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SHORT COMMUNICATION

Laboratory evaluation of occupational exposure to hand-arm vibration (HAV) during grounds maintenance equipment operations

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Abstract

Introduction and Objective. About 2.5 million workers in the USA are exposed to hand-arm vibration (HAV) from power tools. The aims of the study were to evaluate occupational exposure to HAV during grounds maintenance equipment operations and the effect of general work gloves on vibration magnitude under controlled laboratory conditions.

Materials and method. A simulation of grass trimmer, backpack blower, and chainsaw operations was conducted by two participants to measure vibration total value (a_{hv}) using vibration dosimeters wearing gloves. a_{hv} was also measured on the bare hands during grass trimmer and backpack blower operations.

Results. a_{hv} of the gloved hand was 3.5–5.8, 1.1–2.0, and 3.0–3.6 m/s^2 during the grass trimmer, backpack blower, and chainsaw operations, respectively. a_{hv} of the bare hand was 4.5–7.2 and 1.2–2.3 m/s^2 for the grass trimmer and blower operations, respectively.

Conclusion. The highest HAV exposure was observed during the grass trimmer operation which showed higher vibration attenuation of the gloves.

Key words

acceleration, chainsaw, hand-arm vibration (HAV), grass trimmer, backpack blower, vibration exposure assessment

INTRODUCTION

Prolonged, excessive exposure to hand-arm vibration (HAV) can induce hand-arm vibration syndrome (HAVS), a complex of vascular, neurological, and musculoskeletal disorders [1]. There is no Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for vibration in the USA. Currently available standards/guidelines regarding HAV include ISO 5349:2001, ANSI S2.70–2006, American Conference of Governmental Industrial Hygienist (ACGIH) Threshold Limit Values (TLVs), and EU Directive 2002/44/EC [1–4]. The ISO 5349:2001 provides guidance on the evaluation methods of HAV, but exposure limit is not specified. The ANSI S2.70–2006, ACGIH TLVs, and Directive 2002/44/EC all define 5 m/s^2 as the daily exposure limit value and 2.5 m/s^2 as the daily exposure action value.

HAVS is prevalent among workers who regularly use powered hand tools employed in many industries, such as grounds maintenance, construction, and forestry [5–7]. According to the Bureau of Labor Statistics (BLS), there were 1,226,900 grounds maintenance jobs in the USA in 2020, which is expected to increase 8% between 2020–2030 [8].

There are a variety of work-related and individual factors which can substantially affect the results of exposure assessment such as tool model, exposure duration, posture, and contact force. Therefore, conducting HAV studies under the environments in which some of the variables can be controlled would assist in obtaining an improved understanding of occupational exposure assessment. Recent studies have evaluated vibration levels generated from grass trimmers, backpack blowers and chainsaws, while controlling operation mode/duration, tool model/condition, etc. [9–12]. However, there is still limited knowledge of HAV exposure in the USA, and studies on groundskeepers' exposure in particular are scarce [13].

The use of general-purpose safety gloves which are not marketed as anti-vibration gloves often provided for grounds maintenance jobs may be also an important factor which could affect the HAV exposure levels. However, the potential effects of such general work gloves on HAV exposure have been understudied.

OBJECTIVE

The aims of this study were to evaluate the occupational exposure to HAV during the operations of grounds maintenance equipment and the effect of one of the commercially available general work gloves on HAV under controlled laboratory conditions.

MATERIALS AND METHODS

Two researchers voluntarily participated in the study and an IRB-approved consent form was obtained from the participants (No. IRB-300003455). The operations of a string grass trimmer (FS 91 R), a backpack blower (BR 430), and a chainsaw (MS 271) were simulated in the laboratory; all were brand-new, gasoline-powered products (STIHL, Waiblingen,

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Table 1. Characteristics of the power tools

Tool	Chainsaw	Grass Trimmer	Backpack Blower
Model	STIHL MS 271	STIHL FS 91 R	STIHL BR 430
Engine power (kW)	2.6	0.95	2.9
Displacement (cc)	50.2	28.4	63.3
Dry weight (kg)	5.6	5.5	10.1
Average engine operating speed at full throttle (rpm)	12140	5840	6940

Germany). Table 1 summarizes the characteristics of the three power tools. Cowhide leather gloves (Condor, W. W. Grainger Inc., Lake Forest, IL, USA) were selected based on the observations made in a previous study by the authors [13] (Fig.1).

Figure 1. Cowhide leather gloves

Tri-axial vibration dosimeters (SV103, Svantek Sp. z o. o., Warsaw, Poland) were used and accelerometer embedded adapters were worn on the palms of the operators inside the gloves (Fig. 2). Calibration was conducted at an acceleration of 10 m/s² and frequencies of 79.58 and 159.2 Hz using a vibration calibrator (SV110, Svantek Sp. z o.o, Warsaw, Poland). The operating procedure of each tool was simulated based on workers' motions observed in the field. For the grass trimmer operation, the cutting head of trimmer was swung from one side to the other, approximately 30 inches for 1–1.5 seconds each side. For the backpack blower operation, the nozzle was swung from one side to the other, approximately 30 inches for 1–1.5 seconds each side. The swing width was marked on the floor to keep it consistent throughout the simulations. For the chainsaw operation, an oak wood log was cut into slices: one slice every 10 seconds. All of the simulation steps were timed to make sure each movement (i.e., swing and slicing) had a consistent time. Each operation was simulated for five minutes at full throttle and all operations were in triplicate for each operator. Additional five-minute operations of the grass trimmer and backpack blower were simulated three times with bare hands. The chainsaw was excluded for the bare-hand simulation due to safety concerns.

Data in in root-mean-square (r.m.s.) single-axis acceleration

Figure 2. Operator wearing vibration dosimeters with 3 orthogonal axes shown

values of the frequency-weighted vibration for x-axis (a_{hwx}), y-axis (a_{hwy}), and z-axis (a_{hwz}) at the 1/3 octave band center-frequency range of 0.8–1600 Hz were collected every second. The collected data were downloaded and analyzed using Supervisor software (Svantek Sp. z o.o., Warsaw, Poland). The frequency weighting was performed using the W_h weighting curve according to the ISO 5349–1 [1]. Vibration total value of frequency-weighted r.m.s. acceleration (a_{hv}) in m/s² was then calculated using the following equation:

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

The percent difference of acceleration values between gloved hand and bare hand was calculated as follows:

$$\text{Percent Difference (\%)} = \frac{a_{NG} - a_G}{(a_{NG} + a_G) \div 2} \times 100 \quad (2)$$

where a_{NG} is the acceleration value (m/s²) measured during the tool operation with no gloves (NG), and a_G is the acceleration value (m/s²) measured during the operation while wearing gloves (G).

RESULTS

Exposure to HAV during tool operations. The acceleration values of the gloved hand are shown in Table 2. The right/left hand a_{hv} resulted in 3.6±0.6/3.0±0.6 and 3.3±0.5/3.1±0.7 m/s² for operator 1 and 2, respectively, during the chainsaw operation. When the grass trimmer was simulated, the right/left hand a_{hv} was 5.1±0.6/3.5±0.5 and 5.8±0.5/4.3±0.5 m/s² for operator 1 and 2, respectively. For the backpack blower operation, the right hand a_{hv} was 1.1±0.2 and 2.0±0.5 m/s² for operator 1 and 2, respectively. Left hand data was not calculated as only the right hand was exposed to HAV during the backpack blower operation.

Table 2. Acceleration values of the gloved hand in three orthogonal axes (a_{hwx}, a_{hwy}, and a_{hwz}) and vibration total value (a_{hv}) by tool type, operator, and hand side

	Mean (SD), m/s²					
Operators	Chainsaw		Grass Trimmer		Backpack Blower	
	Right	Left	Right	Left	Right	Left
Operator 1						
a_{hwx}	1.3 (0.4)	1.6 (0.6)	3.6 (0.5)	1.2 (0.2)	0.6 (0.1)	-
a_{hwy}	2.7 (0.5)	1.9 (0.4)	1.9 (0.3)	3.0 (0.4)	0.8 (0.3)	-
a_{hwz}	2.0 (0.5)	1.7 (0.5)	3.0 (0.5)	1.2 (0.2)	0.5 (0.1)	-
a_{hv}	3.6 (0.6)	3.0 (0.6)	5.1 (0.6)	3.5 (0.5)	1.1 (0.2)	-
Operator 2						
a_{hwx}	1.3 (0.3)	1.9 (0.7)	4.2 (0.5)	2.1 (0.5)	0.8 (0.2)	-
a_{hwy}	2.6 (0.4)	1.9 (0.3)	1.9 (0.3)	3.2 (0.3)	1.6 (0.5)	-
a_{hwz}	1.6 (0.4)	1.6 (0.6)	3.5 (0.8)	2.1 (0.4)	0.8 (0.2)	-
a_{hv}	3.3 (0.5)	3.1 (0.7)	5.8 (0.5)	4.3 (0.5)	2.0 (0.5)	-

The average vibration spectra of the gloved hand are shown in Fig. 3. The chainsaw operation had a major acceleration peak at 160 Hz in the y- and z-directions measured on the right hand of the operators. On the left hand, a major peak appeared at 160 Hz in the three axes for both operators. The grass trimmer operation showed a major peak at 160 Hz in the all axes for both operators on the right hand, while a major peak occurred at the 80–125 Hz range in the y-direction on the left hand. The backpack blower operation had two peaks at 125 and 250 Hz in the three axes on the right hand for both operators.

Effects of gloves on HAV levels. Table 3 shows the acceleration values of the bare hand. During the grass trimmer operation, the a_{hv} measured on the right/left hand was 5.6±0.4/4.5±0.5 and 7.2±0.4/5.1±0.6 m/s² for operator 1 and 2, respectively. During the backpack blower operation, the a_{hv} measured on the right/left hand was 1.2±0.2/0.1±0.1 and 2.3±0.6/0.1±0.1 m/s² for operator 1 and 2, respectively.

Both grass trimmer and backpack blower operations showed the same pattern in the frequency spectrum as the gloved hand, as described above, but higher acceleration peaks were observed from the grass trimmer (Fig. 4).

Table 3. Acceleration values of the bare hand in three orthogonal axes (a_{hwx}, a_{hwy}, and a_{hwz}) and vibration total value (a_{hv}) by tool type, operator, and hand side

	Mean (SD), m/s²			
Operators	Grass Trimmer		Backpack Blower	
	Right	Left	Right	Left
Operator 1				
a_{hwx}	3.6 (0.2)	1.3 (0.2)	0.7 (0.1)	-
a_{hwy}	2.0 (0.2)	4.0 (0.5)	0.8 (0.3)	-
a_{hwz}	3.8 (0.4)	1.7 (0.3)	0.6 (0.1)	-
a_{hv}	5.6 (0.4)	4.5 (0.5)	1.2 (0.2)	-
Operator 2				
a_{hwx}	5.0 (0.3)	1.9 (0.2)	1.1 (0.5)	-
a_{hwy}	2.2 (0.4)	4.3 (0.6)	1.8 (0.4)	-
a_{hwz}	4.7 (0.4)	2.2 (0.4)	0.9 (0.2)	-
a_{hv}	7.2 (0.4)	5.1 (0.6)	2.3 (0.6)	-

During the grass trimmer operation, the percent difference of a_{hv} between the gloved hand and bare hand ranged from 10.3 – 27.0%. The biggest difference in a_{hw} was observed in the z-axis: 27.4% on the right hand of operator 2 and 30.9% on the left hand of operator 1. During the backpack blower operation, the difference of a_{hv} between gloved hand and bare hand was 7.9 and 11.3% on the right hand for operator 1 and 2, respectively. The largest difference of a_{hw} was 30.1% in the x-axis in operator 2.

Figure 5 shows frequency spectrum of the percent difference. The grass trimmer operation had the largest attenuation (129.9%) at 1,000 Hz in the z-direction and the largest amplification (-42.3%) at 25 Hz in the y-axis both from operator 2's right hand. The backpack blower operation showed the largest attenuation (86.3%) at 1,000 Hz and the largest amplification (-29.2%) at 1Hz both in the y-direction from operator 2.

DISCUSSION

The grass trimmer operation showed the highest vibration among the power tools examined in this study, regardless of glove use. Patil conducted a laboratory test (no grass cutting) and a field test (grass cutting) using a 0.96 kW bike-handle grass trimmer at 7,250 rpm, and the vibration measured near left hand grip was 8.3 m/s² (laboratory test) and 9.2 m/s² (field test), much higher than the results obtained in the current study on the left bare hand, 4.8±0.5 m/s², primarily due to the different tool model and measurement methods [12]. In a simulation study by Landekić et al., vibration from different chainsaw models was measured at the tool handles [11]. The study results from one chainsaw model, which had the similar tool characteristics but was lighter compared to the chainsaw in the current study – 2.2±0.5 m/s² on the front handle and 2.0±0.8 m/s² on the rear handle, were somewhat lower than the findings on the gloved hand, 3.1±0.7 m/s² on the left hand and 3.3±0.5 m/s² on the right hand in the current study. Calvo et al. examined the vibration of multiple agricultural backpack blowers with 2.9–3.6 kW engine power, weighing 11–12 kg at 6,160–7,000 rpm; the mean acceleration value measured at the control handle was 1.7±0.5 m/s² – similar to results obtained in the current study – 1.6±0.4m/s² [14].

Operator 2 appeared to receive higher a_{hv} than operator 1, regardless of glove use, potentially due to the difference in contact force which could not be controlled. Although the difference between the right hand and the left hand was not substantial, the right hand – the dominant hand of both operators – tended to receive more vibration than the left hand. Landekić et al. observed similar vibration values between the front handle and rear handle of chainsaws with the lowest engine power (2.6 kW). However, the front handle vibration became higher when the chainsaws with higher engine power and weight were used.

The dominant frequency of the chainsaw and grass trimmer operations was observed at 160 Hz. Oliveira et al. and Bernardi et al. observed the same dominant frequency from a loop-handle brush cutter and a bike-handle brush cutter, respectively [15, 16]. Two different chainsaws examined by Calvo et al. during olive cultivation exhibited the same fundamental frequency as in the current study [17], while a study by Matache et al. showed a higher dominant frequency [18], largely attributed to the differences in tool characteristics,

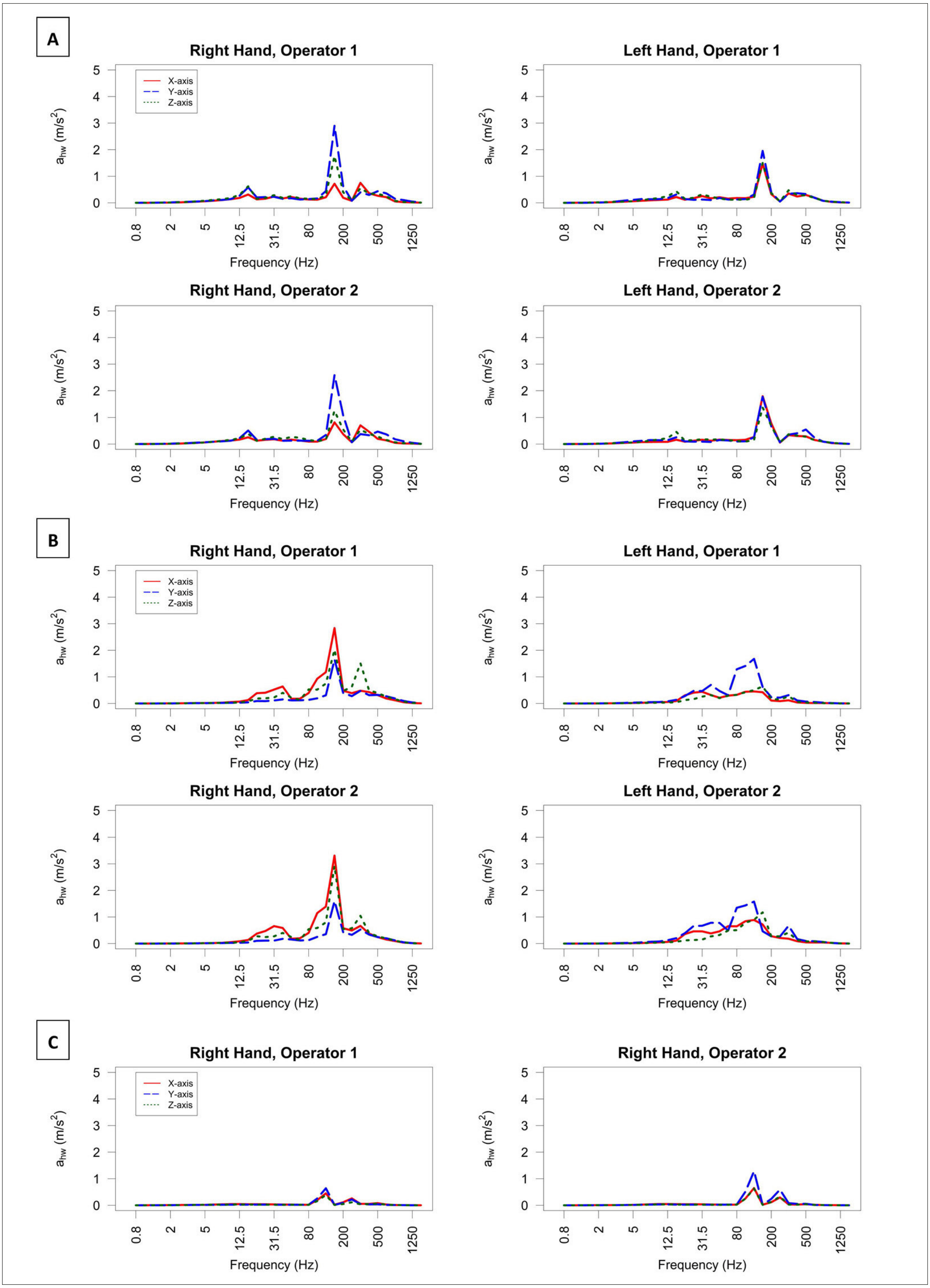

Figure 3. W_h weighted frequency spectra of gloved hand: A – chainsaw; B – grass trimmer; C – backpack blower

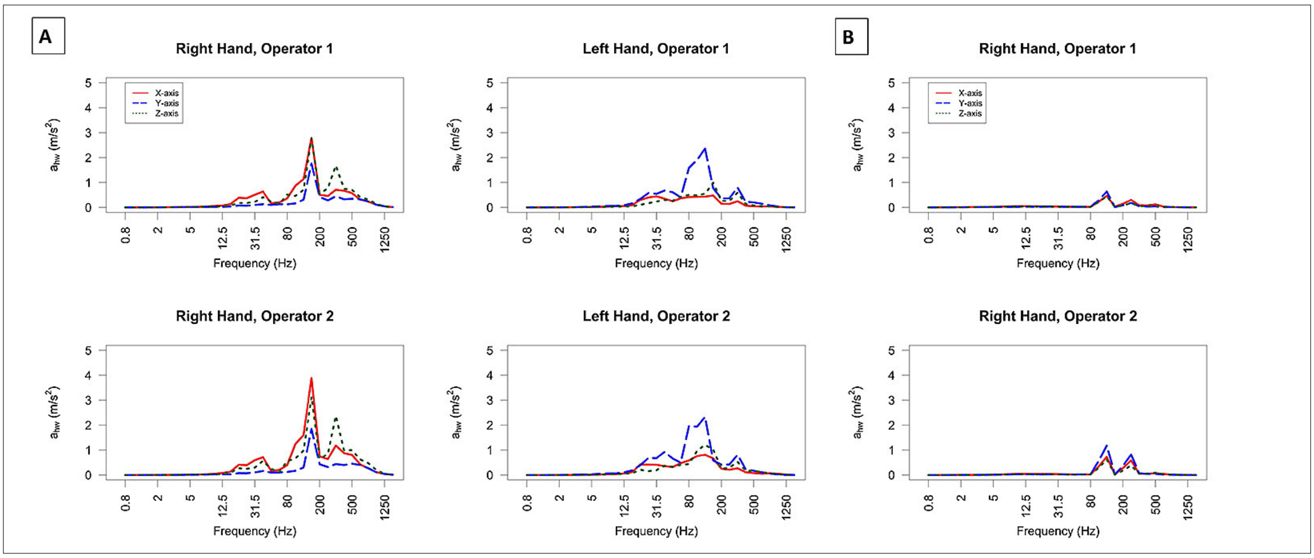

Figure 4. W_h weighted frequency spectra of bare hand: A – grass trimmer; B – backpack blower

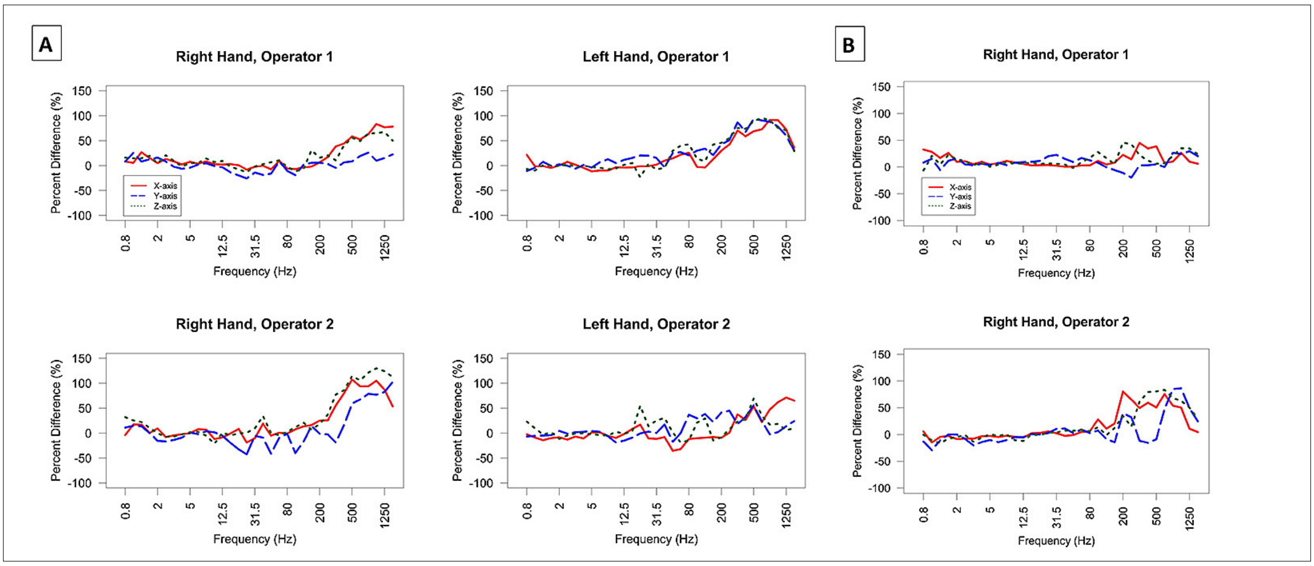

Figure 5. W_h weighted frequency spectra of acceleration percent difference (%): A – grass trimmer; B – backpack blower

wood, etc. Calvo et al. reported two dominant frequencies at 100 and 200 Hz from an agricultural mist blower, lower than in this study because of a variety of factors such as different tools and measurement methods [14]. Careful interpretations of the comparison between different studies must be made due to the use of different tool models, experimental methods and conditions, etc.

The cowhide leather work gloves showed higher vibration attenuation during the grass trimmer operation on the right hand of the operators, compared to the backpack blower operation. However, the attenuation was notable at a higher frequency (≥ 200 Hz) which is not the critical frequency of many power tools [19], contributed in part by the frequency weighting factor. The y-axis vibration deemed to be amplified in the right hand frequency spectra during both grass trimmer and backpack blower operations. Although the general works gloves examined in this study were not anti-vibration gloves, it is worth noting that anti-vibration gloves generally have a poor attenuation effect on the y-direction mainly due to the lower mass of the hand-arm system involved in the response [20].

CONCLUSIONS

The simulation of grass trimmer operation resulted in the highest magnitude of HAV exposure among the three grounds maintenance power tools examined in this study. Vibration attenuation of the general work gloves was observed during the grass trimmer operation in the higher frequency range, which is not the critical frequency of many power tools. There were variations between operators: operator 2 consistently received higher vibration, regardless of glove use, potentially due to the differences in contact force. The right hand, which was the dominant hand of the operators, received higher vibration. More investigations are needed to examine the HAV levels from various tools in a controlled setting with a larger sample size.

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