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HAND-ARM VIBRATION WHILE OPERATING A SIDE BRUSH CUTTER WITH THREE CUTTING IMPLEMENTS IN TWO CROPS

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ABSTRACT

The use of side brushcutters exposes users to vibration and noise, which can cause damage to the operator, as they act as a stressor agent. Excessive vibration is responsible for countless disorders, including *Raynaud's* syndrome. This study aimed to assess the effect of the vibrations of a side brush cutter on the human body. A side brush cutter was used with three cutting implements (double blade, triple blade and double nylon thread) applied to two crops (wheat and ryegrass). The vibration was measured through a three-dimensional accelerometer placed on the handgrips of the brush cutter, in compliance with the provisions of the ISO 5349-1 Standard. The analyzed variables were submitted to the Shapiro-Wilk and Bartlett tests. Due to the abnormality, the data were transformed by the Neperian logarithm and submitted to analysis of variance, and the means were compared by the Tukey test at 5% probability. As a result, the orthogonal y-axis presented a higher vibration level; the three-point blade showed the lowest vibration level compared to the other cutting implements for both crops; these vibration levels did not exceed the NHO10 recommendation. Hence, using the appropriate attachment for each operation may reduce the harm caused by vibration to the operator's body.

Palavras-chave:
Operação semimecanizada
Acelerômetro
Ergonomia aplicada

VIBRAÇÃO EM MÃOS E BRAÇOS NA OPERAÇÃO DE MOTORROÇADORA LATERAL COM TRÊS FERRAMENTAS DE CORTE EM DUAS CULTURAS AGRÍCOLAS

Resumo

O uso de motorroçadoras laterais expõe os usuários à vibração e ao ruído, que podem causar danos ao operador, pois atuam como agente estressor. O excesso de vibração é responsável por inúmeros distúrbios, dentre estes a síndrome de *Raynoud*. Objetivou-se com a pesquisa avaliar o efeito das vibrações de uma motorroçadora lateral sobre o corpo humano. Utilizou-se uma motorroçadora lateral com três ferramentas de corte (lâmina dupla, lâmina tripla e fio duplo de nylon) aplicadas sobre duas culturas (trigo e azevém). A vibração foi mensurada por meio de um acelerômetro tridimensional, posicionado nas empunhaduras da motorroçadora, em atendimento ao que prevê a Norma ISO 5349-1. As variáveis analisadas foram submetidas aos testes de Shapiro-Wilk e Bartlett. Devido a anormalidade, os dados foram transformados pelo logarítmo neperiano e submetidos à análise de variância, e as médias comparadas pelo teste de Tukey a 5% de probabilidade. Como resultado o eixo ortogonal y (vertical) apresentou maior nível de vibração; a lâmina de três pontas teve o menor nível de vibração quando comparado às demais ferramentas de corte em ambas as culturas; estes níveis de vibração não excederam a recomendação da NHO10. Assim, utilizar a ferramenta adequada para cada operação pode reduzir os danos causados pela vibração ao corpo do operador.

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INTRODUCTION

The use of semimechanized machines such as brush cutters is more and more present in rural properties in various types of operations (e.g., pasture management and area cleaning). Work with semimechanized machines and tools is arduous and tiring and may generate various injuries caused throughout the work and life of the operators. This is because operators are exposed to occupational hazards that may be ergonomic (intense physical effort, manual weight lifting and transport, inadequate posture, excessive pace, prolonged working hours, repetitiveness), biological (venomous animals), chemical, caused by the gases emitted by the exhaust system (ALANDER *et al*., 2005), and physical, such as noise and vibration (ROTTENSTEINER & STAMPFER, 2013; JESUS *et al*., 2020).

Many machines end up releasing energy in the form of vibrations (MANSFIELD, 2005). In the case of semimechanized machines, the elements that influence the vibration levels emitted are the dynamic forces of the motor, the cutting mode, the unbalanced moving parts, the friction between gears and bearings, and the interaction with the manipulated material (LANDEKIĆ *et al*., 2020).

Operations with brush cutters have the potential to generate health problems mostly, yet not exclusively, due to the vibrations transmitted by the machine to the operator. Such vibrations may be located in certain body parts, especially the hands and arms, at frequencies ranging from 6.3 Hz to 1250 Hz (GOMES & SAVIONEK, 2014). These are called Hard-Arm Vibrations (HAVs), and exposure to them increases the risk of harm to health, possibly causing disorders in the nervous, vascular, and musculoskeletal systems (HARADA & MAHBUB, 2007; GOMES & SAVIONEK, 2014; NILSSON *et al*., 2017; POOLE *et al*., 2019). To Forouharmajd *et al*. (2017), the effects of vibration appear as mechanical disorders (they may occur to various tissues of the body that are directly damaged as a function of the entry area of the vibration and its resonance) and psychological disorders (stress reactions and cognitive or movement disorders, besides influencing concentration and attention). Cordeiro and Andrade (2019) found that Raynaud's phenomenon (the white finger disease) is predominant among operators of vibrating tools compared to those not exposed, and the authors also mentioned that the number of cases increases with the rise in vibration level and exposure time.

Understanding the physical interactions of workers with their workplaces, whether operating machines, tools, and/or materials, aims to reduce the risk of muscular and skeletal disorders (IIDA, 2005). The tolerable limits regarding the efficiency, safety, and comfort of the vibration are established in the ISO 5349:1 (2001), ISO 5349:2 (2001), ISO 2631-4 (2001), and NHO10 (2013) standards. The latter points out 2.5 $m.s^{-1}$ and 5 $m.s^{-2}$ as the daily limits of action and exposure to vibration, respectively. Also in place is the 2002/44/CE Directive of the European parliament, which defines numerical and fixed values for the vibration limits for daily exposure of eight hours.

Among the factors that influence the intensity of the vibration emitted by brush cutters, the effect of the different cutting mechanisms on the vibration level emitted by such machines is not clear. Wójcik (2015) did not find precise results in this regard; however, they verified that, when using the cutting mechanisms indicated by the brush cutter manufacturer, the operation becomes safer from the viewpoint of the vibration transmitted to the operator. Naskrent *et al.* (2020) inferred that the cutting mechanisms used and the type of vegetation to be mowed significantly influence the noise level emitted by the machine. This led us to the hypothesis that the cutting mechanism may influence the energy level released in the form of vibrations when cutting different crops.

Considering that semimechanized operations are typically treated without the due importance, this study aimed to quantify and observe the behavior of the vibration on the hands and arms of the operator on the three orthogonal axes using a side brush cutter with three cutting implements employed in the management of two plant crops, following the NHO10 standard.

MATERIAL AND METHODS

The experiment was conducted in 2020 in the Brazilian city of Santa Maria, Rio Grande do Sul, in an area with coordinates 29° 41' 02.31" S and 53° 43' 57.63" W and an altitude of 117 m. The tests were performed on a ryegrass crop (*Lolium multiflorum*), of natural reseeding at the flowering and grain formation stages and a wheat crop (*Triticum spp.*) at the phenological stage of 5.3. According to the Köppen classification, the climate of the region is classified as Cfa, humid subtropical with warm summers and an undefined dry season (ALVARES *et al*., 2013). The terrain is characterized as an undulating plain with good drainage, and the soil is classified as Paleudalf (HELDWEIN *et al*., 2009).

The treatments consisted of a combination of two crops (wheat and ryegrass) and three cutting sets (double blade, triple blade and double nylon thread) with nine replications. The assessment was performed in strips on the two crops. The experimental unit consisted of three rows of 50 m in length and 2.5 m in width, totalizing an area of 375 m^2 for each crop. A completely randomized design in a two-factor arrangement was used in this experiment. The treatments consisted of the combination of two crops (wheat and ryegrass) and three cutting sets (two-point blade, three-point blade, and double nylon thread) with nine replicates.

The mowing operation was carried out with a new gasoline-powered side brush cutter with a two-stroke Otto cycle, power of 1.6 kW, and a cylinder capacity of 40.2 cm^3. The machine has a mass of 7.3 kg and 2,800 revolutions per minute (RPM) at low gear and 12,300 RPM at maximum rotation, measurements using a digital tachometer from the Minipa brand, model MDT-2238A. It is equipped with a four-point anti-vibration system and a double support belt. The fuel tank has a volume of 0.64 L. The multifunctional curved profile handlebar allows ample movement and makes the controls available at the operator's fingertips.

The following cutting implements used in the test are widely used and representative for cleaning areas and managing pasture: a) two-point steel blade with a 300 mm diameter, indicated for cutting, cleaning, and maintenance jobs of low to medium difficulty with the mowing of bushes up to 20 mm in diameter (Figure 1A); b) three-point steel blade with a 300 mm diameter for high difficulty mowing jobs with the mowing of bushes up to 20 mm in diameter (Figure 1B); c) double nylon thread, a cutting set with manual adjustment with 200 mm in diameter and 120 mm in height. It has two round cutting threads with 2.5 mm thickness, ideal for cleaning areas (Figure 1C).

The operation was conducted by a professional operator with a body mass of 86 kg, height of 1.76 meters. Has experience and familiarity with the brushcutter model. He used personal protective equipment consisting of a helmet with a visor and ear protectors, leather gloves, overalls for the operator, boots and leggings (Figure 2).

The ISO 5349-1 (2001) Standard was taken as a premise for collecting the vibration levels. For such, a three-dimensional Brüel and Kjaer accelerometer model 4524-B-001 was placed on the right and left handgrips of the side brush cutter (Figure 3), thus respecting the provisions of the standard. A maximum distance from the handgrip center of 20 mm was maintained without harming it.

Figure 1. Cutting sets used in the brushcutter to carry out the experiment: double-ended blade (A); three-pronged blade (B); double nylon thread (C)

Figure 2. Operator with PPE, data collection sensors and side brushcutter

A B

Figure 3. Positioning the accelerometer on the grip handle of the right (A) and left hands (B)

The vibration variable was collected with one reading per second for thirty seconds. The equipment used to collect and store the data was the Brüel & Kjaer portable analyzer model 4447 (Figure 4A), with the Type 4524-B-001 accelerometer (Figure 4B), which measures hand-arm vibration values ranging from 8 Hz to 1000 Hz on the directions of the orthogonal axes (wx, wy, and wz), shown in Figure 4C. These procedures meet the requirements of the ISO 5349-1 (2001) Standard.

Equation 1, found in the ISO 5349-1 (2001) standard, was used to calculate the vibration exposure levels. The equation considers the vibration on the three orthogonal axes, thus calculating the equivalent vibration to which the operator is exposed.

A B C

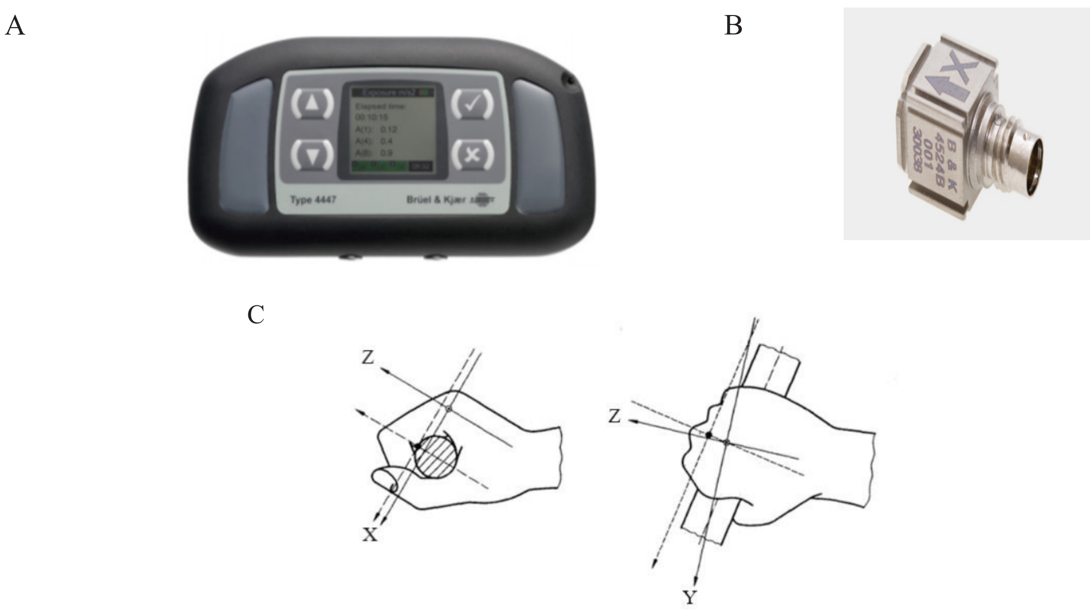

Figure 4. Portable analyzer used to collect vibration levels (A); accelerator used to collect vibration levels (B); orientation of the orthogonal axes, when evaluating vibration in hands and arms, according to ISO 5349-1 (2001) (C)

$$a_{hv} = \sqrt{k_x^2 \cdot a_{\omega x}^2 + k_y^2 \cdot a_{\omega y}^2 + k_z^2 . a_{wz}^2} \qquad (1)$$

Where:
a_{hv} is the equivalent acceleration for the operation mode; k_x^2, k_y^2 *e* k_z^2 are multiplying factors for each orthogonal axes that, in this case, all equate to 1; $a_{\omega x}^2$ is the weighted acceleration on the x-axis; $a_{\omega x}^2$ is the weighted acceleration on the y-axis; and $a_{\omega z}^2$ is the weighted acceleration on the z-axis.

With the purpose of comparing the exposure to the limits established by the NHO10 standard, an exposure normalized as per Equation 2, found in the ISO 5349-1 standard, was used taking into account a daily exposure to vibrations of eight hours.

$$A(8) = a_{hv} \sqrt{\frac{T}{T_0}}, \qquad (2)$$

Where:
a_{hv} is the equivalent acceleration; T is the daily period in which there is exposure to vibration, expressed in hours or minutes; and T_0 equates to 8 h or 480 min.

In the experiment, a completely randomized design was used, in a bifactorial arrangement. The values of the analyzed variables were submitted to the Shapiro-Wilk test to verify the normality of the data and Bartlett's test to verify the homogeneity of the variances. Due to the abnormality, the data were transformed by the Napierian logarithm. The results were submitted to an analysis of variance, and the means were compared through Tukey's test at a 5% probability using the statistical program SISVAR (FERREIRA *et al*., 2014).

RESULTS AND DISCUSSION

As a result, we verified a significant interaction among the crops, the blade type, and the hand-arm vibrations on all analyzed orthogonal axes (wx, wy, wz) (Table 1).

We stress that there was a significant interaction in each factor (crop, blade, and HAV). After analyzing the vibrations in the crop, we found that the z-axis presented the highest value. In turn, for the blade factor, the vibration was the highest on the y-axis. The same was observed for the response variable HAV. The NHO10 standard defines that the daily limit of occupational exposure to vibration is 5 $m.s^{-2}$. Hence, considering a working day of eight hours, none of the tested variables exceeded this limit (Table 2). However, the results for the nylon thread implement were above the daily limit of action of exposure of 2.5 $m.s^{-1}$ for both crops and both hands. This limit was also exceeded when using the two-point blade on the ryegrass crop for the left hand. This is possibly due to the fiber of the ryegrass crop being more resistant than that of wheat.

The nylon thread presented the most significant vibration in the wheat crop compared to the blades (Table 2). Thus, the vibration in the operation with the two-point blade was 41.18% lower than that generated with the nylon thread. In turn, the vibration in the operation with the three-point blade was 37.58% lower than with the nylon thread. The same occurred for the ryegrass crop, yet only 5.66% lower for the two-point blade and 23.58% lower for the three-point blade compared to the nylon thread. This result corroborates those found by Bernardi *et al*. (2018), who obtained superior vibration levels when comparing the nylon thread with the three-point blade. To Schutzer (2018), the nylon thread generates a high vibration level because it consists of irregular and brittle material.

When comparing the three-point blade with the two-point blade, it is possible to notice that the vibration level was lower on the left hand for both crops. The same result was found by Oliveira Júnior *et al*. (2019) when using the same blades for mowing grass (*Panicum maximum).* The greater vibration in the left hand may be related to the greater length of this handle in relation to the transmission shaft of the machine. Unbalanced or unsharpened blades may cause an increase in the vibration levels transmitted to the handgrip (SCHUTZER, 2018). Therefore, this result may be explained by a better balance of the three-point blade relative to the two-point blade, even if both blades used were new.

When using the three-point blade in the wheat crop, there was a slight decrease of 12.22% in the vibration on the right hand (Table 2) compared to when using the two-point blade. In turn, the two-point blade presented a lower vibration in the wheat crop than the ryegrass crop for both hands. In the operation with the nylon thread, the vibration was

Table 1. Summary of the analysis of variance with the mean square values for the crops, blades, hands, and their interactions and the mean on each orthogonal axis and the total (S)

	Mean squares			
Assessment factors	wx	wy	wz	S[1]
Crop (C)	0.192*	0.838*	1.534*	0.588*
Blade (B)	0.795*	1.816*	1.597*	1.329*
HAV[2]	0.701*	3.924*	0.000	1.276*
C × B	0.650*	0.585*	0.362*	0.464*
C × HAV	0.001	0.036*	0.138*	0.002
B × HAV	0.059*	0.130*	0.121*	0.054*
C × B × HAV	0.049*	0.562*	0.133*	0.131*
Mean	1.450	1.510	1.110	2.400

Caption: *Significant effect ($p \leq 0.05$); wx, wy, wz: orthogonal axes; S[1]: total vibration; [2]Hand-arm vibration

Table 2. Equivalent total vibration in $m.s^{-2}$ for the three-point and two-point blades and nylon thread on the right and left hands in the wheat and ryegrass crops

	Blade					
Hand	Three-point		Two-point		Nylon	
	---------------------------------Wheat---------------------------------					
Right	1.58	cBβ	1.80	bBα	2.55	aAβ
Left	2.24	bAα	1.80	cBα	3.57	aAα
	--------------------------------Ryegrass--------------------------------					
Right	1.99	cAβ	2.32	bAβ	2.51	aAβ
Left	2.32	bAα	3.00	aAα	3.14	aBα

Caption: *Means followed by the same lower-case letter on the line, the same upper-case letter in the column for the same hand between crops, and Greek letters in the column for the same crop between the hands do not differ according to Tukey's test at 5% probability ($p < 0.05$)

7.84% lower in the ryegrass crop than in the wheat crop.

Except for the two-point blade in the wheat crop, the others presented more significant vibrations on the left hand than the right (Table 2). Similar results were found by Wójcik (2015) when testing several brush cutters similar to that used in the present work equipped with different cutting mechanisms. This result may be attributed to the construction factors of the brush cutter.

At the very least, these results require taking preventive measures as recommended in the NR15 standard, the focus of which is on using PPE and taking rest breaks during the working day. The lack of personal protective equipment appropriate for these operations may lead to adverse effects on the operator's health (GRZYWIŃSKI *et al*., 2016). As a recommendation for protection, anti-vibration gloves are an alternative to attenuate the vibration that reaches the operator (RUKAT *et al*., 2020). These gloves are typically made of synthetic fibers with a neoprene coating, and the palm has high-relief undulations that absorb the vibration and mechanical shocks to the hands and arms (WERNER *et al*., 2020); besides the anti-vibration protection, they reduce abrasive, excoriating, cutting, and puncturing effects. Their use is described in ANNEX I of the NR6 standard, and they must be certified according to the EN ISO 10819/1996 standard.

From the viewpoint of the international regulation – Directive 2002/44/CE, the use of brush cutters without the due mitigating measures may cause permanent damage to health, such as *Raynaud's* syndrome. This is extremely concerning since the Brazilian standards are focused on serving contracted operators, thus neglecting the compliance of autonomous rural producers who are often unaware of what the regulations provide. They are, thus, exposed to this stressor that may result in health problems throughout their operational lives for being unaware of the operating standards and mitigating measures.

CONCLUSIONS

- The vibrations on the hands and arms of the operator did not exceed the NHO10 standard in any of the assessed parameters. Regarding the orthogonal axes, the vibration was more significant on the y-axis, which represents the vertical motion of the operation.
- The three-point blade proved to be the best option for managing the crops in this study, followed by the two-point blade. The opposite occurs with the use of the nylon thread, which showed the worst behavior. This experiment contributes to establishing the need to use the appropriate cutting tool for each crop type and ensure safety in the semimechanized operation.

AUTHORSHIP CONTRIBUTION STATEMENT

CELLA, M.C.: Conceptualization, Investigation, Validation, Writing – original draft, Writing – review & editing; **WERNER, V.:** Conceptualization, Formal Analysis, Funding acquisition, Project administration, Resources, Supervision; **BRANDELERO, C.:** Conceptualization, Formal Analysis, Methodology, Resources, Writing – review & editing; **BERTOLLO, G.M.:** Conceptualization, Data curation, Formal Analysis, Software, Writing – review & editing; **SILVA, E.F.C.:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing; **SCHLOSSER, J.F.:** Methodology, Resources, Software, Visualization, Writing – original draft; **MARTIN, T.N.:** Formal Analysis, Resources, Validation, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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