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Vibration Transmission to the Hand-Arm System by Means of Portable Olive Beater: the Effect of Body Mass

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Olive is one of the oldest cultivated fruit in Mediterranean basin countries. Currently, full mechanic harvesting is getting more and more spread in super high density orchards for oil production, nevertheless in small sized farms (as well as in those producing table olives) hand harvesting by means of olive beaters is still the most used method. When operating hand held olive harvesters, workers undergo high levels of hand-arm vibrations (HAV). The prolonged exposure to these types of stresses could cause the so called hand-arm vibration syndrome (HAVS).
To determine which factors significantly affect operators' exposure, five operators having different body mass indexes were monitored. They were requested to operate a battery powered olive beater both in idling and simulated working conditions and the vibrations transmitted to their hand-arm system were acquired by means of daily calibrated ICP triaxial accelerometers. Rough data were processed in compliance with the UNI EN ISO 5349-1:2004 and 5349-2:2015 standards to calculate the vibration total value (a_v) the hand-arm system as the square root of the sum of the squares of the frequency-weighted accelerations along the axes (a_{wx}, a_{wy} and a_{wz}). Further processing foresaw statistical comparison tests and multivariate processing by means of Principal Components Analysis (PCA).
According to results, a_v values at the rear handle resulted lower than those at the front one in all the conditions and for all the operators. Multivariate analysis pointed out that, besides the axis of the vibration, operators' bodies can influence the recorded acceleration values.

1. Introduction

Olive (Olea europaea) is one of the oldest cultivated fruits that, from its homeland, has spread to Mediterranean basin countries (Sessiz and Özcan, 2006): among these, as reported by FAO (2016), Spain is the country with the highest cultivated surface (26.3% of world olive cultivated surface) followed by Tunisia (17.6%), Italy (12.5%) and Greece (8.8%). With particular reference to Italy, olive cultivation is mainly located in the South regions of the Country (62% of cultivated surface) that, basing on 2000-2011 data, provide for 77% of national olive production (Table 1), usually in hilly lands (ISTAT, 2016).
Despite the progressive introduction of olive tree super high density orchards for oil production (Proietti et al., 2015) has been making widespread the use of trunk shakers for olive harvesting, hand harvesting is still the most widely used. Even though economical feasible mechanical harvesting methods are actually in development to improve this sector competitiveness, in small farms the full mechanic harvesting could be uneconomical (Jimenez-Jimenez et al., 2015). Hand held olive harvesters are particularly used in sloping/terraced grounds (Sessiz and Özcan, 2006) and can be either pneumatic or electric. Equipped with small motors and one telescopic extension pole, they allow the picking up of the fruits thanks to the vibrations transmitted olive branches by means of hooks as well as of combs/rakes that cause branches to move with such a high frequency that fruits detach and fall down. When operating such devices workers experience high levels of hand-arm vibrations (HAV) due to hand contact with the handle of hand-held. The prolonged

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exposure to these types of stresses could cause the so called hand arm vibration syndrome (HAVS) that affects the various structures of the upper limb (musculoskeletal, nervous and vascular).

Table 1: Distribution of surfaces and olive production in Italy - Istat (2016)

Italian Territory	2000-2011 Avg. Surface (ha)	2000-2011 Avg. Production (Mg)
North-East	8 498 ± 565	15 218 ± 2 378
North-West	17 844 ± 1,087	31 086 ± 8 780
Islands	196 634 ± 2,074	363 273 ± 36 855
Centre	223 602 ± 3 294	401 472 ± 85 431
South	726 252 ± 9 063	2 747 094 ± 368 636

Following studies focused on the epidemiologic aspects of HAV exposure (Bovenzi, 1998; Punnet and Wegman, 2004; Bovenzi, 2005) the UE issued the European Directive 2002/44/EC (European Commission, 2002): it contains the definition of the hand-arm transmitted vibration and recommends the assessment of the vibration exposures in workplaces for operators' health and safety. Later on the issue of the EU directive 2006/42/EC (European Commission, 2006) recommends manufacturers shall provide detailed information (including data on vibration emission) about the tools they put into commerce. The hand-arm vibration damage depends on multiple factors: the stimulus intensity, the propagation direction, the exposure duration and the operators' grip forces on the tool's handles (Deboli and Calvo, 2009). In a study carried out by Costa et al. (2013) it has been pointed out that the HAV levels operators are exposed to may exceed the limit of exposure imposed by law; moreover, operators often have misperceptions of the effects of their exposure to HAV: such misperception opens serious health issues as it means that, despite the legal framework, workers don't undertake any preventive measure. However, in studies of vibrational comfort, the body mass index (BMI), obtained by the ratio between the person's weight in kilograms and the square of height in meters, affects the recorded values (Caffaro et al., 2016).
The objective of this study was to determine and evaluate the exposure of the operator to vibrations and in particular if the body mass index could have a statistical effect on differences between data collected.

2. Material and methods

2.1. Measurement instruments

Tests were carried out using a battery powered (12 VDC) olive beater (Jolly Italia s.r.l., Trecastelli, Ancona, Italy) with the oscillating head equipped with carbon fibre sticks (Figure 1). The head was mounted on a metallic pole 1.83 m long used as extension arm and the beater was equipped with the electronic control of the beating sticks lowering the oscillating frequency of the comb from 400 to 1400 beats per minute when idle.

Figure 1: Olive beater and the device to develop tests

The test method relied on a custom-built device (Deboli et al., 2014) designed to simulate as best as possible the interaction between olive tree branches and harvester sticks that results in an induced vibration to operator's arms and hands transmitted through the metallic pole. The device was made of one rectangular wooden frame (500 mm high and 600 mm wide) with nine vertical and nine horizontal regularly-spaced and tensioned wires (Figure 1) whose purpose was to guarantee controlled and repeatable laboratory conditions (McDowell et al., 2012).

To record the vibrations transmitted to the hand arm system the following instrumental chain had been set up:

- one laptop equipped with 8-channels acquisition/measuring system equipped with software package for vibration engineering measurements (Sinus Messetechnik Gmbh, Leipzig, Germany).
- one handheld shaker vibration reference source for accelerometer calibration (mod. 394C06 from Piezotronics vibration division, Depew, NY, USA);
- two ICP triaxial accelerometers for the hand-arm system (mod. SEM 020 from Piezotronics vibration division, Depew, NY, USA): one has been mounted on the front handle (Figure 2, a) and one mounted on the rear one (Figure 2, b).

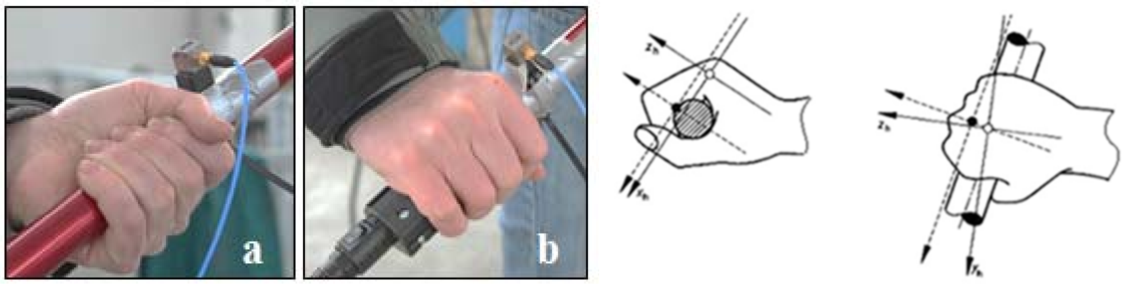

Figure 2: (on the left) of the positioning of the triaxial accelerometers (a: front handle; b: rear handle) and (on the right) representation of the standard frame of reference for the hand while grasping a cylindrical handle (ISO 5349-1 and ISO 8727). Solid lines refer to biodynamic coordinate system, dashed lines refer to basicentric coordinate system

Before and after each day of measurement sessions, accelerometer calibrations were carried out using the above-mentioned calibration device to check the compliance of the bias from the primary calibration with the recommended standard and, in case, operate the accurate adjustment of the used instrumentation to indicate the standard level of acceleration.

Table 2: Anthropometric data of the monitored operators

Operator	Weight (kg)	Height (cm)	BMI (kg/m^2)	Distance between the hands while grasping (cm)	Elbow-Wrist distance (cm)
α	80	184	23.6	95	28.0
β	72	176	23.2	79	27.5
γ	77	175	25.1	78	28.0
δ	92	187	26.3	97	31.0
ε	87	184	25.7	96	31.0

2.2. The measured variable

The object of the measurement is the root mean square (r.m.s.) of the weighed acceleration aw (eq. 1) acquired along each axial component of the acceleration vector (a_x, a_y, a_z) in compliance with the EN ISO 20643/A1 standard (European Committee for Standardisation, 2012). Signals from the accelerometers were frequency-weighted using the weighting curve Wh (ISO 5349-1 standard - ISO, 2001) both in idling (without the tree-simulating device) and operating conditions:

$$a_w = \left[\frac{1}{T}\int_0^T a_w^2\,(t)\,dt\right]^{\frac{1}{2}} \qquad (1)$$

where:

- a_w is the frequency weighed acceleration (m s^{-2});
- T is the measurement durations (s).

The vibration total value (a_v) the hand arm system was exposed to was calculated (Eq. 2) as the square root of the sum of the squares of the frequency-weighted accelerations a_{wx}, a_{wy} and a_{wz} along the axes:

$$a_v = (k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2)^{\frac{1}{2}} \quad (2)$$

where:

- a_v is vibration total value (m s^{-2});
- a_{wx}, a_{wy}, a_{wz} are the weighed r.m.s. accelerations along x, y and z axes (m s^{-2});
- k_x, k_y, k_z are correction coefficients (dimensionless).

Vibration total values were acquired for each hand position (front and rear): acquisition times were set at 30 s, in case of idling conditions, and 120 s when simulating the harvesting of the olives.

2.3. The testing procedure

Trials have been carried out according to UNI EN ISO 5349-1-2:2004 standards for hand-arm system defining an anatomically-based biodynamic (BD) Cartesian coordinate system and a tool-based basicentric (BC) Cartesian coordinate system (Dong et al., 2015). The BD system has its origin at the center of the head of the third metacarpal bone (the distal one); the z_h-BD axis is the long axis of the third metacarpal bone, and the xh-BD axis is approximately normal to the palm of the hand and perpendicular to the z_h-BD axis. The y_h-BD axis is perpendicular to the two axes. The BC system has its origin on the handle surface; its zh-BC axis is parallel to z_h-BD in the x-z plane, and its x_h-BC is parallel to x_h-BD, but its yh-BC axis is parallel to the handle axis (Figure 2, on the right).

Triaxial accelerometers (see 2.2), oriented in accordance with BD Cartesian coordinate system, were firmly attached to the handles during olive beater operation: they simultaneously recorded a_{wx}, a_{wy}, a_{wz} values in the 3.6 – 1250 Hz frequency range. Trials have been carried out employing five (unskilled) operators that were asked to operate the olive harvester with and without the tree simulating device. Before starting with the recordings, they were asked grab the rear handle with the hand and spontaneously place the other hand in the front part of the pole following their own natural gestures and the distance between the hands was recorded. During trials without the tree simulating device (idling conditions - with the device oscillating at the lower frequency) the operator kept the harvester 45°-inclined throughout the whole acquisition time (30 s) avoiding to lean the machine as well as his arms on his own body. During harvesting simulations operators were asked to move the oscillating head in such a way to sequentially hit any of the four quadrant that the simulator surface could have been hypothetically divided into (when sticks hit the simulator for the first time the oscillating speed shifts from the minimum to the maximum). For any tested conditions five replications of the measurements have been carried out.

2.3. Data processing

The collected data were organized and processed by means of MS Excel™ spreadsheet and “R” open-source statistical software (R Development Core Team, 2008). The array of data has been subjected to preliminary tests for normality and homoscedasticity in order to use the most suitable comparison test. Moreover, to increase the knowledge attained from the considered variables and, according to them, discriminate as many as differences as possible all data, after standardization, underwent multivariate processing by means of Principal Components Analysis (PCA) to find out the existence of groups or classes non a priori defined and whose existence is not accidental (Todeschini, 1998).

3. Results and discussion

The accelerations measured in the two rod positions, have shown for the x-axis an average value of 18.69 ± 13.02 m s^{-2}, for the y-axis an average of 1.35 ± 0.80 m s^{-2} and for the z-axis an average of 5.39 ± 3.11 m s^{-2} (average ± standard deviation of one hundred data). Their average sum (a_v) was 19.65 ± 13.18 m s^{-2} and single values ranged between 4.69 m s^{-2} and 49.56 m s^{-2}.

The maximum value of the accelerations’ sum (50.53 ms^{-2}) was recorded by the accelerometer placed closest to the oscillating head, in working conditions (with the rod inserted into the wooden frame) while the higher sum of accelerations acquired at the more distal handle (always in working conditions) showed a value of 44.28 m s^{-2}. Given the non-normality of the data (according to Shapiro-Wilk test), they were processed by means of the Kruskal-Wallis test. This pointed out that using or not the frame significantly affected all the response variables while, as far as accelerometer position is concerned, it turned out that frontal and rear acquisitions were significantly different along x- and z-axes only.

More in detail, a_v values at the rear handle resulted lower than those at the front one in all the conditions and for all the operators.

The PCA carried out on data acquired in working conditions resulted in the biplot displayed in Figure 3, in which the 1st PC (component 1) explained the 40.32 % of the variability and the 2nd PC (component 2) explained the 28.75 %. In such biplot, the variables many related to anthropometric data are those affecting

the 1st PC the most as it can be seen from their projections on such component (actually they allow the discrimination of the different operators). Those related to acquisitions (labelled x_axis, y_axis and z_axis), on the contrary, being mainly projected on the 2nd PC, have a lower influence on the dataset an allow the discrimination between front (F) and rear (R) acquisitions.
More in detail, it can be noticed that overall three groups of data are highlighted: on the left those related to operator β, in the middle those of α and γ operators and in the far right the group made by the data related to operators δ and ε. Actually, on the one hand, the groups on the left and on the right of the score plot can be explained by the BMI of the operators (see Table 2), on the other, the group represented by α and γ, being composed by operators of different morphology, gives reason of the differences that may arise to the different forces that operators apply in grasping the cylindrical handle of the olive beater and that arise from man/machine interaction. This confirms the issues related to the wide range that characterizes human responses to hand-transmitted vibration that, introduced by Griffin (2012) and deepened by Dong et al. (2013), confirm the key role played by man/machine interaction.

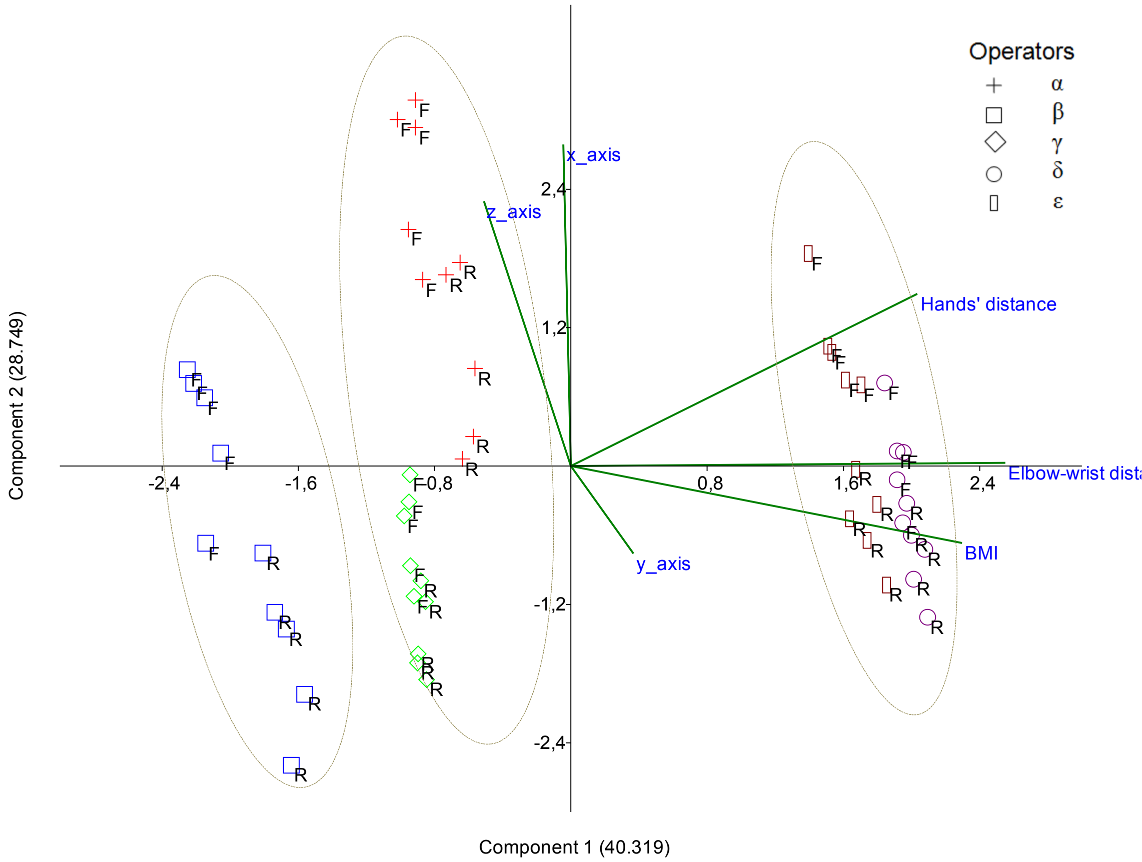

Figure 3: Biplot of the PCA. Symbols labelled with "F" refer to acquisitions at the front handle, those labelled with "R", refer to acquisitions at the rear one (the 1st component is the horizontal axis; the 2nd component is the vertical axis).

4. Conclusions

Following UNI EN ISO 5349-1-2:2004 standards, the solicitations affecting the hand arm system of five operators during the usage of a battery powered olive beater were assessed. The accelerations along x, y and z axes measured at the front and at the rear handles were measured in both idling and operating conditions (simulating the effect of olive branches with an on purpose designed wooden frame).
According to results, univariate data processing pointed out that, when idling, av values at the rear handle were lower than those acquired at the front one, irrespective of the operators, while in operating conditions. Only multivariate processing could point out that differences among the operators arise both in idling and operating conditions suggesting that, to improve the safety of working conditions, more attention should be given to man/machine interaction.

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