high acceleration values, as the 2002/44 Directive states, permit to work for less than half an hour (Figure 5) to stay under the EAV (2.5 ms^{-2}), while for the ELV (5 ms^{-2}) the maximum allowed working time is less than two hours (Figure 5), but only for the A1 beater: for all the other machines the TLV is always less than one hour.

Table 7 here

Figure 5 here

Monarca *et al.* (2007a) in field observed *A(8)* values ranging from around 5 to 8 ms^{-2} at the most exposed upper limbs (using similar electric beaters), for a working period of 7 hours.

Also Catania *et al.* (2013) obtained worse *A(8)* values in other two types of hand held olive harvesters (hook and flap) tested in field, with data higher of 42 and 20 ms^{-2} at the right hand, respectively for the hook and the flap (the duration time was 4 hours). Lower values were registered at the left hand (more than 30 and 18 ms^{-2} for the hook and the flap).

4. Conclusions

Even though the limits of this work (e.g. one operator, one site, one olive variety) some interesting results were obtained: for example, the chance to follow step by step the harvesting work of a skilled operator by video, gave the possibility to review the operator's behaviour during the harvesting and afterwards to discuss with him both the harvesting method with the beaters (to appreciate possible differences among them) and the acceleration values. The target of the work was not only to compare vibration data by different electric harvesters of the same type among them, but also to analyse the meaning of these numbers for the operator.

All the examined beaters show high acceleration values and almost all of them could not be normally used for more than 5-10 minutes to stay under the time action value.

A criticism could be moved against these times, observing that these machines are not used during all the year, but only for few months (or, in some cases, for few weeks), but the European Directive 2002/44 does not mention exposures which only occur for few weeks: EAV and ELV arising from seasonal works are to be treated as the same values that continue throughout the year (Griffin, 2004).

As cited by the same Author a qualitative guidance (more than the quantitative one) is the best approach to afford the HAV question, in this case with a better beater design.

However, observing the operator at work with these machines, it was marked that the beater lightness could not deaden the energy released from the sticks when they hit the branches. On the other hand the lightness of the beaters is a main requirement to use them for a long time: the operator, in fact, performs from 25 to 40 approaches per minute to the tree branches with the machine head, as observed by video.

Moreover, the beaters which give out higher acceleration values are preferred by the operators, because these machines detach the drupes better and they accordingly permit an higher work productivity, as:

1. many workers are paid in function of the harvested olives, not of the worked hours;

2. the olives must be bestowed to the oil mills at specific times and the harvested fruits cannot stay stored for a long time, worth their quality loss;

3. the olive groves dimension in these areas are small and the farmers cannot afford high manpower expenses.

The workers therefore passively accept to have a tingling sensation in the fingers at the end of the olive harvesting daily work: after observing the high vibration data emitted by the harvesters, the operator involved in this work was able to realize this occurrence. A next step will be to involve also the manufacturers, providing them with standards to certify the vibration values of their machines in the user manual.

There are other risks for the operators that use these beaters: the upper limb working musculoskeletal disorders (UL-WMSDs). In fact, in this work it was observed that the operator worked with the arms over the shoulders for almost all the harvesting time and this occurrence, together with the frequency and repetitiveness of movements (25 to 40 per minute), the use of the force and the duration of exposure (more than 4 hours per day) may result in extremity disorders (Colombini *et al.*, 2007).

It should be more suitable that the operators that use the electric beaters deeper knew all the risks rising from machines like these, also if they apparently are both less dangerous than the cutting machines (chainsaws, for example) and used for short periods of the year. Physical risks (as hand arm vibration are) are still less known and long term risk factors are not yet widespread, especially in the olive growing sector, where operators are exposed to HAV with a large amount of hand held machines (e.g. brush cutters, pneumatic shears, hand guided cultivators) during all the year long.

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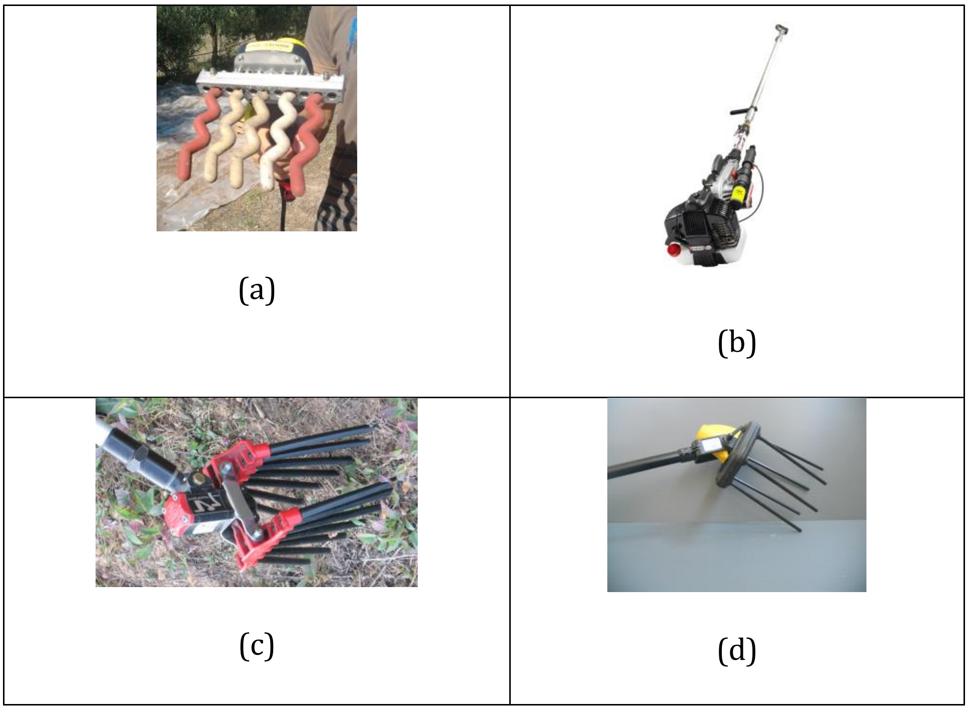

Figure 1. Some types of hand held olive harvesters (a: comb, b: hook, c: flap, d: beater)

Figure 2. The hand held olive harvesters studied in this work (from left to right: C2, B1, B2, A1). The C1 beater is omitted because it has the same shape of C2.

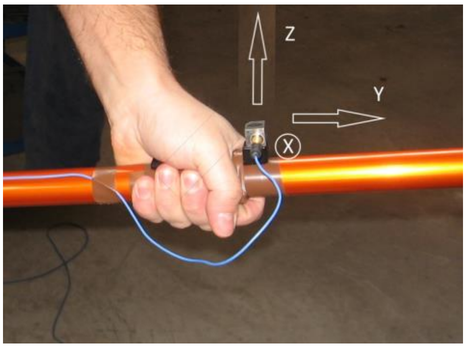

Figure 3. Vibration measurement directions on the harvester pole

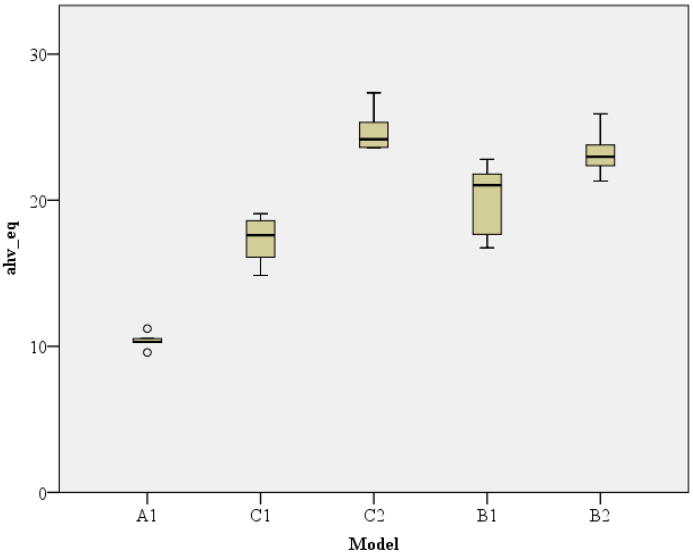

Figure 4. Boxplot of median and quartiles (25th and 75th at the box borders) of the equivalent vibration total values ($a_{hv,eq}$) of the examined beaters

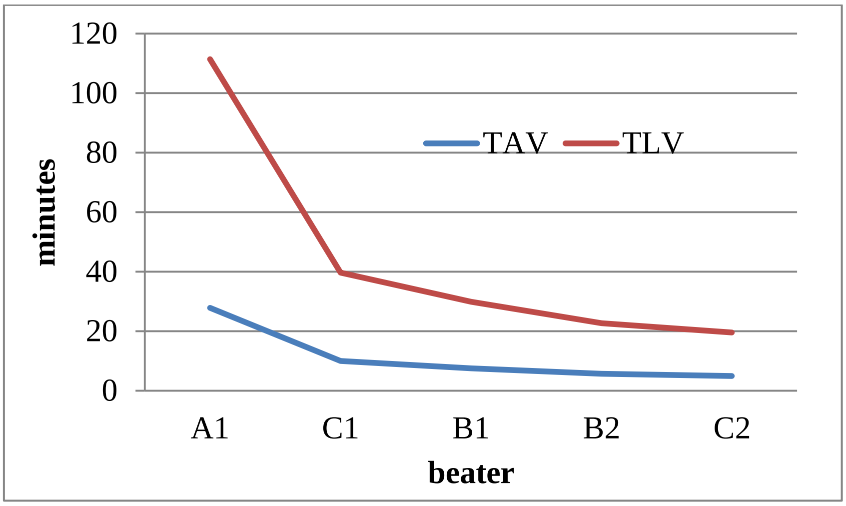

Figure 5. Time action (TAV) and time limit (TLV) values trends in the examined beaters

Table 1. Technical characteristics of the tested beaters.

Technical data	Unit	A1	B1	B2	C1	C2
Beats per minute	bpm	1020	1035	1086	1150	1320
Mass without power cord	g	2000	2200	1800	1650	1650
Telescopic pole length	m	2.40-3.70	2.50-4.50	1.30-2.50	1.70-3.10	1.70-3.10
Sticks number		6	6	5	8	8
Sticks length	mm	360	360	360	350	350
Stick diameter	mm	5	10	10	5	5
Supply voltage	V	12 - 24	12 - 24	12	12	12
Current cons. (work)	A	4-5	4-5	5	3-5	5

Table 2. Operators characteristics.

Operator code	Height (cm)	Mass (kg)
1	185	90
2	175	82
3	180	75

Table 3. Analysis of the vibration total values in idling and full load conditions (at front and rear hand position) and Dunnett's multiple comparison procedure among the means (different letters in the columns denote a statistically significant difference at the 95% confidence level) of the three operators using the C2 beater.

Op_code	Idling-front a_{hv}	Idling-rear a_{hv}	Full load-front a_{hv}	Full load-rear a_{hv}
		Average ± standard deviation (ms^{-2})		
1	15.65 a ± 0.29	12.79 a ± 0.26	25.57 a ± 1.49	23.19 a ± 1.63
2	18.45 b ± 0.34	9.94 b ± 0.14	21.77 b ± 1.74	17.74 b ± 1.91
3	13.37 c ± 0.52	13.10 a ± 0.11	22.17 b ± 1.99	17.55 b ± 1.32

a_{hv}, vibration total value

Table 4. Averages and standard deviation of the vibration total values in idling conditions (at front and rear hand position) and Dunnett's multiple comparison procedure among the means (different letters in the columns denote a statistically significant difference at the 95% confidence level) for the different beaters type used by the operator #1.

Model	Average front a_{hv} ± SD (ms^{-2})	Average rear a_{hv} ± SD (ms^{-2})
A1	2.18 a ± 0.19	1.78 a ± 0.26
B1	6.24 c ± 0.06	1.91 a ± 0.05
C1	11.55 d ± 0.40	10.07 c ± 0.39
C2	15.65 f ± 0.29	12.79 d ± 0.27
B2	18.79 g ± 0.64	18.78 e ± 0.94

SD, standard deviation; a_{hv}, vibration total value

Table 5. Average acceleration values and standard deviation in full load conditions (Kruskal-Wallis non parametric test) at front and rear hand positions and Dunnett's multiple comparison procedure for mean differences (different letters in the columns denote a statistically significant difference at the 95% confidence level).

Model	Average front a_{hv} ± SD (ms^{-2})	Average rear a_{hv} ± SD (ms^{-2})
A1	11.18 a ±0.63	5.47 a ±0.47
C1	18.18 b ±1.63	16.00 b ±1.66
B1	21.49 c ±2.41	12.86 c ±1.24
B2	23.66 c ±1.20	19.90 d ±2.68
C2	26.03 d ±1.75	22.55 e ±1.38

SD, standard deviation; a_{hv}, vibration total value

Table 6. Analysis of the average and standard deviation of the equivalent vibration total values (Kruskal-Wallis non parametric test) and Dunnett's multiple comparison procedure for mean differences (different letters in the columns denote a statistically significant difference at the 95% confidence level)

Model	Average $a_{hv,eq}$ ± SD (ms^{-2})
A1	10.38 a ±0.59
C1	17.39 b ±1.46
B1	20.04 c ±2.22
B2	23.03 d ±1.05
C2	24.81 d ±1.58

SD, standard deviation; $a_{hv,eq}$, equivalent vibration total value

Table 7. Equivalent vibration total values, daily vibration exposure (180 and 270 minutes scenarios), time action and time limit values

Model	$a_{hv,eq}$	*A(8)* Scenario 3 hours	*A(8)* Scenario 4.5 hours	TAV (2.5 ms^{-2})	TLV (5 ms^{-2})
		ms^{-2}		min	min
A1	10.38	6.36	7.78	28	111
C1	17.39	10.65	13.04	10	40
B1	20.04	12.22	14.97	7	30
B2	23.03	14.10	17.27	6	23
C2	24.81	15.19	18.61	5	19

$a_{hv,eq}$, equivalent vibration total value; *A(8)*, daily vibration exposure; TAV, time action value; TLV, time limit value