International Journal of Industrial Ergonomics

Volume 53, May 2016, Pages 86–92, doi:10.1016/j.ergon.2015.10.006

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ABSTRACT

In this paper we present the outcome of a Round Robin test carried out to validate a proposed standard procedure to measure the acceleration produced by an hand held olive harvester. Ten independent laboratories using a custom-built device were involved. The device was developed to simulate olive tree branches as far as their interaction with the harvester sticks is concerned.

Collected data were analysed according to the ISO 5725-2 procedure. Accelerations measured in three of the ten laboratories were found by a cluster analysis to be statistically different from those of the remaining seven laboratories. Based on this evidence, results from the three stray laboratories were eliminated from the final sample.

Laboratory data were shown to be statistically consistent with field data in the dominant front and rear X axes as well as in the rear Z axis. No statistically significant discrepancy were found for the front and the rear acceleration vector sums, which are the quantities used to quantify the occupational exposure. The procedure developed in this Round Robin test could represent a viable basis for a future test standard for hand-held olive harvesters.

Keywords: Olive harvester, hand-arm vibration, round robin test

1. INTRODUCTION

The detachment of olives by means of a hand held harvester is not an easy task, because of the small mass and high attachment strength of the drupe (Fridley et al., 1972; Tsatsarelis, 1987). Among the different types of hand-held olive harvesters which are commercialized (beaters, combs and hooks), beaters are the most widely used. Beaters, usually pneumatic or battery powered, consist of a head equipped with oscillating carbon fibre sticks (with a 5 to 10 mm diameter). The head is supported by a telescopic aluminium pole, which can be up to 3.5 metre long. The impact of sticks on the olives or on the willowy branches causes the fruit detachment.

Hand-held harvesters are known to produce strong vibration, and their prolonged use may cause the so called Hand-Arm Vibration Syndrome (HAVS) of the muscle-skeletal, nervous and vascular peripheral structures of the upper limb (Bovenzi, 1998; Bovenzi, 2005).

The EU directive 2006/42/EC (also known as Machinery Directive) mandates that commercialization of a tool should always be accompanied by detailed information which also include data on vibration emission. Such data are usually collected using standard tests, where actual operating conditions are simulated. By providing a rigid test protocol, the aim is to make test conditions identical in different laboratories, so that results, while possibly not fully representative of actual working conditions, can be reliably compared. The majority of existing vibrating tools, including hand held olive harvesters, lacks such standard test methods to measure vibration. Vibration data are accordingly either entirely omitted by manufacturers or at best are measured according to generic standards, so that they cannot claim any relationship to actual field data.

In this paper we present the outcome of a round robin test where the vibration of one olive harvester has been measured by ten independent laboratories. Similar tests have been carried out on angle grinders (Liljelind et al., 2010) mostly aimed at elucidating the various concurring sources of variability.

The results found in this paper could represent the basis for a future standard where a common test method is established, that can be used by all manufacturers to simulate field operations using a laboratory device, and guarantees both repeatability and reproducibility as well as vibration magnitudes close to field values.

2. METHODS

2.1. The tree-simulator

The test method proposed in this work is based on a custom built device (Deboli et al., 2014, hereafter "tree simulator") intended to provide a good approximation of the olive tree branches in terms of their interaction with the harvester. Investigations of hand-transmitted vibration make frequent use of simulators, since these devices allow the study to be carried out under better controlled and repeatable laboratory conditions (McDowell et al., 2012). The tree simulator consists of a rectangular wooden frame (500 mm high and 600 mm wide) with nine vertical and nine horizontal regularly spaced wires (Figure 1).

Figure 1 – The tree simulator with the harvester

Multifilament polypropylene UV stabilized wires, braid 16 spindles, 4 g/m specific mass, 90 kg breaking load are used: they are soft and pliable, but provide good mechanical resistance. The upper end of each vertical wire is secured to the frame, whereas the lower end is left free and loaded with a 1 kg iron mass (Figure 1) in order to create an adequate tension: field measurements show in fact that an average force of 10 N is required to laterally bend the smaller twigs (diameter 2 to 5 mm) by 2 – 3 cm. The horizontal wires (spaced 40 mm apart and secured at both ends to the frame with a pre-tension load of 10 N) interweave the vertical wires. Masses of 1 kg were initially added to the right end of each horizontal wire of the device, to reproduce a 10 N force (to simulate the presence of larger twigs, as observed in field). After pre-tensioning, the wires were blocked and the load was removed. The tree simulator is supported by a wooden chassis so that its geometric centre is located at a height of about 1750 mm above the ground. The total mass, including the nine 1 kg iron masses, is 15 kg. The tree simulator was designed and originally assembled by the Institute for Agricultural and Earth-moving Machines of the Italian National Research Council, in Turin (hereafter "IMAMOTER").

2.2. The olive harvester

All tests were carried out using a battery powered (12 V) beater with a head equipped with eight oscillating carbon fibre sticks.

Table 1 – Summary of the harvester characteristics

Quantity	**Unit**	
Working capacity	kg/h	100-400
Beats per minute	bpm	400-1400
Head mass	g	750
Telescopic pole mass	g	900
Telescopic pole length	mm	1700-3100
Stick length	mm	350
Stick diameter	mm	5
Supply voltage	V	12
Current consumption	A	2-5

Standby consumption	A	0.5
Tangential stick speed at the tip	m/s	4.14

All technical characteristics are summarized in Table 1. A cylindrical, metallic 1830 mm long pole was used in all tests. The beater featured electronic control to lower the number of beats per minute from 1400 to 400 when idle. The interaction of the strings of the tree simulator (Figure 2) with the harvester sticks induces a vibration of the latter, that was transmitted by the pole to the operator hands and arms.

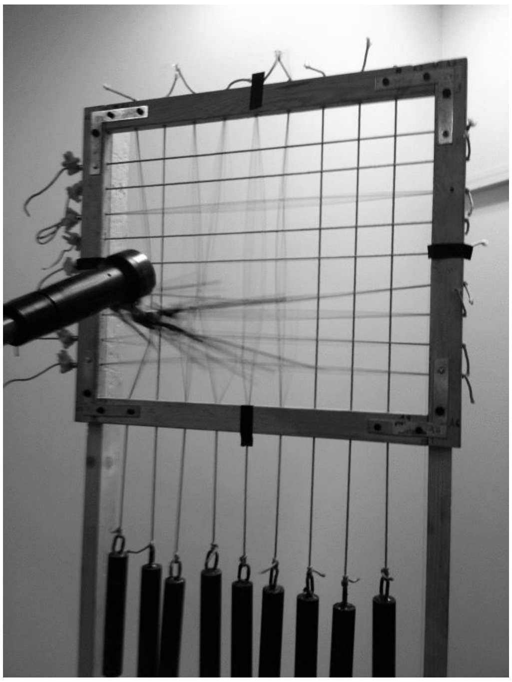


Figure 2 – The harvester interacting with the tree simulator

2.3. Measurements

2.3.1 Measurement protocol

The tree simulator was separated into four quadrants, bounded by black ribbons positioned on the frame (Figure 2). The operator was instructed to direct the beater head to the tree simulator, and make the sticks collide with the wires in a specific quadrant, for a period of 10 seconds. Red ribbons were glued on the sticks 8 cm from the tip, to show the operator the right portion to be inserted through the tree simulator wires. He then proceeded to move the beater head (with no pause) clockwise to the adjacent quadrant, where the sticks remained again for 10 seconds, and so on until test completion after two minutes. The test timing was set by a chronometer which emitted a buzz every 10 seconds. The requirement to direct the sticks to a specific area was intended to simulate conditions similar to those encountered in field measurements, where the operator is forced to tighten the front grip to precisely address given tree areas.

The operator worked always with the machine at full throttle, through the entire 2 minute measurement time. At no time during the test did the harvester switched to the idle mode. Accelerations were calculated as r.m.s. at the end of the 2 minute measurement time. This duration was selected as representative of periods of continuous operation at full throttle by professional workers operating in the field (1.5-2.5 minutes). After this time they usually take the machine away from the olive branches and move to a different area of the tree with the beater in the idle mode.

2.3.2 Measured quantities

Six accelerations were measured for each subject, by means of two triaxial accelerometers in six laboratories (simultaneous measurements) and one triaxial accelerometer in four laboratories (sequential measurements). In order to ensure consistent and homogeneous data collection, an instruction booklet (with schemes and figures) was prepared and shipped along with the tree simulator. The booklet included: instructions on how to properly assemble the device, a step-by-step illustration of the test procedure (including all the actions to be performed during the test) and the data report methodology. The booklet also requested the insertion of a plastic ribbon between the accelerometers and the metallic rod of the harvester to ensure electrical insulation.

Accelerometers were positioned on the pole, near the front and the rear hand of the subject (Figure 3), following the recommendations of EN ISO 20643/A1 (2012). All accelerometers were oriented according to the same axial reference frame: X is left to right, Z is up/down, both in the plane perpendicular to the harvester pole, and Y is along the pole (Figure 3). All the accelerometers were calibrated before tests. Accelerations were frequency weighted using the weighting curve Wh as described in EN ISO 5349-1 (2001). The resulting values were indicated as a_{hwXf}, a_{hwYf}, a_{hwZf} and a_{hwXr}, a_{hwYr}, a_{hwZr} for the front and rear accelerometer respectively. Large variability may emerge as a result of different feed forces applied by different operators, mostly because a higher the feed force results in a stronger coupling between the hand and the tool (Moschioni et al., 2011). In this work, however, since the feed force exerted by the operator on the tool is very limited, this quantity was not measured, neither in the field, nor in the laboratories.

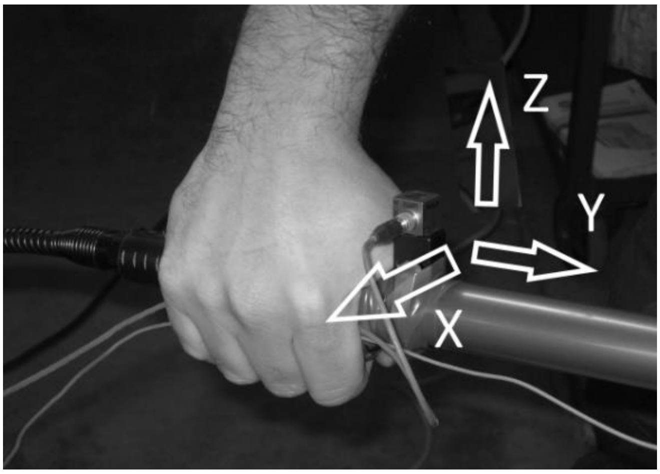


Figure 3 – A triaxial accelerometer positioned near the hand

2.3.3 Round robin scheme

Ten laboratories located in different areas of Italy participated in a round robin test where the tree simulator and the harvester were tested. Each laboratory was qualified in vibration measurements and owned its own instrumentation, which was used during the round robin test. The same harvester was circulated among all laboratories and used in all tests, which were carried out from January to October 2013. The same tree simulator was also circulated. This required that it was assembled and disassembled at each laboratory, which was carried out according to an instruction booklet, also circulated among all laboratories. In each laboratory tests were carried out by three to seven subjects, the most typical number being five. All involved subjects were researchers. Most of them were inexperienced; only some of them had gained significant experience through previous work in olive harvesting campaigns.

In synthesis, test conditions varied among different subjects in the same laboratory for two reasons both related to the subjects' anthropometric characteristics:

1. different subjects operated the harvester with different grip and feed forces;
2. different subjects grip the pole in different points, since electric beaters do not have handles. Because EN ISO 20643 (2008) requires that measurements must be carried out positioning the accelerometers as close as possible to the grip, this also implies different positions of the accelerometers on the pole.

Additionally, test conditions varied among different laboratories because:

3. the tree simulator was assembled with slightly varying string tensions;
4. measurements were taken using different instrumentation.

2.3.4 Field tests

Field tests were performed near Savona, north-west Italy, during the harvesting season (fall, 2012), using the same harvester subsequently used in the Round Robin test.

Two teams of five subjects each were involved in field tests. Only three of the ten subjects were experienced in olive harvesting with the beaters. Each team had its own instrumentation which included two tri-axial accelerometers. Accelerometers were positioned and oriented in the same way as in the laboratory tests.

The field test procedure replicated the work usually done during the olive harvesting campaign: the operator first approached the tree with the instrumented beater in the idle mode; then, as he inserted the sticks into the branches, the beater switched to full power mode, and remained in this condition for the time necessary to collect the olives (around 2 minutes).

3. DATA ANALYSIS

3.1 Mean and coefficient of variation

Data analysis was carried out using the software Kyplot. All experimental data were initially used to calculate the arithmetic mean and the coefficient of variation (CV = standard deviation / arithmetic mean) for each of the six accelerations and each of the ten laboratories.

3.2 Normality of the distributions and outliers

Pre-condition for any further analysis is that the investigated sample is homogeneous. The possible existence of outliers among the ten laboratories was checked using a Grubbs' test (Grubbs, 1969). Because Grubbs' test can only be applied to data that follow an approximately normal distribution, a Lilliefors test (Abdi and Molin, 2007) was preliminarily used to check this assumption.

3.3 Cluster Analysis

A further possibility that deserves careful scrutiny, is that the sample of 10 laboratories may actually consist of two distinct subsamples. This possibility was investigated using a 2D cluster analysis, restricted to the two dominant quantities (a_{hwXf} and a_{hwXr}). The analysis considered each individual subject participating in the tests, in order to have a larger sample to work with and detailed information on the behaviour of possible stray subjects within each laboratory. Clusters were hierarchically assembled, using the Ward's method. Standardized euclidean distances were adopted (Everitt et al., 2011).

3.4 Consistency of a possibly stray laboratory with a group of established laboratories

The possible inconsistency of one specific laboratory with a larger group of established laboratories has been investigated through the application of a purpose-designed test (Wittstock, 2007; Wittstock and Scholl, 2009; EN ISO 12999, 2014), where the statistic

$$CrD_{95} = 2\sqrt{\sigma_R^2\left(1+\frac{1}{p}\right)-\sigma_r^2\left(1+\frac{1}{p}-\frac{1}{n_t}-\frac{1}{p^2}\sum_{i=1}^{p}\frac{1}{n_i}\right)} \qquad (1)$$

is compared to the difference between the mean acceleration a_t found in the tested laboratory and the mean acceleration $\bar{a}$ of the established group

$$D = |a_t - \bar{a}| \qquad (2)$$

In equation (1),

- σ_R is the reproducibility standard deviation;
- σ_r is the repeatability standard deviation;
- p is the number of laboratories in the established group;
- n_t is the number of measurements carried out in the tested laboratory;
- n_i is the number of measurements carried out in the i^{th} laboratory of the established group.

3.5 Synthesis of laboratory data

Data analysis was undertaken following the procedure outlined in ISO 5725-2 (1994). The round robin test results were synthesized for each of the six measured accelerations a_j, using a grand mean m_j and a between-laboratory standard deviation σ_{Lj}

3.6 Comparison with field data

Field data were independently collected by two teams, each with its own measurement instrumentation and experimental set-up. A mean and a standard distribution were therefore calculated for each team. Field data were eventually summarized, for each of the six accelerations a_j, using the mean of the two teams a_{fj} and by the standard deviation σ_{fj} between the two teams.

In order to check whether the Round Robin test results can reliably predict field data, six independent t-tests for the difference between two means have been carried out. The critical value for such tests, with a 95% confidence level and $\nu = 7$ degrees of freedom, is $t_{0.05,7} = 2.365$.

4.RESULTS AND DISCUSSION

4.1 Mean and coefficient of variation

A synthesis of results is provided in Table 2, showing the arithmetic mean and the coefficient of variations (CV = standard deviation / arithmetic mean) for each of the six measured accelerations. Figure 4 shows that the inter-subject coefficient of variation, within the same laboratory, lies between 5% and 35% in 56 out of 60 cases (93%).

Table 2 – Means and coefficients of variation for the six measured quantities and the 10 laboratories participating in the round robin

Mean							
Lab	**# of subj.**	**a_{hwXf}**	**a_{hwYf}**	**a_{hwZf}**	**a_{hwXr}**	**a_{hwYr}**	**a_{hwZr}**
		(ms^{-2})	**(ms^{-2})**	**(ms^{-2})**	**(ms^{-2})**	**(ms^{-2})**	**(ms^{-2})**
A	5	30.3	1.7	11.3	28.2	2.4	5.9
B	5	33.0	2.1	9.7	29.1	2.2	5.6
C	5	9.7	1.4	10.0	13.6	1.6	5.4

D	5	26.5	2.0	9.4	20.8	5.1	4.9
E	7	8.5	1.6	5.2	8.2	1.6	5.7
F	4	11.8	1.7	5.3	13.9	1.9	3.3
G	3	24.0	2.2	10.3	28.5	4.5	6.7
H	5	18.3	1.8	8.3	20.6	2.4	3.9
I	5	26.4	2.5	7.4	22.8	2.8	5.7
J	3	26.6	1.6	9.5	25.9	2.3	5.1
Coefficient of Variation							
A	5	0.12	0.10	0.13	0.04	0.11	0.08
B	5	0.18	0.10	0.14	0.16	0.10	0.19
C	5	0.18	0.25	0.26	0.13	0.24	0.39
D	5	0.20	0.16	0.14	0.12	0.21	0.34
E	7	0.29	0.09	0.32	0.23	0.22	0.28
F	4	0.10	0.06	0.20	0.14	0.08	0.17
G	3	0.07	0.16	0.19	0.06	0.45	0.15
H	5	0.26	0.05	0.10	0.18	0.14	0.20
I	5	0.18	0.18	0.33	0.18	0.16	0.59
J	3	0.08	0.16	0.08	0.14	0.07	0.11

Larger values appear in just three cases, and never in the dominant front and rear X axes. Variations of this magnitude are not unexpected given the different conditions determined by the subjects' anthropometric characteristics discussed in §2.3.3, items 1 and 2. Similar investigations carried out for different tools (Liljelind et al., 2011, for angle grinders) also found inter-subject standard variations to be in the range 15 – 30% of the mean.

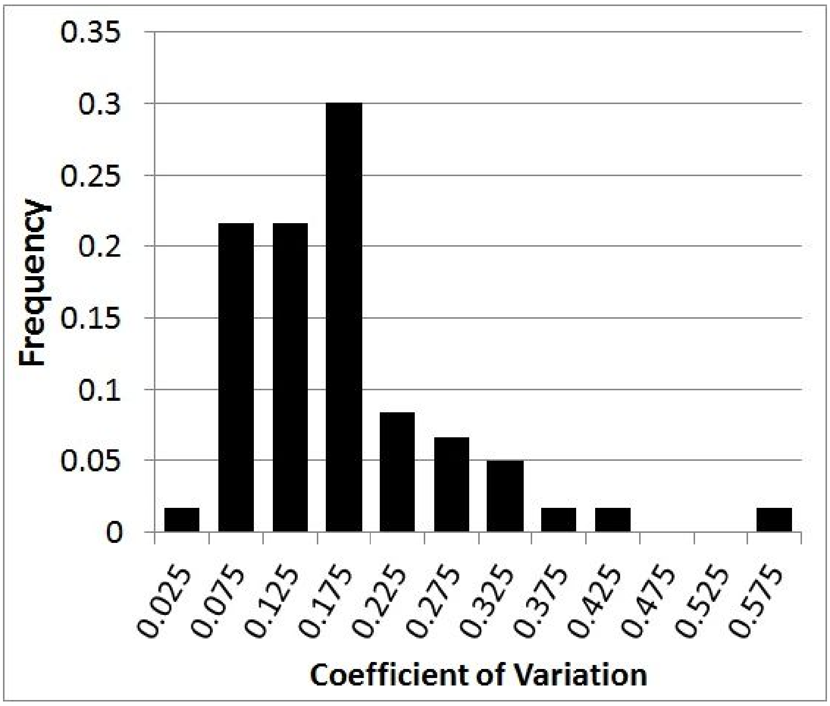
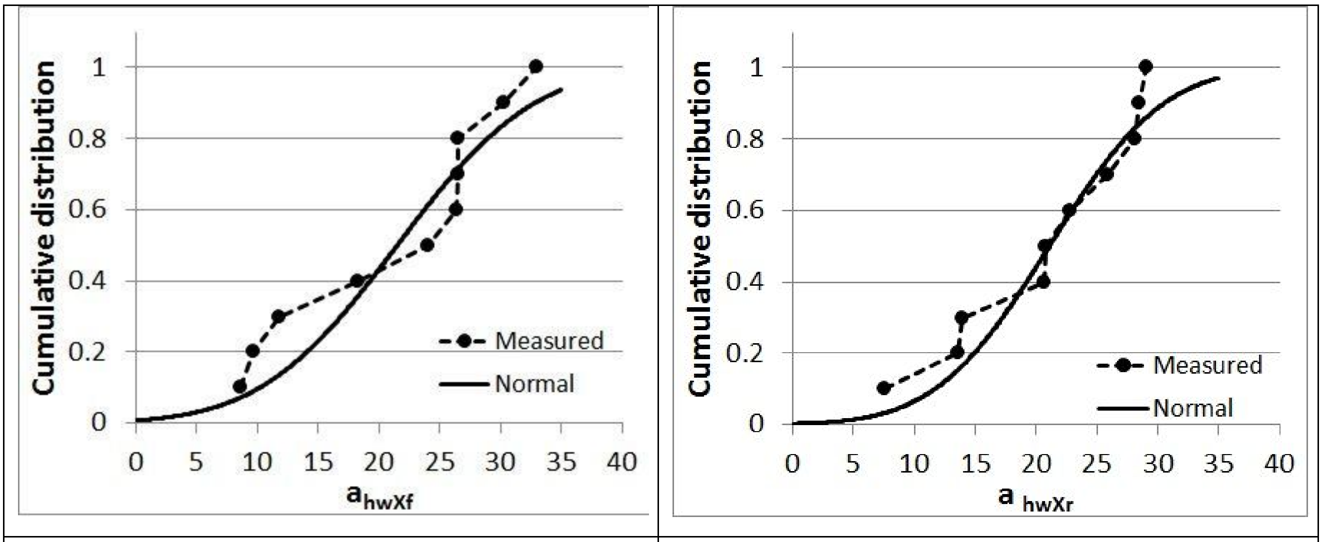


Figure 4 – Normalized distribution of the 60 CV's shown in Table 2

4.2 Normality of the distributions and outliers

The Lilliefors test statistic for the six acceleration datasets ranged from 0.137 to 0.196: none of the values exceeded the critical value, which for a sample size of 10 elements and a confidence level of 95%, is 0.2616. In practice this means that the null assumption that the distribution is normal cannot be rejected. This was somehow expected given that samples are all very small (10 elements) and the ratios of the standard deviation to the mean are all quite large (Table 2). Figure 5 shows the cumulated experimental and theoretical distributions for the two dominant accelerations a_{hwXf} and a_{hwXr}.

Having verified that a normal distribution is consistent with each sample, six Grubbs tests were performed, one for each acceleration. None of the 60 values (6 variables, 10 laboratories) was found to exceed the critical test value of 2.29 (Table 2), which was determined using the same assumptions of a sample size of 10 and a confidence level of 95%. No true outlier could accordingly be identified.



(a) (b)

Figure 5 – Experimental (dashed line) and normal (solid line) distributions of the front (a) and rear (b) X-axis accelerations in the ten laboratories

Table 3 – Results of Grubbs' tests

Lab	**# of subj.**	a_{hwXf}	a_{hwYf}	a_{hwZf}	a_{hwXr}	a_{hwYr}	a_{hwZr}
A	5	1.00	-0.43	1.23	0.96	-0.25	0.64
B	5	1.30	0.77	0.53	1.09	-0.41	0.40
C	5	-1.35	-1.45	0.66	-1.03	-0.86	0.18
D	5	0.57	0.40	0.37	-0.04	2.06	-0.29
E	7	-1.46	-0.79	-1.80	-1.84	-0.98	0.44
F	4	-1.10	-0.56	-1.51	-0.98	-0.63	-1.93
G	3	0.28	1.06	0.80	1.01	1.51	1.55
H	5	-0.37	-0.23	-0.15	-0.06	-0.23	-1.31
I	5	0.55	1.86	-0.54	0.23	0.12	0.49
J	3	0.57	-0.63	0.42	0.65	-0.33	-0.16

4.3 Cluster Analysis

The combined presence in Table 3 of: a) very wide distributions and b) a few laboratories, most notably laboratories C E and F, showing large Grubbs statistics, strongly suggests the presence of two sub-samples in the group of ten laboratories. The dendrogram built from the sample of 47 subjects (Figure 6) shows the existence of two well separated clusters which join together only at a distance about three times larger than the size of each individual cluster. The distance between cluster centroids is 22.33 ms^{-2}; the cluster radii are 7.60 ms^{-2} and 4.05 ms^{-2} for the larger and smaller cluster respectively.

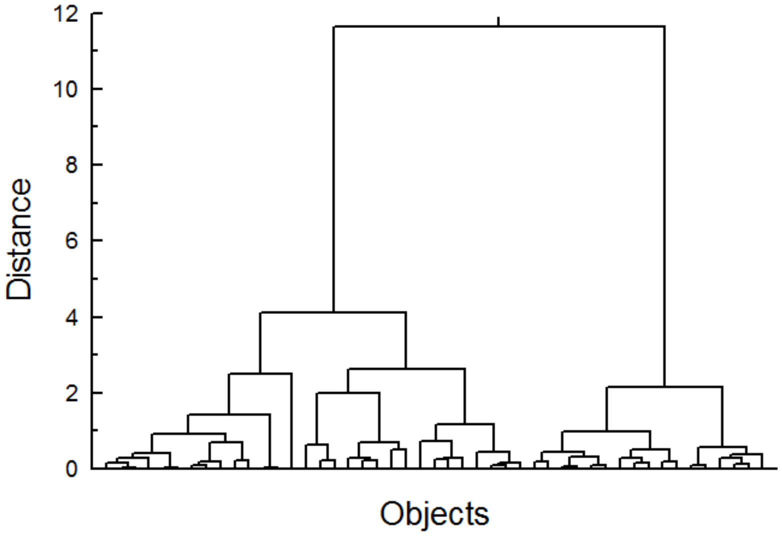


Figure 6 – Dendrogram of hierarchical clustering

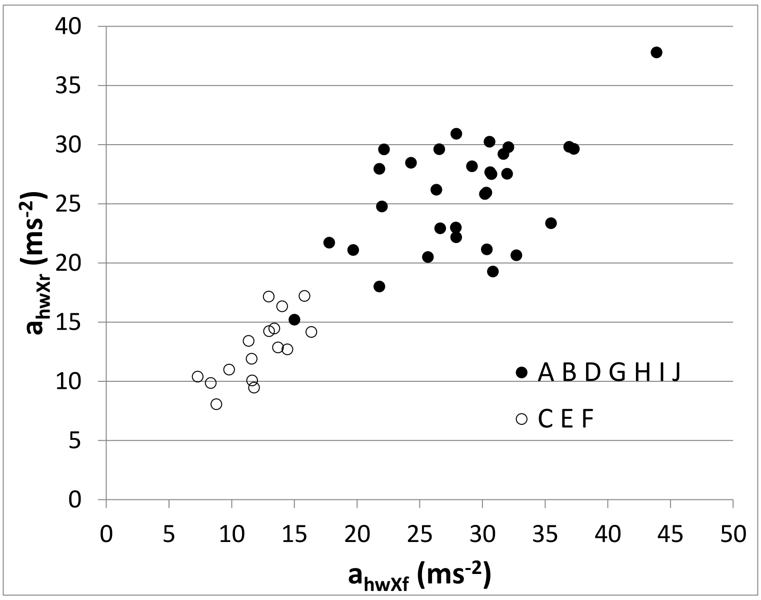


Figure 7 – Graphical illustration of the two clusters found by cluster analysis

Figure 7 clarifies that the two clusters found by CA reflect almost exactly (apart from one point) a separation of the original group of ten laboratories into the two subgroups of seven (A B D G H I J) and three (C E F) laboratories. The latter include precisely those three laboratories previously singled out for their peculiarly large negative values in the Grubbs test.

4.4 Consistency of a possibly stray laboratory with a group of established laboratories

Wittstock test (§3.4) has been used to check the consistency of each of the three laboratories belonging to the smaller group (C E F), with the larger group of seven laboratories (A B D G H I J).

Table 4 – Results of the Wittstock test. In italics: cases where the test was passed

	a_{hwXf}	a_{hwYf}	a_{hwZf}	a_{hwXr}	a_{hwYr}	a_{hwZr}
Laboratory C						
D (eq. 2)	*16.8*	*0.6*	0.6	*11.6*	1.4	*1.9*
CrD_{95} (eq. 3)	*6.2*	*0.4*	0.7	*5.4*	2.2	*0.0*
Laboratory E						
D (eq. 2)	*18.0*	*0.4*	*4.2*	*16.9*	1.4	0.3
CrD_{95} (eq. 3)	*5.9*	*0.4*	*0.0*	*5.2*	2.2	1.9
Laboratory F						
D (eq. 2)	*14.7*	0.3	*4.1*	*11.2*	1.2	*2.1*
CrD_{95} (eq. 3)	*6.4*	0.4	*0.9*	*5.6*	2.2	*1.9*

Table 4 shows that the critical value CrD_{95} (equation 3) is exceeded in many cases (*in italics*), and in particular for the two dominant accelerations a_{hwXf} and a_{hwXr}, by all the three tested laboratories (C E F). Based on the consistent outcome of the cluster analysis and the Wittstock test, the three laboratories (C E F) have been removed from the sample. Any further analysis has been carried out on the remaining seven laboratories (A B D G H I J). Post-factum scrutiny has shown evidence that the discrepancy was possibly due to incorrect assembling of the harvester, itself due to misunderstanding of instructions: in the harvester as assembled by the three laboratories C, E and F, the anti-breaking devices, positioned between the sticks to avoid their bending (marked with B in Figure 8), were missing. Without the anti-breaking devices, the sticks were more flexible, their impacts against the tree simulator were of lower intensity, which in its turn resulted in lower vibration levels.

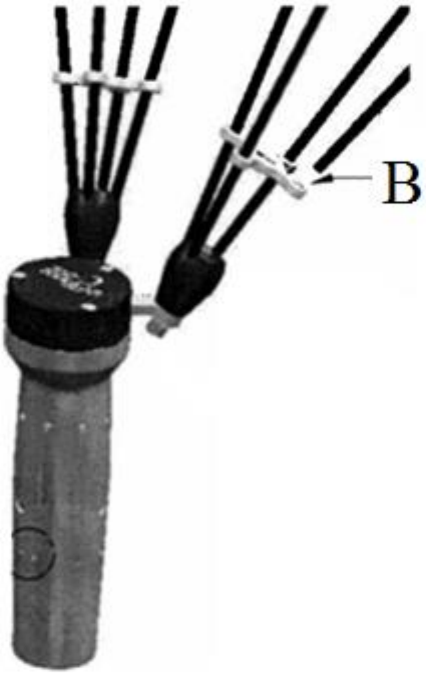


Figure 8 – Graphical instructions for the mounting of the anti-breaking devices (extracted from the beater user manual)

4.5 Synthesis of laboratory data

Table 5 shows that the inter-laboratory coefficient of variation CV is between 11% and 17% for four of the six measured accelerations. The large value found in the rear Y axis (38%) is of limited significance since the acceleration mean a_{hwYr} is extremely low. As discussed in the previous section detailing the Round Robin scheme, such fluctuations may be attributed to variations in the experimental set-up with respect to both the assembling of the tree simulator (in particular the string tensions), and the use of different instrumentation. Additionally, the measured vibration level is also influenced by the operator experience: inexperienced subjects have been found to operate the beater pole using stronger grip forces (Costa et al., 2013), which implies lower measured accelerations. The same trend has been observed for chainsaws by Malinowska-Borowska et al. (2013), who found that higher coupling forces were exerted by inexperienced tree fellers.

Similarly, Färkkilä et al. (1979) showed that higher coupling forces were applied by younger lumberjacks in comparison with older ones.

Table 5 – Comparison of Round Robin test results with field data. In italics: cases where the test was passed

Statistic	a_{hwXf}	a_{hwYf}	a_{hwZf}	a_{hwXr}	a_{hwYr}	a_{hwZr}	a_{wsumf}	a_{wsumr}
Round Robin test results								
m_j	26.6	2.0	9.3	24.9	3.0	5.3	28.2	25.6
σ_{Lj}	4.4	0.3	1.1	3.5	1.1	0.3	4.3	3.6
Field data								
a_{fj}	25.8	3.0	9.8	20.8	1.9	4.0	27.8	21.3
σ_{fj}	2.7	0.2	0.2	2.1	0.1	0.6	2.6	2.1
t test for the difference of two means								
t_j	0.30	*-5.31*	-1.14	2.05	*2.61*	*3.15*	0.16	2.12
$t_{0.95.7}$	2.365	2.365	2.365	2.365	2.365	2.365	2.365	2.365

4.6 Comparison with field data

Table 5 also presents the outcome of the t-tests carried out to check consistency between laboratory and field data. Results presented at the bottom of Table 5 show that there is no statistically significant difference for the accelerations along the two dominant axes a_{hwXf} and a_{hwXr}. The same holds for a_{hwZf}, which is the third largest of the six accelerations measured. There are statistically significant discrepancies on a_{hwYf}, a_{hwYr}, a_{hwZr} (in italics). Their relevance in the context of the accuracy of the declared emission value is however limited, given the low values of the accelerations along these three axes. This is confirmed by a test carried out on the values of the front and rear acceleration vector sums a_{wsumf} and a_{wsumr} (columns 8 and 9 of Table 5). Both tests fail to show any statistically significant discrepancy. Note that the mean vector sums a_{wsumf} and a_{wsumr} have been calculated as means of individual vector sums instead of as vector sums of mean axial accelerations, following the indication given in this sense by the ISO/IEC Guide 98-3 (2008), in the case of non linear functions.

5. CONCLUSIONS

Data collected during a Round Robin test carried out to validate a proposed standard procedure to measure the acceleration produced by an olive harvester were analyzed to check the method's suitability, which makes use of an original tree simulator.

Results from three of the ten laboratories which participated in Round Robin test were discarded due to inconsistencies most likely due to the incorrect assembling of the harvester.

Data analysis on the remaining seven laboratories shows that the magnitude of intra-laboratory standard deviations is between 5 and 35% of the mean. This is in excellent agreement with the outcome of a similar investigation carried out for for angle grinders (15 – 30%) and can be associated to the varying anthropometric characteristics of the subjects. The magnitude of inter-laboratory coefficient of variations (10 – 15% on the dominant X axes, up to 30% in the Y axes) is consistent with the expected variability associated to the different experimental set-ups in the different laboratories.

Laboratory data are statistically consistent with field data in the dominant front and rear X axes, as well as in the front Z axis. There are lingering statistically significant discrepancies for the accelerations along the front and rear Y axes and along the rear Z axis. However the tests carried out for the difference between laboratory and field acceleration vector sums fail to prove any statistically significant difference.

The very good overall agreement between laboratory and field data supports the adoption of the simulator and of the test procedure discussed in this paper in a future test standard for hand-held olive harvesters which is currently missing.

ACKNOWLEDGEMENTS

This work has only been possible thanks to the joint effort by the ten laboratories who took part in the Round Robin test.

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