Determining Noise and Vibration Exposure in Conifer Cross-Cutting Operations by Using Li-Ion Batteries and Electric Chainsaws

Article *in* Forests · August 2018

DOI: 10.3390/f9080501

6 authors, including:

Andrea Laschi
University of Florence
14 PUBLICATIONS **65** CITATIONS

Cristiano Foderi
University of Florence
22 PUBLICATIONS **37** CITATIONS

Fabio Fabiano
University of Florence
21 PUBLICATIONS **44** CITATIONS

Enrico Marchi
University of Florence
113 PUBLICATIONS **657** CITATIONS

forests

MDPI

Article

Determining Noise and Vibration Exposure in Conifer Cross-Cutting Operations by Using Li-Ion Batteries and Electric Chainsaws

Francesco Neri [1], Andrea Laschi [1,*], Cristiano Foderi [1], Fabio Fabiano [1], Lucia Bertuzzi [2] and Enrico Marchi [1]

1 Department of Agricultural, Food and Forest Systems GESAAF, University of Florence, Via San Bonaventura 13, 50145 Florence, Italy; francesco.neri@unifi.it (F.N.); cristiano.foderi@unifi.it (C.F.); fabio.fabiano@unifi.it (F.F.); enrico.marchi@unifi.it (E.M.)

2 Department of Prevention, Tuscan Agency of Public Health (UFC PISLL Zona Fiorentina Sud-Est), Via di San Salvi 12, 50135 Florence, Italy; lucia.bertuzzi@uslcentro.toscana.it

* Correspondence: andrea.laschi@unifi.it; Tel.: +39-055-275-5615

Received: 20 July 2018; Accepted: 14 August 2018; Published: 17 August 2018

check for updates

Abstract: In many activities, chainsaw users are exposed to the risk of injuries and several other hazard factors that may cause health problems. In fact, environmental and working conditions when using chainsaws result in workers' exposure to hazards such as noise, vibration, exhaust gases, and wood dust. Repeated or continuous exposure to these unfavourable conditions can lead to occupational diseases that become apparent after a certain period of time has elapsed. Since the use of electric tools is increasing in forestry, the present research aims to evaluate the noise and vibration exposure caused by four models of electric chainsaws (Stihl MSA160T, Stihl MSA200C Li-Ion battery powered and Stihl MSE180C, Stihl MSE220C wired) during cross-cutting. Values measured on the Stihl MSA160T chainsaw (Li-Ion battery) showed similar vibration levels on both right and left handles (0.9–1.0 m s^{-2}, respectively) and so did the other battery-powered chainsaw, the Stihl MSA200C (2.2–2.3 m s^{-2} for right and left handles, respectively). Results showed a range of noise included between 81 and 90 dB(A) for the analysed chainsaws. In conclusion, the vibrations and noise were lower for the battery chainsaws than the wired ones, but, in general, all the values were lower than those measured in previous studies of endothermic chainsaws.

Keywords: forest operation; professional disease; health and safety; vibrations white finger; chainsaw; batteries

1. Introduction

Motor-manual tree felling, processing, and pruning by chainsaws, powered by internal combustion engines, are still very common in many countries [1–5] due to its multifunctional use and low financial investment [6–8]. However, the use of chainsaws results in the exposure of workers to hazards such as noise, hand-arm vibrations (HAVs), exhaust gases, and wood dust [9,10]. Chainsaw use shows one of the highest accident rates in professional and non-professional work [11–14] and causes several types of occupational diseases due to the repeated or continuous exposure to unfavourable environmental conditions. Some of these hazards, such as vibrations and noise, are underestimated by workers since they do not represent an immediate risk to human health. Indeed, disease symptoms can appear several years afterwards. However, this is not a reason to ignore the problem as the consequences of being exposed to noise and vibrations can be very serious [15]. Regarding vibrations, the signs and symptoms related to the use of chainsaws in forests are reported in many studies [16–19] and are known collectively as the hand-arm vibration syndrome (HAVs). HAVs consists of disturbances in the circulation of the fingers (Vibration White Finger, VWF) and the peripheral nerves of the hands and arms. In addition, muscle fatigue and bone and joint degeneration have been reported, but their association with HAVs is not well founded [20–23]. There is an association between vibration acceleration, latency, and the prevalence of HAVs [22]. The international standard of a model predicting the prevalence of VWF has been updated in 2001 [24]. According to the standard, the risk is related to the total vibration energy, i.e., the magnitude and duration of exposure. The risk also depends on the frequency of the vibration. Numbness of the hands and arms or a tingling in fingers and deterioration of finger tactile perception have been detected in workers exposed to vibration [25–27]. Numbness may generally affect the arms during and after exposure, especially during the night-time [22,27]. Carpal-tunnel syndrome was also investigated since 1990 as it has always been associated with HAVs exposure [25,28–30]. Bovenzi et al. [31] observed the dose–effect relationship between vibration exposure and the bicipital tendinitis and epicondylitis in forestry workers. Another epidemiological study has also revealed several associations between physical workload factors and some common upper limb disorders [32].

The other aspect considered in this study is the exposure to noise. In fact, this is an important and preventable cause of hearing loss [33], currently imposing a heavy burden on society at a global level [34]. Noise-induced hearing loss can be caused by short exposures to extremely high sound levels or by repeated exposures to moderate levels. The main effect of high-intensity sound is manifested in the form of a temporary or permanent loss of sensitivity and acuity [35–37].

In recent years, the major brands that produce tools for forestry and green maintenance have started to develop tools powered by electricity and Lithium-Ion batteries in order to protect the environment and the operator's health. Battery-powered chainsaws are able to decrease the number of specific risks, which makes them ideal for use in pruning operations, urban green maintenance, and arboriculture, where occupational hazards are high and it is important to minimize them [38–43]. Electric instruments technology has been developed deeply, but is newly introduced in the urban green areas management because of the need to have a relatively high power that is away from the public network [44,45], and present during the total duration of the working day.

The recent development of batteries provides a sufficiently high level of power and durability that is suitable for this purpose, with considerably reduced weights compared to older types of battery. Moreover, Lithium-ion batteries could now be recycled with an efficiency of 97% w/w of the valuable battery active materials [46,47]. In the only accessible previous study on chainsaws powered by alternative sources [38,48], it was established that the use of battery-powered chainsaws may decrease the exposure to noise and onset of HAV when compared with the use of petrol chainsaws. No recent studies have focused their attention on noise and vibration exposure by wired electric chainsaws in comparison to Li-Ion batteries models.

In order to fill the gap in knowledge and to have a comprehensive framework on the exposure of workers to vibrations, field surveys during the cross-cutting operations of conifer logs with chainsaws were carried out in Central Italy. The objectives of this study were to evaluate the exposure to vibration among forest workers and other categories of workers that might have some work restriction due to noise and vibrations and to evaluate the operator's behaviour during chainsaw handling that may influence the amount of vibrations measured.

2. Materials and Methods

2.1. Occupational Exposure Limits

In relation to vibration exposure, the EU Directive 2002/44/CE "Vibration" refers directly to the Standards ISO 5349-1:2001 and ISO 5349-2:2001 [49,50], which incorporate the state-of-the-art procedures concerning the measurement and assessment of vibration at the workplace. These standards and the requirements of the Vibration Directive provide several amendments and changes. Among others, they require a risk assessment, the informing of the employees, and the initiation of a program for the reduction of vibration exposure. According to the EU Directive, vibration is measured as the frequency-weighted acceleration on the handles of the power tool. The assessment of the vibration exposure is calculated in relation to a standardised 8 h daily exposure level A(8). Depending on the daily exposure action value (2.5 m s^{-2}) and the daily exposure limit value (5 m s^{-2}), the Directive requires different actions by the employer.

If the operator's daily exposure to vibration is kept below the Exposure Action Level, it should help him avoid vibration related diseases. If the operator's daily exposure exceeds the Exposure Limit Value, then there is a significant increase in the risk of developing vibration related diseases. Whenever an employee is affected by a vibration exposure A(8) exceeding the daily exposure action level of 2.5 m s^{-2}, the employer has to carry out a risk assessment of the operation that the employee is carrying out and introduce control measures for vibrations exposure as well as for noise. For this last aspect, the European Union has set clearly defined exposure limit values on the daily noise level and peak sound pressure. According to Directive 2003/10/EC, daily exposure should not exceed 87 dB(A) or 140 dB(C) under any circumstances. The same directive also sets the upper exposure action value at 85 dB(A) or 137 dB(C), and the lower exposure action value at 80 dB(A) or 135 dB(C).

2.2. Sampling and Analysis

Manual cross-cutting tests with wire-electric and battery-powered chainsaws were carried out in the Apennine mountain range in Tuscany (Central Italy–43°44′03.3″ N, 11°33′22.9″ E). The study included two electric chainsaws powered by Li–Ion batteries and two electric chainsaws (wired models) produced by the Stihl company (Table 1; Figures 1 and 2). The chainsaws' weight, guide bar length, and chain type are shown in Table 2. The test site was located close to electric network plugs. Silver fir (*Abies alba* Mill.) and douglas fir (*Psudotsuga menziesii* Franco) logs with a diameter ranging between 18 and 32 cm were used for the test. Before starting, the logs were placed horizontally at about 1 m from the ground by means of a wooden support. Measurements were made during the cross-cutting of the 5 cm (approximate) thick slice of wood (Figure 3) following a vertical direction (from the top to the bottom of the log).

The tests were carried out by three forest workers (A, B, and C) with high training level and long-lasting experience in chainsaw use (more than 5 years).

Table 1. The characteristics of chainsaws tested during the study.

Chainsaw	Type	Year of Production	Power (kW)	Weight (kg)
Stihl MSA160T	Li-Ion accumulator	2014	na	3.6 (1)
Stihl MSA200C	Li-Ion accumulator	2014	na	4.7 (2)
Stihl MSE180C	Electric/wired	2008	1.8	4.6
Stihl MSE220C	Electric/wired	2011	2.2	6.7

(1) Accumulator AP115, 118 Wh; (2) Accumulator AP180, 178 Wh.

(**a**) (**b**)

Figure 1. The Li-Ion batteries chainsaws: (**a**) Stihl MSA160T and (**b**) Stihl MSA200C.

(**a**) (**b**)

Figure 2. The wired chainsaws models: (**a**) Stihl MSE180C; (**b**) Stihl MSE220C.

Table 2. The technical characteristic of the chainsaws and their accessories, together with log characteristics (species and diameter).

Chainsaw Model	Bar Length (cm)	Real Length of Cut (cm)	Chain Type	Chain Pitch (″)	Cutting Tooth Profile	Species and Ø of Cut Logs (cm)
Stihl MSA160T	30	25	RSC3	3/8″	Square chisel	Douglas fir, 18–19
Stihl MSA200C	35	30	PS3	3/8″ Picco	Semi-chisel	Silver fir, 28–29.5
Stihl MSE180C	40	35	PM3	1/4″	Semi-chisel	Silver fir, 27–28.5
Stihl MSE220C	45	40	PM3	1/4″	Semi-chisel	Silver fir, 30–32

Figure 3. The measurements during cross-cutting.

The crosscut was repeated 8 times for both handles for each chainsaw and for each and every one of the 3 operators. In total, 192 measures were collected, half for the left handle and half for the right handle. HAVs exposures on the feller were measured in accordance with the ISO 5349:2001 standard using a vibration meter and accelerometer. To determine the daily exposure values of HAV, A(8) frequency-weighted acceleration values were used, which combined all three measuring axes at each handle. In detail, ISO 5349–1 "Part 1: General requirements" specifies the general requirements for the measurement and the record of the exposure to mechanical vibrations transmitted to the hand on the three orthogonal axes (x, y, z). It defines the weighting frequency and the band filters in order to obtain a uniform and standardized comparison of the measurements. The obtained values can be utilized to calculate the negative effects of the vibrations transmitted to the hand for the one-third-octave band mid-frequency interval (6.3 Hz to 1250 Hz) according to ISO 5349-2: 2001 [50] specifications. Furthermore, the normative defines the Cartesian axes system orientation. The orthogonal reference system starts at the head of the third metacarpal segment, being the "z" axis parallel to the hand axis, the "y" axis perpendicular to the plane delimited by the "x" and "z" axes with a right-left orientation. In agreement with ISO 5349-1 [49], the equation we used to calculate A(8) was the following:

$$A(8) = A_{(w)sum}\left(\frac{T_e}{8}\right)^{1/2}$$

where:

T_e: total daily vibration exposure (6 h in the present study);

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

a_{wx} a_{wy} a_{wz}: root mean square values of frequency-weighted acceleration (m s^{-2}) on the x, y, and z axes (Figure 4).

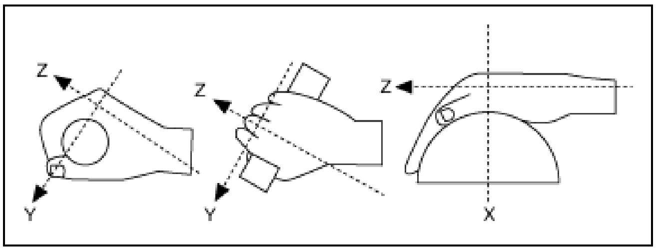

Figure 4. Graphical representation of the three orthogonal axes (x, y, z) defined to measure hand-arm vibration (taken from Reference [47]).

Vibrations were measured with

- a three-channels vibrometer Larson Davis mod. HVM100, equipped with a triaxial accelerometer SEN021–sensitivity 10 mV g^{-1}, Figure 4;
- a calibrator for accelerometer APTechnology Mod. AT01;

The accelerometer was fixed by plastic ties to the right handle first, and after measurement, to the left handle. The instruments were placed whilst paying attention to not interfere with the normal working positions. In Figure 5, a Larson Davis vibrometer was mounted on the left handle.

Figure 5. The accelerometer fixed by plastic ties for measurement with the Larson Davis mod. HVM100.

In parallel, noise measures were carried out to define the equivalent continuous A-weighted sound pressure level (L_{Aeq}). The measurements of noise exposure were conducted according to the European Directive 2003/10/EC [51] and international standards ISO 9612:2011 [52] and ISO 11201:2010 [53] by using a noise meter and microphone. The "task-based measurement" option was chosen from among the three alternative strategies proposed by ISO 9612:2011 [52] because it fit the experimental design better. Three random noise measurements were collected for each chainsaw. The instrument used in this study was a four-channel analyzer 01 dB mod. Harmonie, with a microphone 01 dB mod. MCE212, calibrated by an acoustic calibrator 01 dB mod, Cal21. The following noise load indicators were measured: equivalent continuous A-weighted sound pressure level (L_{Aeq}) with a full sound frequency spectrum in 1/3 octave bands and a maximum value of the C-weighted instantaneous sound pressure (LCpeak). Noise exposures were successfully recorded during cross-cutting operations. The assessment of the noise exposure was calculated in relation to a standardised 8 h daily exposure level (L_{EX}, 8 h).

L_{EX}, at 8 h was calculated with equation

$$L_{EX},\ 8h = 10\log\left[\frac{1}{T_0}\sum_{i=1}^{n} T_i 10^{0,1L_i}\right]$$

where

T_i is the daily exposure time in minutes (360 min in the present study);
L_i is the continuous equivalent level (L_{Aeq}) of the noise source;
T_0 is the daily working time of 8 h.

2.3. Statistical Analysis

Considering the applied methodologies to assess the vibrations and noise exposures, only data related to vibrations were allowed to compute a statistical analysis. Daily exposure values of vibration A(8) recorded during the cross-cutting test were analysed in order to investigate the differences between the electric chainsaw models. Inter-operators variability to the vibration exposure was also tested to provide an evaluation of the influence of worker behaviour during the cross-cutting operation. Analyses were computed with the open-source statistical software R version 3.4.4 (R foundation, Vienna, Austria) [54]. The normality of data distribution was checked by Bartlett's test and the homogeneity of variances was measured by Levene's test in order to define the appropriate statistical method to investigate the differences in the vibration exposure. Due to the non-normal distribution of the data collected, a Kruskal Wallis test was applied [55]. This non-parametric method is a rank-based test used to determine statistically significant differences between two or more groups of independent variables (different operators and different chainsaw models) on a continuous or ordinal dependent variable [56], in this case, the recorded values of the daily exposure of vibration during the cross-cutting of the logs. After the Kruskal Wallis test, in order to provide multiple comparisons of each group analysed, a Dunn's rank sum test was performed [57]. To control the family-wise error rate (FWER), a Holm-Šidák adjustment was applied [58], a step-up reiteration procedure of Dunn's test with a progressively increased p-value threshold assuming the dependence between tests.

3. Results

In the first step, a statistical analysis was applied to investigate the intra-operator (considering the same operator in cutting) and inter-operator (differences between operators) variability in daily exposure values of vibrations. The intra-operator exposure values varied between 10% and 27%, while the inter-operator variability was always under 10%. Figure 6 showed an inter-operator distribution and an absence of statistically significant differences was confirmed by the Holm–Šidák Pairwise comparison matrix results reported in Table 3.

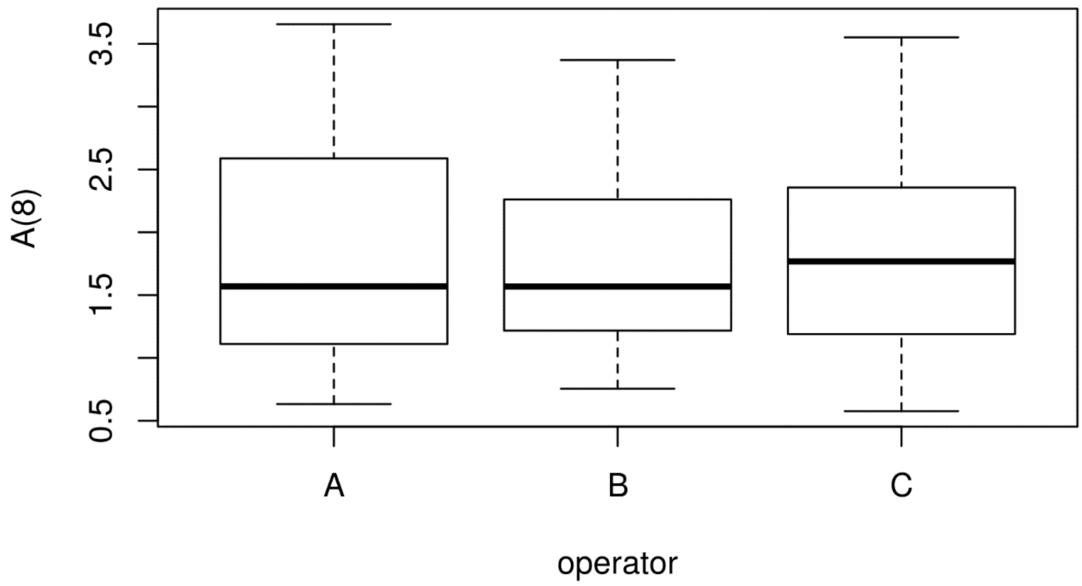

Figure 6. The graphical representation of the A(8) distribution by the operator.

Daily exposure values to vibrations A(8) for both Li-Ion batteries and electric wired chainsaws are reported in Table 4. Looking at electric wired chainsaws, a considerable difference between the median values of acceleration in right and left handles were recorded. The median values were about 52% and 44% lower in the left handle in Stihl MSE180C and Stihl MSE220C, respectively. In both the battery powered chainsaws, the difference between the handle was about 5%, with a higher median value in the left handle. The lowest values of acceleration were recorded for the Stihl MSA160T for both handles (Table 4). The differences shown in the daily vibration exposure values were confirmed by the results of the statistical analysis (Table 5). The null hypothesis, verified by Dunn's test, was that there were no differences among the median values for each group. The adjusted *p*-values are marked with an asterisk if the results of the comparison reject the null hypotheses at the specified significance level (Table 5). On the basis of this analysis, it is possible to highlight that the Stihl MSA160T showed significantly lower values than all the other chainsaws.

The noise measurements are shown in Figure 7 (L_{Aeq}). On the basis of these data, the daily exposure level (L_{EX}, 8 h) can be determined. The results highlighted the lower values in the Li-Ion battery chainsaws than in the wired ones. The "L_{EX}, 8 h" values were 79.5 dB(A) for Stihl MSA160T, 1.1 dB(A) for Stihl MSA200C, 82.1 dB(A) for Stihl MSE180C, and 89.2 dB(A) for Stihl MSE220C.

Table 3. The Holm–Šidák Pairwise comparison matrix of A(8) by chainsaw operators (alpha = 0.05; reject H_0 if $p \leq$ alpha/2).

Operator/Operator	A	B
B	0.155 p = 0.438	
C	−0.411 p = 0.566	−0.571 p = 0.633

Kruskal-Wallis chi-squared = 0.3484, df = 2, *p*-value = 0.84.

Table 4. The daily vibration exposure values (A(8) in m s^{-2}) reported for each chainsaw model recorded on the left and right handles.

Vibration Daily Exposure (A(8) in m s^{-2})							
	Handle	**n**	**Mean**	**sd**	**Median**	**Min**	**Max**
Stihl MSA160T	left	24	0.953	0.195	0.981	0.576	1.237
	right	24	0.939	0.130	0.943	0.752	1.206
Stihl MSA200C	left	24	2.043	0.521	2.292	1.188	2.793
	right	24	2.104	0.542	2.177	1.287	3.026
Stihl MSE180C	left	24	1.536	0.185	1.525	1.111	1.933
	right	24	2.799	0.725	3.152	1.415	3.656
Stihl MSE220C	left	24	1.527	0.184	1.551	1.242	1.768
	right	24	2.550	0.449	2.677	1.786	3.311

Table 5. The comparison between the different chainsaw models on vibrations daily exposure: results of Dunn's Test (Holm-Šidák adjustment) after the Kruskal–Wallis test. Significant differences are marked with *.

	Stihl MSA160T	**Stihl MSA200C**	**Stihl MSE180C**
Stihl MSA200C	−8.521 p = 0.000 *	-	-
Stihl MSE180C	−8.702 p = 0.000 *	−0.135 p = 0.446	-
Stihl MSE220C	−8.613 p = 0.000 *	0.160 p = 0.683	0.299 p = 0.765

Kruskal-Wallis chi-squared = 111.152, df = 3, p-value = 0. Holm-Šidák comparison by group: α = 0.005; reject H_0 if $p \leq \alpha/2$.

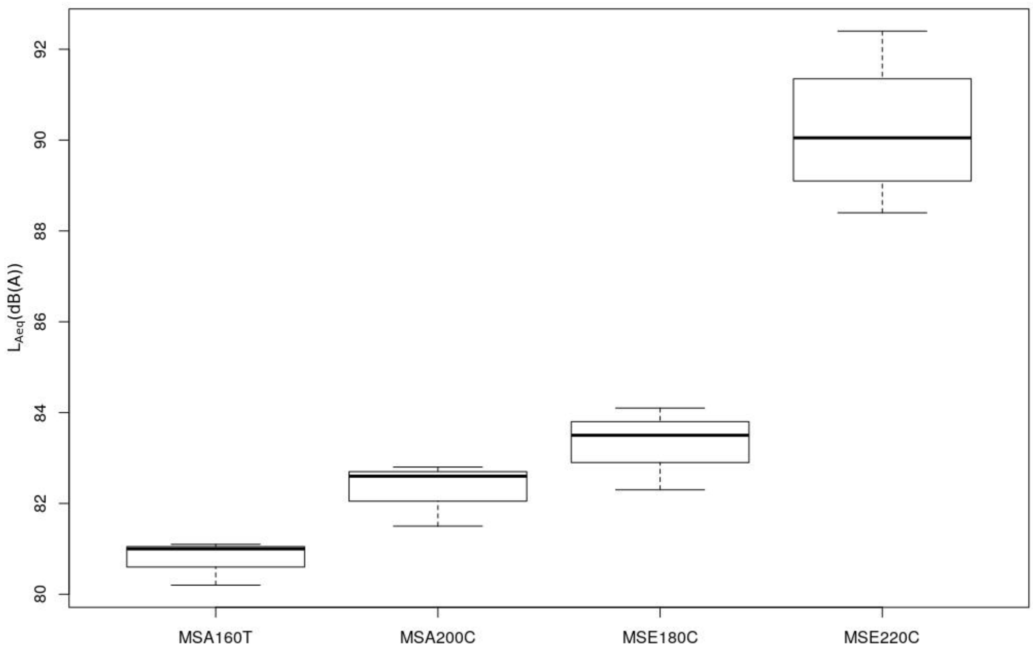

Figure 7. The graphical representation of the noise measurements (L_{Aeq}) of the tested chainsaw.

4. Discussion

The first clear result of our study was that the average acceleration values recorded for electric chainsaws are lower than those measured in previous studies for endothermic chainsaws [38]. It was quite obvious that the machine powers, uses, and construction technologies were completely different. Considering the A(8) values (Table 4), the ones measured on Stihl MSA160T (Li-Ion battery) showed similar vibrations values, about 1.0 m s^{-2} for both handles, the Stihl MSA200C also showed similar values for both handles (around 2.2 m s^{-2} for both handles). On the contrary, the wired models showed significant differences between the left and right handles; in fact, in Stihl MSE180C, the mean values on the right handle were almost double than the left ones. Additionally, in Stihl MSE220C, the HAV values were significantly higher for the right handle. Similar differences between the right and left handles have been recorded by a study conducted on endo-thermic chainsaws [59].

The differences in daily exposure that emerged between the two models powered by batteries were likely due to the different power, bar length, and the diameter of the logs. The Stihl MSA200C values were also close to those measured for the wired models, probably because of the similar construction design. According to ISO 5349-2 [50], the value to be considered was the highest one measured between the left and right handles. Our findings showed that the maximum values of acceleration were well below the daily exposure limit of 5 m s^{-2} reported in the EU Directive 2002/44/CE "Vibration" for each model of electric chainsaw considered. One model (MSA160T) of the examined battery-powered chainsaws gave a maximum daily exposure vibration value lower than 1.3 m s^{-2}. Our findings were also consistent with the preliminary data reported by Poje et al. [38], which compared Li-Ion battery and petrol chainsaws. No studies have tried to compare different electric models powered by different sources.

Another aspect to be considered was the operator's behaviour during the chainsaw handling. Our results did not show significant differences between the three operators (A, B, C), demonstrating that in our study operator behaviour did not affect the vibration exposure.

4.1. Comparison of Obtained Results with the Information Declared by Constructor

The information about vibrations and noise emissions included in the use and maintenance manual of chainsaws were reported in Table 6. In relation to vibrations, the measured values showed some differences to those reported in the user manual by the manufacturer. We can state that the differences observed could be due to the fact that we applied the UNI EN ISO 5349 standards [24,49,50] for measuring the vibrations in working conditions, while the manufacturer would have usually measured them in laboratory conditions or by using different standards (e.g., ISO 22867:2011) [60]. For this reason, the differences could be due to the type of wood cut, the type of chain used, and the number of samples. Anyway, it is interesting to notice that for wired chainsaws, the declared values by the manufacturer were similar between the left and right handles, while our measurements showed significant differences between the handles (Table 6). For this reason, further research could be required to better understand the handle influence on vibration measures.

The results of the noise emissions analysis showed that, for Li-Ion battery chainsaws, the values are in line with the ones declared by the manufacturer, while for wired types, the measured emissions were about 5 dB(A) lower than the values reported in the user manuals (Table 6). However, these noise emissions were considerably lower than the noise levels produced by endothermic engines, which are at least 15–20 dB(A) higher [38].

Table 6. The noise and vibration emissions of the tested chainsaws; comparison between the max measured values and the values declared by the manufacturer.

Chainsaw Model	Noise dB(A) L_{EX}, 8 h		Vibrations m s^{-2}			
			Left Handle		Right Handle	
	Declared	Measured	Declared	Measured	Declared	Measured
Stihl MSA160T	81	−1.9%	<2.5	−51%	<2.5	−52%
Stihl MSA200C	84	−3.5%	4.5	−38%	4.0	−33%
Stihl MSE180C	92	−10.7%	2.2	−12%	2.7	+66%
Stihl MSE220C	95	−6.1%	2.3	−23%	2.5	+44%

4.2. Potential Role of Electric Chainsaws in Forestry

The few studies available at present [38,48] have made comparisons between electric and traditional endothermic chainsaws and the results have clearly shown lower emissions of both vibrations and noise in electric chainsaws than in the others, but these cannot be used in the same operations. In forest conditions, wired chainsaws are obviously inappropriate due to their need of an electric connection, while battery chainsaws can be used in specific operations only, such as delimbing and the cross-cutting of small-diameter trees, but not in felling and the processing of medium and large diameter trees. Nevertheless, a great advantage could be provided by battery chainsaws in pruning operations and arboriculture, especially in urban areas. In fact, in this operative context, there is a lower requirement of power and production in terms of quantity, but it is important to guarantee safe work conditions. In this case, the improvement of health and safety standards does not affect the productivity of the work. Moreover, the different starting system between traditional and electric engines allow for a safer and more comfortable use with electric solutions, especially for on-tree works. Electric engines may be operated by pressing a button, while in endothermic chainsaws, a manual recoil starter is needed. In some conditions, this difference may be strategic because it may be complicated and dangerous to start a chainsaw engine whilst working on trees (e.g., tree-climbing). Moreover, in such situations, there are many working phases when the chainsaw is not used and several starting manoeuvres may be needed in a workday, thus suggesting that battery powered solutions are ergonomically better. From a technological point of view, it is interesting to highlight that the vibration exposure using electric chainsaws is considerably lower in comparison with the endothermic ones, even if the anti-vibrations systems (tools that physically separate the handle part of the machine from the engine and cutting tools) are not present in electric models. In this context, a further reduction of vibration levels could be obtained in electric machines by adding anti-vibration systems.

5. Conclusions

We investigated the exposure of forest workers to noise and vibrations during the manual cross-cutting operations by electric chainsaws. The machines were chosen between Li-Ion batteries and wired models powered by an electric network. Our findings clearly showed lower emissions of both vibrations and noise by Li-Ion batteries chainsaws. Similar to other fields, the results confirmed a positive impact of research on the alternative power supply of hand tools. The development of electric tools for forestry is expected to intensify with the development of more powerful batteries, autonomously being the actual major bottleneck. At present, these machines could be considered as an alternative to internal combustion engine chainsaws in case of pruning and first thinning operations in conifer stands or in gardening activities or for those people that have some work restriction due to noise and vibrations. If technology will be able to improve autonomy, it is reasonable to plan the use of this light tools also in other small-scale forestry operations.

Author Contributions: Conceptualization, F.F., E.M. and F.N.; Methodology, C.F., A.L. and F.F.; Software, C.F. and L.B.; Validation, E.M., A.L. and C.F.; Formal Analysis, A.L and C.F..; Investigation, F.F., L.B. and C.F.; Resources, F.F., E.M. and F.N.; Data Curation, C.F., A.L., L.B. and F.N.; Writing-Original Draft Preparation, F.N. and A.L.; Writing-Review & Editing, F.N. and A.L.; Visualization, F.N. and C.F.; Supervision, E.M. and F.N.; Project Administration, E.M. and F.N.; Funding Acquisition, F.F., F.N. and E.M.

Acknowledgments: The authors would like to thank Andreas Stihl Spa for providing the chainsaws used in this study, and the Territorial Office for Biodiversity of Vallombrosa (ex-Corpo Forestale dello Stato, now Carabinieri Forestale) for worksite organization.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Albizu-Urionabarrenetxea, P.; Tolosana-Esteban, E.; Roman-Jordan, E. Safety and health in forest harvesting operations. Diagnosis and preventive actions. A review. *For. Syst.* **2013**, *22*, 392–400. [CrossRef]
2. Vusić, D.; Šušnjar, M.; Marchi, E.; Spina, R.; Zečić, Ž.; Picchio, R. Skidding operations in thinning and shelterwood cut of mixed stands—Work productivity, energy inputs and emissions. *Ecol. Eng.* **2013**, *61*, 216–223. [CrossRef]
3. Çalişkan, E. Productivity and cost analysis of manual felling and skidding in oriental spruce (*Picea orientalis* L.) forests. *Ann. For. Res.* **2012**, *55*, 297–308.
4. Montorselli, N.B.; Lombardini, C.; Magagnotti, N.; Marchi, E.; Neri, F.; Picchi, G.; Spinelli, R. Relating safety, productivity and company type for motor-manual logging operations in the Italian Alps. *Accid. Anal. Prev.* **2010**, *42*, 2013–2017. [CrossRef] [PubMed]
5. Picchio, R.; Blasi, S.; Sirna, A. Survey on Mechanization and Safety Evolution in Forest Works in Italy. In Proceedings of the International Conference Ragusa SHWA2010, Ragusa, Italy, 16–18 September 2010; pp. 16–18.
6. Liepiņš, K.; Lazdiņš, A.; Liepiņš, J.; Prindulis, U. Productivity and Cost-Effectiveness of Mechanized and Motor-Manual Harvesting of Grey Alder (Alnus incana (L.) Moench): A Case Study in Latvia. *Small-Scale For.* **2015**, *14*, 493–506. [CrossRef]
7. Jourgholami, M.; Majnounian, B.; Zargham, N. Performance, Capability and Costs of Motor-Manual Tree Felling in Hyrcanian Hardwood Forest. *Croat. J. For. Eng.* **2013**, *34*, 283–293.
8. Russell, F.; Mortimer, D. *A Review of Small-Scale Harvesting Systems in Use Worldwide and Their Potential Application in Irish Forestry*; COFORD: Dublin, Ireland, 2005; pp. 1–56.
9. Marchi, E.; Neri, F.; Cambi, M.; Laschi, A.; Foderi, C.; Sciarra, G.; Fabiano, F. Analysis of dust exposure during chainsaw forest operations. *IForest* **2017**, *10*. [CrossRef]
10. Neri, F.; Foderi, C.; Laschi, A.; Fabiano, F.; Cambi, M.; Sciarra, G.; Aprea, M.C.; Cenni, A.; Marchi, E. Determining exhaust fumes exposure in chainsaw operations. *Environ. Pollut.* **2016**, *218*. [CrossRef] [PubMed]
11. Laschi, A.; Marchi, E.; Foderi, C.; Neri, F. Identifying causes, dynamics and consequences of work accidents in forest operations in an alpine context. *Saf. Sci.* **2016**, *89*, 28–35. [CrossRef]
12. Tsioras, P.A.; Rottensteiner, C.; Stampfer, K. Wood harvesting accidents in the Austrian State Forest Enterprise 2000–2009. *Saf. Sci.* **2014**, *62*, 400–408. [CrossRef]
13. Suchomel, J.; Belanová, K. Influence of selected meteorological phenomena on work injury frequency in timber harvesting process. *Croat. J. For. Eng.* **2009**, *30*, 185–191.
14. Klun, J.; Medved, M. Fatal accidents in forestry in some European countries. *Croat. J. For. Eng.* **2007**, *28*, 55–62.
15. Monarca, D.; Biondi, P.; Cecchini, M.; Santi, M.; Guerrieri, M.; Colantoni, A.; Colopardi, F. Transmission of Vibrations from Portable Agricultural Machinery to the Hand-Arm System (HAV): Risk Assessment and Definition of Exposure Time for Daily Action and Exposure Limits. In Proceedings of the International Conference: Innovation Technology to Empower Safety, Health and Welfare in Agriculture and Agro-food Systems, Ragusa, Italy, 15–17 September 2008.
16. Barnes, R.; Longley, E.O.; Smith, A.R.B.; Allen, J.G. Vibration disease. *Med. J. Aust.* **1969**, *1*, 901–905.
17. Axelsson, S. *Analysis of Vibration in Power Saws*; Royal College of Forestry: Stockholm, Sweden, 1968; p. 59.
18. Taylor, W.; Pearson, J.; Kell, R.L.; Keighley, G.D. Vibration syndrome in Forestry Commission chain saw operators. *Brit. J. Industr. Med.* **1971**, *28*, 83–89. [CrossRef] [PubMed]
19. Miura, T.; Kimura, K.; Tominaga, Y.; Kimotsuki, K. *On the Raynaud's Phenomenon of Occupational Origin due to Vibrating Tools—Its Incidence in Japan*; Report of the Institute for Science of Labour; Institute for Science of Labour: Tokyo, Japan, 1966; Volume 65, pp. 1–11.
20. Bovenzi, M. Exposure-response relationship in the hand-arm vibration syndrome: An overview of current epidemiology research. *Int. Arch. Occup. Environ. Health* **1998**, *71*, 509–519. [CrossRef] [PubMed]
21. Stenlund, B.; Goldie, I.; Hagberg, M.; Hogstedt, C.; Marions, O. Radiographic osteoarthrosis in the acromioclavicular joint resulting from manual work or exposure to vibration. *Br. J. Ind. Med.* **1992**, *49*, 588–593. [CrossRef] [PubMed]

22. Färkkilä, M.; Aatola, S.; Starck, J.; Pyykko, I.; Korhonen, O. Vibration induced neuropathy among forest workers. *Acta Neurol. Scand.* **1985**, *71*, 221–225. [CrossRef] [PubMed]
23. Pyykkö, I. The prevalence and symptoms of traumatic vasospastic disease among lumberjacks in Finland A field study. *Work Environ. Health* **1974**, *11*, 118–131. [PubMed]
24. *International Organization for Standardization ISO 5349—Vibration and Shock-Guidelines for the Measurement and Assessment of Human Exposure to Hand-Arm Vibration*; International Organization for Standardization: Geneva, Switzerland, 2001.
25. Brammer, A.J.; Pyykkö, I. Vibration-induced neuropathy: Detection by nerve conduction measurements. *Scand. J. Work Environ. Health* **1987**, *13*, 317–322. [CrossRef] [PubMed]
26. Araki, S.; Honma, T.; Aoyama, K. Peripheral nerve conduction velocities in chain saw operators. *Jpn. J. Ind. Health* **1976**, *18*, 516–520. [CrossRef]
27. Seppäläinen, A.M. Peripheral neuropathy in forest workers. A field study. *Work Environ. Health* **1972**, *9*, 106–111.
28. Bovenzi, M.; Giannini, F.; Rossi, S. Vibration-induced multifocal neuropathy in forestry workers: Electrophysiological findings in relation to vibration exposure and finger circulation. *Int. Arch. Occup. Environ. Health* **2000**, *73*, 519–527. [CrossRef] [PubMed]
29. Giannini, F.; Rossi, S.; Passero, S.; Bovenzi, M.; Cannavà, G.; Mancini, R.; Cioni, R.; Battistini, N. Multifocal neural conduction impairment in forestry workers exposed and not exposed to vibration. *Clin. Neurophysiol.* **1999**, *110*, 1276–1283. [CrossRef]
30. Koskimies, K.; Farkkila, M.; Pyykko, I.; Jantti, V.; Aatola, S.; Starck, J.; Inaba, R. Carpal tunnel syndrome in vibration disease. *Br. J. Ind. Med.* **1990**, *47*, 411–416. [CrossRef] [PubMed]
31. Bovenzi, M.; Zadini, A.; Franzinelli, A.; Borgogni, F. Occupational musculoskeletal disorders in the neck and upper limbs of forestry workers exposed to hand-arm vibration. *Ergonomics* **1991**, *34*, 547–562. [CrossRef] [PubMed]
32. Viikari-Juntura, E. Risk factors for upper limb disorders. Implications for prevention and treatment. *Clin. Orthop. Relat. Res.* **1998**, *351*, 39–43. [CrossRef]
33. Dobie, R.A. The burdens of age-related and occupational noise-induced hearing loss in the United States. *Ear Hear.* **2008**, *29*, 565–577. [CrossRef] [PubMed]
34. Nelson, D.I.; Nelson, R.Y.; Concha-Barrientos, M.; Fingerhut, M. The global burden of occupational noise-induced hearing loss. *Am. J. Ind. Med.* **2005**, *48*, 446–458. [CrossRef] [PubMed]
35. Dixon, W. Effects of high intensity sound. In *Handbook of Acoustics*; Crocker, M.J., Ed.; Wiley & Sons Inc.: Hoboken, NJ, USA, 1998; ISBN 978-0-471-25293-1.
36. Fonseca, A.; Aghazadeh, F.; de Hoop, C.; Ikuma, L.; Al-Qaisi, S. Effect of noise emitted by forestry equipment on workers' hearing capacity. *Int. J. Ind. Ergon.* **2015**, *46*, 105–112. [CrossRef]
37. Neitzel, R.; Yost, M. Task-Based Assessment of Occupational Vibration and Noise Exposures in Forestry Workers. *AIHA J.* **2002**, *63*, 617–627. [CrossRef]
38. Poje, A.; Potočnik, I.; Mihelič, M. Comparison of Electric and Petrol Chainsaws in Terms of Efficiency and Safety When Used in Young Spruce Stands in Small-Scale Private Forests. *Small-Scale For.* **2018**, 1–12. [CrossRef]
39. Cividino, S.R.S.; Blanchini, F.; Lombardo, R.; Dell'Antonia, D.; Vujinovic, T.D.; Malev, O.; Gubiani, R. An improved safety device for electric chainsaws. *Contemp. Eng. Sci.* **2015**, *8*, 1229–1244. [CrossRef]
40. Marucci, A.; Monarca, D.; Cecchini, M.; Colantoni, A.; Di Giacinto, S.; Cappuccini, A. The heat stress for workers employed in a dairy farm. *J. Agric. Eng.* **2013**, *44*, 170–174. [CrossRef]
41. Di Giacinto, S.; Colantoni, A.; Cecchini, M.; Monarca, D.; Moscetti, R.; Massantini, R. Produzione casearia in ambienti termici vincolati e sicurezza degli addetti alla produzione. *Ind. Aliment.* **2012**, *530*, 5–12.
42. Marucci, A.; Pagniello, B.; Monarca, D.; Cecchini, M.; Colantoni, A.; Biondi, P. Heat stress suffered by workers employed in vegetable grafting in greenhouses. *J. Food Agric. Environ.* **2012**, *10*, 1117–1121.
43. Cecchini, M.; Colantoni, A.; Massantini, R.; Monarca, D. The risk of musculoskeletal disorders for workers due to repetitive movements during tomato harvesting. *J. Agric. Saf. Health* **2010**, *16*, 87–98. [CrossRef] [PubMed]
44. Blanco, I.; Pascuzzi, S.; Anifantis, A.S.; Scarascia-Mugnozza, G. Study of a pilot photovoltaic-electrolyser-fuel cell power system for a geothermal heat pump heated greenhouse and evaluation of the electrolyser efficiency and operational mode. *J. Agric. Eng.* **2014**, *45*, 111–118. [CrossRef]

45. Blanco, I.; Anifantis, A.S.; Pascuzzi, S.; Scarascia Mugnozza, G. Hydrogen and renewable energy sources integrated system for greenhouse heating. *J. Agric. Eng.* **2013**, *44*, 226–230. [CrossRef]
46. Hanisch, C.; Loellhoeffel, T.; Diekmann, J.; Markley, K.J.; Haselrieder, W.; Kwade, A. Recycling of lithium-ion batteries: A novel method to separate coating and foil of electrodes. *J. Clean. Prod.* **2015**, *108*, 301–311. [CrossRef]
47. Boubaker, K.; Colantoni, A.; Allegrini, E.; Longo, L.; Di Giacinto, S.; Monarca, D.; Cecchini, M. A model for musculoskeletal disorder-related fatigue in upper limb manipulation during industrial vegetables sorting. *Int. J. Ind. Ergon.* **2014**, *44*, 601–605. [CrossRef]
48. Colantoni, A.; Mazzocchi, F.; Cossio, F.; Cecchini, M.; Bedini, R.; Monarca, D. Comparisons between battery chainsaws and internal combustion engine chainsaws: Performance and safety. *Contemp. Eng. Sci.* **2016**, *9*, 1315–1337. [CrossRef]
49. *International Organization for Standardization UNI EN ISO 5349-1:2001 Mechanical Vibration—Measurement and Evaluation of Human Exposure to Hand- Transmitted Vibration—Part 1: General Requirements*; International Organization for Standardization: Geneva, Switzerland, 2001.
50. *International Organization for Standardization UNI EN ISO 5349-2:2001 Mechanical Vibration—Measurement and Evaluation of Human Exposure to Hand- Transmitted Vibration—Part 2: Practical Guidance for Measurement at the Workplace*; International Organization for Standardization: Geneva, Switzerland, 2001.
51. European Commission Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). *Off. J. Eur. Commun.* **2003**, *42*, 38.
52. *International Organization for Standardization ISO 9612:2011 Acoustics—Determination of Occupational Noise Exposure—Engineering Method*; International Organization for Standardization: Geneva, Switzerland, 2011.
53. *International Organization for Standarization (ISO) ISO 11201:2010—Acoustics: Noise Emitted by Machinery and Equipment; Determination of Emission Sound Pressure Levels at a Work Station and at Other Specified Positions in an Essentially Free Field over a Reflecting Plane with Negligible Environmental cor*; International Organization for Standardization: Geneva, Switzerland, 2010.
54. *R Development Core Team R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2008; ISBN 3-900051-07-0.
55. Kruskal, W.H.; Wallis, W.A. Use of Ranks in One-Criterion Variance Analysis. *J. Am. Stat. Assoc.* **1952**, *47*, 583–621. [CrossRef]
56. Hollander, M.; Wolfe, D.A. *Nonparametric Statistical Methods*; John Wiley & Sons: New York, NY, USA, 1973.
57. Dunn, O.J. Multiple Comparisons Using Rank Sums. *Technometrics* **1964**, *6*, 241–252. [CrossRef]
58. Holm, S. A Simple Sequentially Rejective Multiple Test Procedure. *Scand. J. Stat.* **1979**, *6*, 65–70.
59. Pitts, P. *Hand-Arm Vibration Emission of Chainsaws-Comparison with Vibration Exposure*; Health and Safety Laboratory: Buxton, UK, 2004; 60p. Available online: http://www.hse.gov.uk/research/hsl_pdf/2004/hsl0413.pdf (accessed on 10 August 2018).
60. Rukat, W.; Jakubek, B. The influence of the cutting tooth design and wear of a saw chain on the vibration level of a chainsaw. *Vib. Phys. Syst.* **2017**, *28*, 1–8.