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Do Standardised European Chain-saw Tests Represent the Noise Hazard During Real Use?

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ABSTRACT

Machinery supplied within the European Economic Area must comply with the noise requirements of Machinery Directive 2006/42/EC, that is, it must be designed to minimise noise risk and be supplied with information to enable use of the machine without risk, if noise hazard remains. Noise information provided by machinery manufacturers should alert purchasers to noise hazard and, with work pattern details, be suitable for estimating noise exposures that guide management of the noise; including identification of models of equivalent machinery with lower noise risk. Noise information provided in instructions according to harmonised European Standards shows that chain-saws present a high noise hazard, with manufacturers' declared emission sound pressure levels for combustion-engine machines typically around 100 dB(A). According to ISO 12001, these should 'be representative of the noisiest operation in typical usage of the machine'. The success of harmonised standards for chain-saws in meeting this requirement has been investigated. The noise generated at the operator's ear was measured for a sample of electric, battery and petrol chain-saws during tasks to represent real use, including cross-cutting and snedding. These real use noise levels have shown that the noise information in instructions can be reliable for warning of noise hazard and helping buyers to select lower noise chain-saws.

Keywords: Noise, Hazard, Chain-saws
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1. INTRODUCTION

Chain-saws are widely used by professional operators for forest/tree services and landscape gardening and by domestic users for gardening and cutting firewood. Their use exposes operators to a number of hazards, including noise. Machinery Directive 2006/42/EC[1] requires that machinery supplied within the European Economic Area be designed and constructed to minimise risk from noise. If a noise hazard remains, information (including noise emission values) must be supplied to buyers of the machinery that enable employers to put in place appropriate control measures so that workers can use the machinery without risk from noise.

The noise content of the instructions supplied with 66 chain-saws was assessed against the noise requirements of the Machinery Directive as part of a market surveillance exercise across Europe[2]. This study found that 74% of the chain-saws sampled were supplied with an emission sound pressure level (L_{pA}) that provided a clear indication of noise hazard, that is, the reported value was sufficient to alert purchasers to the possibility of worker noise exposures exceeding criteria for risk set out in the Physical Agents (Noise) Directive 2003/10/EC[3]. Further work was recommended to establish whether the emission L_{pA} and its associated uncertainty a) represent accurately the noise hazard during normal use and b) permits valid comparisons between chain-saws, that is, distinguishes real differences in noise hazard.

The noise generated by a sample of chains-saws during typical real use activities was measured. These real use noise levels were used to assess the reliability of manufacturer's noise information provided in chain-saw instructions for reporting noise hazard and for identifying lower noise chain-saws. This paper describes the methods used to determine the noise data and the results obtained and investigates the credibility of chain-saw emission L_{pA} to represent noise hazard during the intended uses of the tool.

2. STANDARDISED NOISE TESTS FOR CHAIN-SAWS

2.1 Noise Emission Data

The Machinery Directive requires chain-saw instructions to include the A-weighted emission sound pressure level (L_{pA}) at the workstation and its associated uncertainty (K) and the measured sound power level determined according to the method specified in the Noise Emission in the Environment by Equipment for Use Outdoors Directive[4].

According to the guide to the application of the Machinery Directive[5], the noise emission declaration has two main purposes: to help users choose machinery with reduced noise emission; and provide information useful for a workplace risk assessment. The emission L_{pA} is a measure of the noise produced by a machine at a workstation; it excludes the effects of background noise and workplace reflections. It should represent the real use noise hazard and enable comparison of "competing machines", that is, similar machines intended to carry out the same function with equivalent performance characteristics. The sound power level is a measure of the total sound energy of noise emission; it does not directly provide any information about noise hazard but should help compare competing machines on the basis of noise. Chain-saw Harmonised Standards

European harmonised standards are commonly used by machinery manufacturers to demonstrate compliance with the requirements of the Machinery Directive. EN ISO 12001:2009[6] sets out the rules for the drafting and presentation of a noise test code for a specific family of machinery.

The methods for determining chain-saw emission L_{pA} are set out in several interrelated standards. For electric and battery operated chain-saws these are: EN

60745-1:2009+A11:2011[7]; EN 60745-2-13:2009+A1:2011[8]; and the noise test code EN ISO 22868:2011[9]. For combustion-engine (petrol) chain-saws these are: EN ISO 11681-1:2011[10]; EN 11681-2:2011[11]; and the noise test code EN ISO 22868:2011.

2.2 Standardised Operating Conditions for Emission L_{pA}

According to EN ISO 12001 *"the noise test code shall specify an operating condition that is reproducible and is representative of the noisiest operation in typical usage of the machine under test"*. Despite this requirement, Patel and Brereton[12] identified noise test codes for a range of machine types that produced noise emission data, which do not adequately represent the noise hazard of machinery during its intended uses.

The emission L_{pA} for chain-saws is determined during operating conditions intended to simulate real use machine modes. According to the chain-saw noise test code, EN ISO 22868, the operating conditions defined in the standard test are those considered when assessing noise exposure over a typical working day. Typically chain-saws with a petrol engine of <80 cm^3 are used for operations, which include felling (cutting down a tree), delimbing/snedding (removing branches from the trunk of a fallen tree) and bucking/cross cutting (cutting a felled and delimbed tree into logs); chain-saws with a petrol engine of ≥80 cm^3 are normally used for felling and bucking. Delimbing will use the chain-saw at maximum speed; therefore, standard tests only include racing for saws with a <80 cm^3 engine. Table 1 provides a summary of the operating conditions used in chain-saw noise test codes.

Table 1: Operating conditions to determine chain-saw emission L_{pA}

Standardised Operating Conditions	**Chain-saw Type**		
	Petrol - Engine displacement		**Electric/ Battery**
	<80 cm^3	**≥80 cm^3**	
IDLING Operation at no-load, with maximum speed settings (Electric/battery chain-saws) Operation with fully released throttle trigger (Petrol chain-saws)	✓	✓	✓
FULL LOAD Simulated cross-cutting with throttle fully open (bucking)	✓	✓	✓
RACING Engine speed at 133% of speed at maximum engine power (simulates delimbing/snedding)	✓	✗	✗

2.3 Standardised Measurements for Emission L_{pA}

Standardised tests for electric and battery operated chain-saws require determination of the sound power level (L_{WA}) under two operating conditions, idling and full load, from which the emission L_{pA} is calculated as (L_{WA} – 11 dB).

The emission L_{pA} for petrol chain-saws is determined from measurements made with a microphone located 70 cm above the top of the front handle of the chain-saw and vertically above its centreline, between the root of the spiked bumper (helps to prevent kickback) and the outer edge of the rear handle. This is intended to represent the operator's position.

3. CHAIN-SAWS TESTED

The United Kingdom sampled the 10 chain-saws detailed in Table 2 as part of a European wide Market Surveillance exercise[13]. The sample included petrol, electric and battery powered chain-saws aimed mainly at domestic users.

The market surveillance exercise assessed the conformity of a set of chain-saws with the requirements of the Machinery Directive. These assessments included strength testing of the handles and determination of the adequacy of hand protection, chain-brake stopping times, protection against kickback and the functioning of the chain-catcher. These conformance tests meant that prior to noise testing the chain-saws had to be assessed as being safe to use. Some of the machines failed this assessment and, where possible, were replaced by new samples of the same chain-saw model.

Table 2: Summary of chain-saws tested

Chain-saw ID	Type	Size[a]	Weight, kg[b]	Safety Assessment
UK01	Electric	1800 W	4.7	New sample
UK02	Petrol	53 cm^3	6.0	Conformity assessment previously carried out; limited real use tests possible
UK03	Battery	18 V	3.1	New sample
UK04	Petrol	42 cm^3	5.5	Conformity assessment previously carried out; sample in good condition
UK05	Petrol	58 cm^3	5.5	Conformity assessment previously carried out; sample in good condition
UK06	Petrol	61.5 cm^3	5.4	New sample
UK07	Petrol	38.9 cm^3	4.4	Conformity assessment previously carried out; sample in good condition
UK08	Petrol	41 cm^3	4.5	Conformity assessment previously carried out; sample in good condition
UK09	Electric	2400 W	5.6	Conformity assessment previously carried out; sample in good condition
UK10	Petrol	25.4 cm^3	2.9	Conformity assessment previously carried out; real use tests not possible and unable to buy replacement

[a] Engine capacity (displacement) for petrol chain-saws; power/voltage for electric/battery chain-saws
[b] Without fuel for petrol chain-saws

The emission L_{pA} and associated uncertainty K provided in the instructions of the chain-saws tested are shown in Table 3. The uncertainty K is a value chosen by manufacturers such that if a standard test is reproduced, the reproduced L_{pA} will be less than the manufacturer's ($L_{pA} + K$). Emission L_{pA} values were not provided for two of the chain-saws sampled which is a breach of the legal requirements of the Machinery Directive.

Table 3: Noise information provided in chain-saw instructions

Chain-saw ID	Noise data in instruction manual		Relevant standards referenced in instructions
	Emission L_{pA}, dB	***K* value, dB**	
UK01	91.7	2.5	EN 60745-1, EN 60745-2-13
UK02	99.1	3	EN ISO 22868, EN ISO 11681-1
UK03	70.5	1.5	EN 60745-1, EN 60745-2-13
UK04	101.3	1[a]	ISO 22868
UK05	-	-	EN ISO 11681-1
UK06	101.2	3	EN ISO 11681-1
UK07	99.6	2.3	EN ISO 22868, EN ISO 11681-1
UK08	99	3	EN ISO 11681-1
UK09	85.62	3	EN 60745-1, EN 60745-2-13
UK10	-	-	EN ISO 11681-1

[a] Manufacturer has provided standard deviation of 1 dB; this is not a *K* value.

4. METHOD USED TO DETERMINE REAL USE NOISE DATA

4.1 Test Description

A professional arborist (tree surgeon and experienced chain-saw user) operated the chain-saws during the noise tests. The chain-saws were set up according to the manufacturers' instructions. The instructions supplied with all the chain-saws stated that the tools were designed for felling, bucking and limbing trees and shrubs. Simulated real use tests were carried out to investigate the noise levels likely to be generated by the chain-saws during normal use.

The test area was a circular concrete pad with diameter 30 m surrounded by grass and trees, with buildings more than 30 m away.

The chain-saws were run at maximum speed prior to the noise tests to ensure the engines were warm and stable during the tests.

4.2 Simulated Real Use Tests

The chain-saw operator carried out the following tasks with each of the chain-saws, where possible:

Cross cutting (full load test): The operator cut through sections of oak logs (hard wood), which were undried with bark attached. The logs were approximately 30 cm in diameter and 2 m long. They were supported on a saw horse, which positioned the top of the log 1 m above the ground during the tests as shown in Figure 1. The operator made 5 cuts through the logs with each chain-saw; each cut was approximately 5 cm from the end of the log. During these tests, the petrol chain-saws were operated with the throttle fully open and the electric and battery chain-saws with the trigger at maximum speed.

Snedding (racing test): The operator removed all the branches from spruce trees approximately 2.5 m long placed on the concrete ground as shown in Figure 2. One tree was used for each chain-saw; the measurement period included non-snedding times as the tree was rotated. The chain-saw was run with the throttle fully open (petrol) or a maximum speed settings (electric/battery) during these tests.

Idling: The operator held petrol chain-saws as shown in Figure 3; electric and battery operated saws were held in the same position but with the guide bar pointing forwards. Chain-saw standards give contradictory definitions of idling for petrol and electric/battery chain-saws. Petrol chain-saws were run with the throttle trigger fully released; the electric and battery operated chain-saws were run at the maximum speed settings (as for the racing test).

Figure 1: Cross cutting

Figure 2: Snedding

Figure 3: Idling

4.3 Data Acquisition and Analysis

Noise measurements were made using a half-inch free field microphone. This was positioned close to the chain-saw operator's right ear; this is the side on which the chain-saw was predominantly used. The microphone was mounted on an extendable carbon rod to ensure the safety of the scientist making the noise measurements during the chain-saw tasks. Background noise measurements were also made without the chain-saws running.

The microphone was connected to a noise analyser, set up for linear averaging over the duration of the measurements to give equivalent A-weighted sound pressure levels, L_{pAeq}. Additional measurements were made using a sound level meter to determine the noise level at the operator's ear during idling.

The measurement periods were between 18 and 36 s (average 26 s) for cross cutting, between 41 and 140 s (average 83 s) for snedding, and approximately 20 s for idling. The range of measurement periods reflect the different efficiencies of the chain-saws tested. The petrol chain-saws were generally faster than the electric and battery operated tools at carrying out the simulated real use tasks.

5. RESULTS

The equivalent A-weighted sound pressure levels, L_{pAeq} measured at the chain-saw operator's ear during the simulated real use tasks are given in Table 4. The mean and standard deviation values for the cross cutting task were determined by combining the noise levels generated during each of the 5 cuts.

Table 4: A-weighted sound pressure levels measured during simulated real use tests

Chain-saw ID	Equivalent A-weighted sound pressure level at operator's ear (L_{pAeq}), dB			
	Cross cutting, L_{pAeqFL}		Snedding, L_{pAeqRa}	Idling, L_{pAeqId}
	Mean	Standard deviation		
UK01	93.7	0.9	86.6	91.1
UK02	-	-	-	83.1
UK03	82.9	0.4	79.6	80.5
UK04	98.5	0.6	99.5	77.5
UK05	104.4	0.9	101.0	86.9[a]
UK06	101.7	1.4	97.3	88.4
UK07	103.4	0.6	97.4	79.6
UK08	98.9	1.0	97.2	77.7
UK09	92.3	1.5	90.8	92.2
UK10	-	-	-	-

[a] For safety reasons, this measurement was made with the chain-saw on the ground

6. DISCUSSION

6.1 Comparison of Declared and Simulated Real Use Noise Data

Researchers at the Health and Safety Executive have reported difficulties in verifying manufacturers' declared noise emissions, for example for sanders and concrete breakers[12]. In the majority of cases, this was due to poorly defined noise test codes with unclear and obsolete measurement methods and operating conditions and, in some cases reference to unsuitable standards. These issues result in noise emission declarations for competing machinery that are neither consistent nor comparable.

The aim of the work reported here was not to verify manufacturers' chain-saw noise emission L_{pA} data but to assess the credibility of the reported emission L_{pA} values according to the operating conditions to which they were traceable. Before comparisons were made, the data reported in Table 4 were developed into a single number representative of the noise for the combined modes of operation based on the methods defined in the test standards.

Noise emission data for electric and battery operated chain-saws are based on measurements during idling (this is similar to the racing conditions specified for petrol chain-saws) and full load conditions. An estimate of the overall L_{pAeq} was calculated using Equation 1 and the data in Table 4. The equation is based on that specified in EN 60745-2-13 for the determination of sound power level.

Equation 1: Overall $L_{pAeq} = 10log[(1/2)(10^{0.1LpAeqId} + 10^{0.1LpAeqFL})]$; where L_{pAeqId} is the L_{pAeq} from the idling measurements and L_{pAeqFL} is the L_{pAeq} from the full load measurements.

An estimate of the overall L_{pAeq} for petrol chain-saws was calculated using Equation 2 and the data in Table 4. This equation is defined in EN ISO 22868 for determination of the emission L_{pA} for petrol chain-saws with engine displacement less than 80 cm^3.

Equation 2: Overall $L_{pAeq} = 10log[(1/3)(10^{0.1LpAeqId} + 10^{0.1LpAeqFL} + 10^{0.1LpAeqRa})]$; where L_{pAeqRa} is the L_{pAeq} from the racing measurements.

Table 5 gives, for each chain-saw tested, the declared emission L_{pA} values and the estimated overall L_{pAeq} values calculated from the measurements at the operator's ear. The emission L_{pA} and the L_{pAeq} at the operator's ear were considered suitable for comparison as the environmental correction is negligible for chain-saw noise emission tests (outdoor measurements on a hard flat concrete surface). The differences in Table 5 show that for petrol chain-saws the declared emission L_{pA} were generally higher, by up to 4 dB, than the overall L_{pAeq} values estimated from the simulated real use levels measured at the operator's ear. These may be due to differences in measurement position; emission L_{pA} is determined from measurements 70 cm above the body of the chain-saw while the L_{pAeq} values were measured at the operator's ear, approximately 60 cm above the chain-saw and 50 cm to the left of the centreline of the chain-saw.

Table 5: Comparison of declared emission L_{pA} and estimated overall L_{pAeq}

Chain-saw ID	**Type**	**Declared emission L_{pA}, dB**	**Overall L_{pAeq}, dB**	**Emission L_{pA} – Overall L_{pAeq}, dB**
UK01	Electric	91.7	92.6	-0.9
UK02	Petrol	99.16	-	-
UK03	Battery	70.5	81.9	-11.4
UK04	Petrol	101.3	97.3	4.0
UK05	Petrol	-	101.3	-
UK06	Petrol	101.2	98.4	2.8
UK07	Petrol	99.6	99.6	0.0
UK08	Petrol	99.0	96.4	2.6
UK09	Electric	85.62	92.2	-6.58
UK10	Petrol	-	-	-

The emission L_{pA} values reported for two of the electric/battery operated chain-saws tested (UK03 and UK09) were lower than the overall L_{pAeq} values determined here. Concern about emission values for these two chain-saws was also identified in the European Market Surveillance exercise[13], where the same chain-saws were among 5 of the 66 that had differences between the sound power level and the emission L_{pA} of 20 dB when a value of 11 dB was expected. Appropriate noise test codes were referenced in the manufacturer's instructions for both UK03 and UK09, but the declared emission L_{pA} values are too low to have been determined in accordance with these standards. The differences reported in Table 5 for UK03 and UK09 support this observation.

6.2 Estimation of Noise Risk

Declared noise emission values are the final step in the hierarchy of controls to ensure that machinery can, in accordance with the Machinery Directive "*be operated, adjusted and maintained without putting persons at risk when these operations are carried out under the conditions foreseen but also taking into account any reasonably foreseeable misuse.*"

For each chain-saw, Figure 4 shows the manufacturer's declared emission L_{pA} and the noise levels generated at the operator's ear during simulated real use tasks. The highest noise levels were generally measured during cross cutting. The highest L_{pAeq} levels are compared with the declared emission L_{pA} values in Table 6.

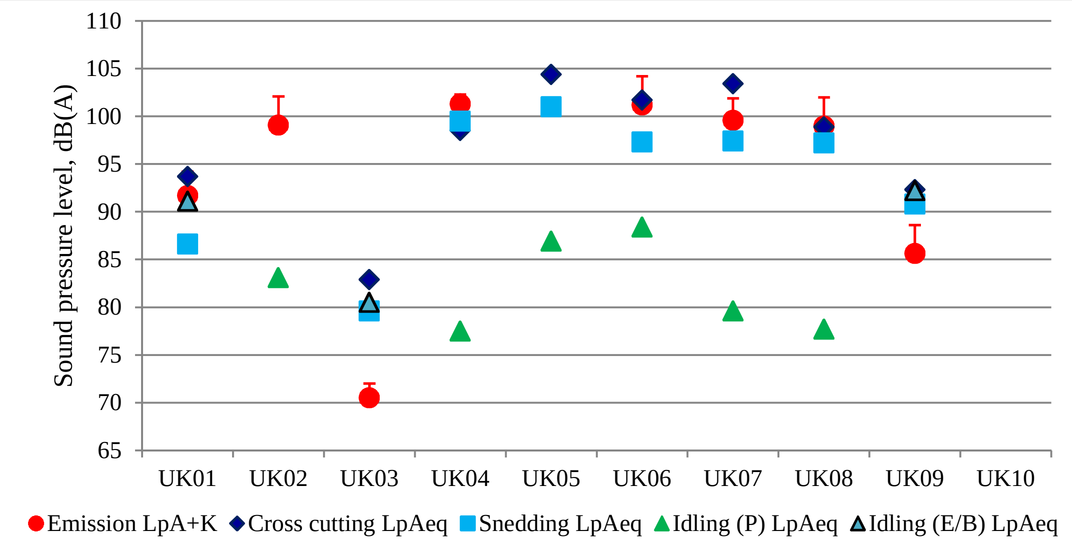

Figure 4: Comparison of declared emission L_{pA} and real use noise levels at the chain-saw operator's ear

Table 6: Comparison of declared emission L_{pA} and L_{pAeq} for noisiest operation

Chain-saw ID	**Type**	**Declared emission L_{pA}, dB**	**Noisiest operation L_{pAeq}, dB**	**Emission L_{pA} – Noisiest L_{pAeq}, dB**
UK01	Electric	91.7	93.7	-2.0
UK02	Petrol	99.16	-	-
UK03	Battery	70.5	82.9	-12.4
UK04	Petrol	101.3	99.5	1.8
UK05	Petrol	-	-	-
UK06	Petrol	101.2	101.7	-0.5
UK07	Petrol	99.6	103.4	-3.8
UK08	Petrol	99.0	98.9	0.1
UK09	Electric	85.62	92.3	-6.68
UK10	Petrol	-	-	-

The data in Table 6 shows that the emission L_{pA} and the noisiest real use L_{pAeq} values are within 2 dB for 4 of those 7 chain-saws tested that had emission data. These results suggest that the chain-saw emission L_{pA} data are sufficient to make clear the noise hazard when determined correctly according to appropriate standard noise test codes.

The emission L_{pA} values reported for two of the chain-saws tested, UK03 and UK09, underestimated cross cutting noise levels by 12.4 dB and 6.68 dB respectively. They are not credible indicators of noise hazard and could not be used by users to adequately assess or manage the noise risk associated with these chain-saws during their intended uses.

Although the emission data provided with UK09 is not reliable, the instructions advise the user to *"wear adequate noise protection equipment. The impact of noise can cause hearing damage or hearing loss. Take frequent work breaks. Limit the amount of exposure per day."* An emission L_{pA} value of 70.5 dB(A) was provided in the instructions for UK03; this is not considered a hazardous level of noise although the instructions warn that hearing damage is possible and state that use of hearing protectors will reduce personal injuries. This may be confusing for the user. Inconsistent advice and unreliable noise emission data will make it difficult to properly manage the noise risk for chain-saw operators.

The instructions for the petrol chain-saw UK05 did not include emission L_{pA} data, despite claiming conformity with the requirements of the Machinery Directive. The measured L_{pAeq} values at the operator's ear during cross cutting and snedding exceeded 100 dB(A). This is a high hazard machine and demonstrates the importance of the Machinery Directive requirement to provide reliable noise emission data to warn chain-saw users of the potential risk for noise.

6.3 Identification of Lower Noise Chain-saws

The range of real use noise levels for cross cutting in Table 4 is 21 dB, with absolute L_{pAeq} values between 83 and 104 dB(A); for snedding the range is 21 dB with absolute levels between 80 and 101 dB(A). These ranges are considerably smaller than the range of more than 30 dB in the manufacturers' declared emission L_{pA} values for the same chain-saws. However, if the declared emission L_{pA} data for UK03 and UK09 are substituted by (L_{WA} – 11 dB), which is how the appropriate standards define emission L_{pA} for electric and battery operated chain-saws, the range of declared emission values becomes 21 dB, with the absolute levels between 80 and 101 dB(A).

The real use data suggest that there may be an opportunity to reduce noise at the ear by up to 20 dB by using the quietest rather than the noisiest chain-saw. Figure 5 shows that emission L_{pA} data can be used to reliably rank the chain-saws to identify low or lower noise machines in actual use therefore making it possible to achieve the 20 dB potential reduction. But the sample of chain-saws is limited in particular for the petrol chain-saws; their reported emission L_{pA} values are within 2 dB and real use levels are within 5 dB.

While Figure 5 implies there is a choice of low and high noise chain-saws and the instructions suggest that all the chain-saws can be used for similar operations, the professional chain-saw operator observed there may not be such a choice in practice. The battery operated chain-saw was the quietest machine, but was also the least effective; it *"bounced around"*, ripping rather than cutting off the spruce branches during snedding and failed to cut through the hard wood log during cross cutting. The petrol chain-saws were generally more efficient than the electric and battery operated tools at carrying out the simulated real use tasks.

Chain-saws should be chosen first for their ability to do the job; noise should be a secondary consideration. Higher noise models of those machines capable of doing the job should be rejected. For the sample of chain-saws tested here the electric tools, although significantly quieter than the petrol tools, are unlikely to be selected for jobs requiring significant felling and cross cutting.

The sample of petrol chain-saws tested have similar noise levels. As such it is unclear that a significant reduction in risk would be achieved by choosing between them; in all cases users would be required to wear hearing protection to control the risk associated with the high levels of noise they generate.

Three of the petrol chain-saws tested have comparable engine sizes; these are UK02, UK05 and UK06 and they should be all suited to similar types of work. Informed buyers should avoid selecting UK05 for two reasons: it has not been supplied with emission L_{pA} data and real use noise measurements suggest that alternative quieter models are available from manufacturers who have achieved state-of-the-art design with regards to noise.

The benefits of using low noise chain-saws is limited if they take longer to do specified jobs or are less effective. Further work is needed to investigate the availability of lower noise chain-saws with sufficient power to work efficiently. The petrol chain-saws in this study were too similar; engine displacements were between 40 and 60 cm^3 and engine powers between 1.5 and 2.3 kW.

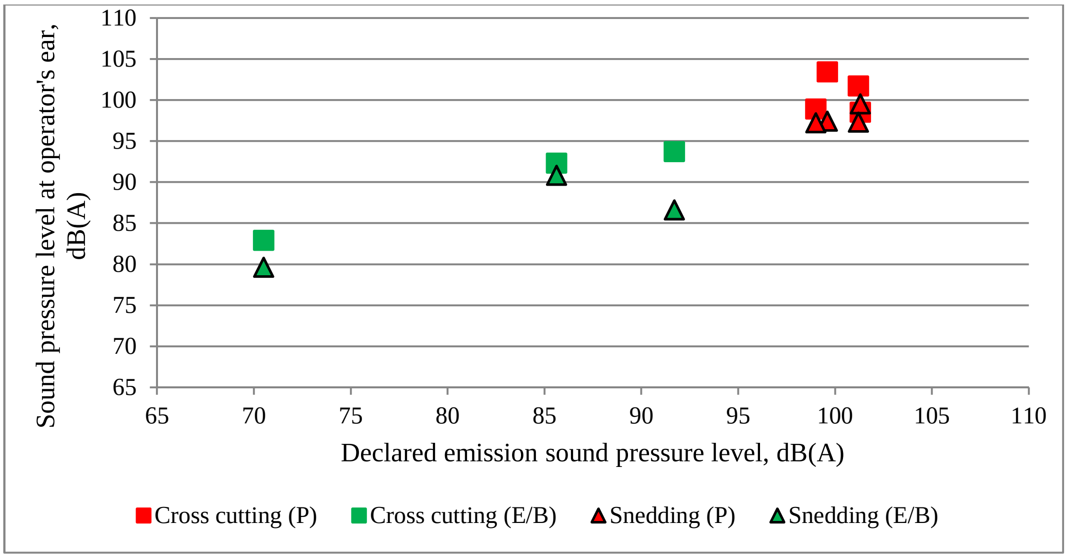

Figure 5: Declared emission L_{pA} plotted against simulated real use L_{pAeq} values during typical chain-saw operations. Note: P indicates data for petrol chain-saws; E/B indicates data for electric and battery operated chain-saws

7. CONCLUSIONS

The harmonised noise test codes for chain-saws define operating conditions that represent the noise generated during the intended uses of the machine. Real use measurements at the chain-saw operator’s ear showed that the reported emission L_{pA} values for 5 of the 7 chain-saws, for which measurements in all relevant operating conditions were possible, are likely to have been determined according to the noise tests codes referenced.

Emission L_{pA} data provided with electric and battery operated chain-saws suggested incorrect application by the manufacturers of the appropriate noise test code. This error produces emission L_{pA} data that misleadingly imply quieter chain-saws.

Emission data provided with the chain-saws tested are potentially a reliable indicator of real use noise hazard. Emission L_{pA} were within 2 dB of the L_{pAeq} values generated at the operator’s ear during the noisiest operation for 4 of the 7 chain-saws that were supplied with emission data and could be tested.

The instructions supplied with two of the chain-saws tested did not include noise emission data; in accordance with Use of Work Equipment Directive 2009/104/EC[14], buyers should avoid purchasing noisy machinery not provided with noise hazard information.

Chain-saw emission data are sufficient to make clear the noise hazard, but only when determined correctly according to appropriate standard noise test codes.

Emission data provided with chain-saws can reliably identify chain-saws that generate lower noise during real use. However the sample of machines tested here is limited. It shows that electric and battery operated chain-saws are quieter than the petrol chain saws. These may be preferred on the basis of noise but only if their overall cutting performance is acceptable. This work has identified a gap in current knowledge of the relationship between noise and other performance characteristics.

DISCLAIMER

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