Semi-mechanized wood harvesting: what are the ergonomic gaps in these workstations?

Corte semi-mecanizado de madeira: quais são as lacunas ergonómicas destes postos de trabalho?

Corte semimecanizado de la madera: ¿cuáles son las carencias ergonómicas de estos puestos de trabajo?

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ABSTRACT

Semi-mechanized wood harvesting is feasible for ventures with limited financial resources; however, it entails significant occupational risks for operators. Therefore, the objective of this study was to conduct an ergonomic analysis of semi-mechanized wood harvesting, correlating variables in an integrated manner with their intervention requirements. Hence, physical workload, hand and arm vibration, thermal comfort, noise, and illuminance were assessed during semi-mechanized cutting and manual wood extraction. Subsequently, a color-coded system was established to indicate the need for ergonomic intervention. Operators had an average age of 30 years and a Body Mass Index of 24.9. The manual extraction phase exhibited higher values for cardiovascular workload (> 40%), Maximum Heart Rate (194 bpm), and Average Partial Exposure (12.5 m. s⁻¹) compared to the cutting phase. The average thermal comfort index recorded at the start of the work shift was 18.9 °C. Noise exposure levels during cutting surpassed regulated limits. Illuminance levels throughout the work shift averaged 22,701 lux. Consequently, it is concluded that both semi-mechanized harvesting and manual extraction require urgent ergonomic intervention in at least one variable. The use of personal protective equipment, implementation of controlled breaks, and replacement of machinery with more modern equipment are recommended.

Keywords: ergonomics, timber harvesting, semi-mechanized, chainsaw.
RESUMO
A colheita semimecanizada de madeira é viável para empreendimentos com recursos financeiros limitados, mas apresenta riscos ocupacionais significativos para os operadores. Assim, o objetivo deste estudo foi realizar uma análise ergonómica da colheita semi-mecanizada de madeira, correlacionando variáveis de forma integrada com suas necessidades de intervenção. Assim, foram avaliadas a carga física de trabalho, a vibração das mãos e dos braços, o conforto térmico, o ruído e a iluminância durante o corte semimecanizado e a extração manual da madeira. Posteriormente, foi estabelecido um sistema de código de cores para indicar a necessidade de intervenção ergonómica. Os operadores tinham uma idade média de 30 anos e um Índice de Massa Corporal de 24,9. A fase de extração manual apresentou valores mais elevados de carga de trabalho cardiovascular (> 40%), de Frequência Cardíaca Máxima (194 bpm) e de Exposição Parcial Média (12,5 m. s-1) comparativamente à fase de corte. O índice médio de conforto térmico registado no início do turno de trabalho foi de 18,9 ºC. Os níveis de exposição ao ruído durante o corte ultrapassaram os limites regulamentares. Os níveis de iluminação durante o turno de trabalho foram em média de 22.701 lux. Conclui-se, assim, que tanto a colheita semimecanizada como a extração manual requerem uma intervenção ergonómica urgente em pelo menos uma variável. Recomenda-se a utilização de equipamentos de proteção individual, a implementação de pausas controladas e a substituição de máquinas por equipamentos mais modernos.

Palavras-chave: ergonomia, colheita de madeira, semi-mecanizada, motosserra.
1 INTRODUCTION

The forestry production sector, along with its associated production chain, is characterized by its environmental, economic, and social importance, as well as its versatility and variety of products generated (Moreira; De Oliveira, 2017). In Brazil, for instance, the sector contributed an increase of 244.6 billion reais to the country's revenue in 2021 and created over 2 million jobs (direct and indirect) by that year. Regarding the main segments of these products, they include cellulose and paper, wood panels, laminated flooring, sawn timber, charcoal, and furniture, in addition to the non-timber forest products (IBÁ, 2022).

Although it is a notably profitable sector, forestry production at competitive levels requires considerable investments, especially in the logistical realm, which is considered the most delicate and impactful production stage, potentially representing up to 60% of the value of the wood produced and traded (Fiedler et al., 2020). Thus, a dilemma arises in the operational process of wood production, concerning the need to reduce these costs, particularly in the harvesting/extraction and transportation stages, while increasing productivity.

Considering this scenario, one of the most adopted planning approaches by large-scale enterprises is to strategically size the harvesting modes. This strategy involves the careful selection of machinery with the best cost-benefit ratio, i.e., those that offer higher productivity at more affordable costs, both in terms of acquisition and maintenance (Cezar; Robert; Vargas, 2018). However, this reality does not always align with smaller-scale enterprises or those with modest monthly demands, which often resort to less productive harvesting systems that nonetheless fit within their budget limitations, such as semi-mechanized systems.

Moreover, the semi-mechanized harvesting system, based on the integration of manual and mechanized techniques aimed at improving productivity and reducing waste in the wood cutting and processing process (Machado, 2014), using chainsaws, is also an efficient operational alternative for areas with considerably rugged terrain or weakened soil support structures that limit the use of fully mechanized systems. Therefore, despite being less productive, this equipment allow wood cutting and processing operations to take place in locations with peculiar characteristics.

However, the semi-mechanized harvesting system, despite presenting itself as a viable alternative for enterprises with more limited financial resources, it is important to emphasize that
practices involving the use of chainsaws can pose health risks to operators, due to exposure to vibration, noise, incompatible anthropometric dimensions, and excessive stress (Depoi et al., 2022).

Several studies highlight the importance of compliance with safety standards and the need for effective management of occupational risks in semi-mechanized wood harvesting operations. Camargo et al. (2023) and Soranso et al. (2019), for example, demonstrated that workers in wood harvesting and processing systems are constantly exposed to heat, noise, and vibration levels above the exposure limit proposed by international regulations.

In this context, aiming to delineate an effective approach to managing the risks of inadequate working conditions within ergonomic aspects in semi-mechanized forestry harvesting, the objective of this research was to analyze the ergonomic conditions of semi-mechanized wood harvesting work, correlating variables in an integrated manner with their classification according to the urgency of intervention, aiming for better understanding and practicality in the application of evaluation results.

2 MATERIAL E METHODS

2.1 STUDY AREA

The research was conducted in forest areas comprising species of the genus Eucalyptus sp., subjected to clear-cutting (a practice where all trees in a certain area are felled, leaving no remaining trees) at seven years old, in the Espírito Santo, Brazil (Figure 1).
The climate of the region is characterized as Cwa with a dry winter and rainy summer, according to the Köppen classification, with an average annual temperature between 23.2°C and 27.4°C, and relative humidity between 72.7% and 84.2% (Alvares et al., 2014).

2.2 ACTIVITIES EVALUATED

The cutting activities were evaluated using the semi-mechanized method, with a Stihl brand chainsaw, model MS 361, gasoline-powered, with 4.6 horsepower, 59 cc displacement, weight of 5.6 kg, maximum speed of 14,000 rpm, equipped with an anti-vibration system and a manufacturer-reported sound pressure level of 103 dB(A). Wood extraction was carried out using the manual felling method, which involves pushing the wood downhill by hand, on slopes or steep terrain, to a collection point or processing area.

The analyzed activities presented in Figure 2, where the partial elements of the cutting activity were classified as felling, delimming, and bucking, while for the extraction activity, they were classified as manual felling and stacking.
The work schedule was from Monday to Friday, from 7 am to 4 pm, with a one-hour break. Workers were free to take short breaks for water and snacks.

2.3 APPROVAL BY THE ETHICS COUNCIL

As this research involves the participation of human subjects, it was submitted to analysis and subsequent approval by the Ethics Committee of the Federal University of Espírito Santo (CAAE: 45525421.1.0000.8151, approved on May 24, 2021), according to informed opinion number 4,728,519, safeguarding the rights of the participants.

2.4 SAMPLING PROCEDURE

Three collaborators who had been performing their duties for more than four years underwent ergonomic analyses to record age, body mass, height, and Body Mass Index (BMI) over 7 days. The workers' participation in the study was voluntary, and all received explanations about the objectives and methods of the study.

A pilot study of systematic sampling was used to determine the necessary number of observations for each ergonomic variable inherent in the semi-mechanized cutting and manual extraction activities. The required number of observations to provide a maximum sampling error of 5% was delimited by the methodology proposed by Murphy (2005) (Equation 1).

\[ n = \frac{t^2 \times CV^2}{LE^2} \]  

where:
n is the number of required observations, t is the t-value for the desired probability level at (n-1) degrees of freedom. CV refers to the coefficient of variation, in percentage, and LE corresponds to the acceptable error limit, in percentage.

For thermal comfort and illuminance, data were collected from 9 am to 3 pm with intervals of 30 minutes over 8 days. For the assessment of physical workload, vibration, and noise, the samples varied according to the activity, so an average value was calculated, as shown in Table 1.

<table>
<thead>
<tr>
<th>Ergonomic Variables</th>
<th>Nº of Samples Collected</th>
<th>Minimum Average nº of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Workload (PW)</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>Hand-Arm Vibration (HAV)</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Thermal Comfort (TC)</td>
<td>104</td>
<td>4</td>
</tr>
<tr>
<td>Noise (N)</td>
<td>22</td>
<td>2</td>
</tr>
<tr>
<td>Illuminance (I)</td>
<td>104</td>
<td>97</td>
</tr>
</tbody>
</table>

Source: Authors.

2.5 ERGONOMIC VARIABLES EVALUATED

For the present research, the following variables were evaluated: Physical Workload (PW); Hand-Arm Vibration (HAV); Thermal Comfort (TC); Noise (N); and Illuminance (I).

2.5.1 Physical Workload (PW)

To evaluate PW, a heart rate monitor from Polar brand, model RS400, consisting of a chest strap sensor and a wrist receiver, was used. It was installed on the collaborators throughout the entire work shift.

According to the methodology proposed by Apud (1989), with the obtained database, it was possible to calculate the Cardiovascular Load (CVL), the Maximum Heart Rate (MHR), and the Resting Time (RT).

The CVL corresponds to the percentage of heart rate during work relative to the maximum usable heart rate (Equation 2).

\[
CVL = \frac{AWHR - RHR}{MHR - RHR} \times 100 \tag{2}
\]
where:

CVL is the cardiovascular load (%), AWHR is the Average Working Heart Rate (bpm), MHR is the Maximum Heart Rate (220 - age) (bpm), and RHR refers to the Resting Heart Rate (bpm).

According to (APUD, 1989), the cardiovascular load of the worker for an 8-hour work shift should not exceed 40% of the Maximum Heart Rate (MHR) during work, therefore, Equation 3 was applied to calculate the MHR for the cardiovascular load of 40%.

\[
MHR = 0.40 \times (MHR - RHR) + RHR
\]  

(3)

where:

MHR is the Maximum Heart Rate (bpm), MHR is the Maximum Heart Rate (220 - age) (bpm), and RHR refers to the Resting Heart Rate (bpm).

If the maximum heart rate exceeded the value of 40%, it is necessary to reorganize the work and establish acceptable limits for continuous performance that is not harmful to the workers' health, in other words, it is necessary to define a Resting Time (Equation 4).

\[
RT = \frac{DW \times (AWHR - LHR)}{AWHR - RHR}
\]  

(4)

where:

RT is the Resting Time, rest, or breaks (minutes), DW is the Duration of Work (minutes), AWHR is the Average Working Heart Rate (bpm), and LHR is the Limit Heart Rate (bpm).

Based on the results, the physical workload required for each activity was classified, and the physical workload was adjusted to the workers' capacity, according to the method proposed by (APUD, 1989), as described in Table 2.
Table 2. Classification of Physical Workload (PW) According to Heart Rate

<table>
<thead>
<tr>
<th>Heart Rate (bpm)</th>
<th>Physical Workload (PW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 75</td>
<td>Very Light</td>
</tr>
<tr>
<td>75 a 100</td>
<td>Light</td>
</tr>
<tr>
<td>100 a 125</td>
<td>Moderately Heavy</td>
</tr>
<tr>
<td>125 a 150</td>
<td>Heavy</td>
</tr>
<tr>
<td>150 a 175</td>
<td>Very Heavy</td>
</tr>
<tr>
<td>175 a 200</td>
<td>Extremely Heavy</td>
</tr>
</tbody>
</table>


### 2.5.2 Hand and Arm Vibration (HAV)

HAV was evaluated using a triaxial accelerometer model NK20 and a vibration meter model NK300, both from the Teknikao brand.

According to the Occupational Hygiene Standard 10 (NHO 10), the vibration levels collected in the three orthogonal axes, X, Y, and Z, represent the palm of the hand, the fingertips, and the parallel of the forearm bones, respectively (Masioli et al., 2020; FUNDACENTRO, 2013).

Next, the following parameters were calculated: Average Resultant Acceleration (ARC) (Equation 5), Average Partial Exposure Acceleration (APEA) (Equation 6), Resultant Partial Exposure Acceleration (REAP) (Equation 7), Resultant Exposure Acceleration (REA) (Equation 8), and Normalized Resultant Exposure Acceleration (NREA) (Equation 9). Additionally, the observed values were compared to the values recommended by the Brazilian Regulatory Standard for unhealthy activities and operations, NR-15 (Brasil, 1978).

\[
ARC = \sqrt{(f_x \times AA_x)^2 + (f_y \times AA_y)^2 + (f_z \times AA_z)^2} \tag{5}
\]

where

\[
APEA = \frac{1}{S} \sum_{K=1}^{S} AA_{x,y,z} \tag{6}
\]

ARC is the Average Resultant Acceleration, AA is the Average Acceleration in the x, y, z axes, and f refers to the multiplication factor depending on the considered axis (f = 1 for all three axes).
where:

\[
ARPE = \sqrt{ \frac{APEAT_x^2 + APEAT_y^2 + APEAT_z^2}{s}}
\]  

where:

ARPE is the Acceleration Resultant Partial Exposure, APEA is the Average Partial Exposure Acceleration, and AA is the Average Acceleration in the x, y, z axes.

\[
ARE = \sqrt{ \frac{1}{DEC_i} \sum_{i=1}^{m} n_i \times ARPE_i^2 \times DDW_i}
\]  

where:

ARE is the Acceleration Resultant Exposure, DDW is the Duration of Daily Work, \( n_i \) refers to the number of repetitions of the acceleration component in the work shift, ARPE is the Acceleration Resultant Partial Exposure, and DEC, is the Duration of the Exposure Component.

\[
ANRE = ARE \frac{DDW}{ET_0}
\]  

where:

ANRE is the Acceleration Normalized Resultant Exposure, ARE is the Acceleration Resultant Exposure, DDW is the Duration of Daily Work, and ET_0 is the Exposure Time of the Operator to Vibration.

2.5.3 Thermal Comfort (TC)

The TC was measured using a thermal stress meter with Wet Bulb Globe Temperature (WBGT) index from the Instrutherm brand, model TGD-200. According to the Occupational Hygiene Standard NHO 06 (FUNDACENTRO, 2017), the WBGT meter was positioned at 1.70
m above the ground at a fixed location with environmental characteristics representative of the operating area (Figure 6B).

The data were recorded between the months of May to July during an eight-hour work shift, with intervals of 30 minutes. Subsequently, the Thermal Comfort Index (Equation 10) was calculated, following the Regulatory Standard for outdoor work, NR 15 (Brasil, 2024).

\[
WBGT = (0.7 \times NWBT) + (0.1 + DBT) + (0.2 + GT) \tag{10}
\]

where:

\[WBGT\] is the Wet Bulb Globe Temperature index, \[NWBT\] is the Natural Wet Bulb Temperature, \[DBT\] is the Dry Bulb Temperature, and \[GT\] is the Globe Temperature.

### 2.5.4 Noise (N)

The noise variable was assessed using a digital sound level meter from Minipa, model MSL-1301. The equipment was set to measure continuous noise with slow response, "A" frequency weighting, a tolerance limit of 85 dB(A) for 8 hours of daily exposure, and a doubling dose factor of 3, as stipulated by the Occupational Hygiene Standard NHO 01 (FUNDACENTRO, 2001).

Measurements were taken at 15-second intervals throughout the workday. Subsequently, the Normalized Exposure Level (NEL) (Equation 11) and the Mean Level (MEL) representing the exposure of the evaluated work (Equation 12) were calculated and compared to the maximum exposure limit for an eight-hour workday, without corrective ergonomic measures according to NHO 01 (FUNDACENTRO, 2001).

\[
NEL = MEL + 10 \log \frac{DDW}{480} \tag{11}
\]

where:

\[NEL\] is the Normalized Exposure Level, \[ML\] is the Mean Level representing the exposure of the evaluated work, and \[DDW\] is the Duration time, in minutes, of the Daily Work shift.
\[ ML = 10 \log \left( \frac{1}{n} \left( n_1 \times 10^{0.1 ML_1} + n_2 \times 10^{0.1 ML_2} + \ldots + n_i \times 10^{0.1 ML_i} + \ldots + n_n \times 10^{0.1 ML_n} \right) \right) \] \tag{12}

where:

- ML is the Mean Level representing the exposure of the evaluated work,
- \( n_i \) is the number of readings obtained for the same assumed partial mean number - ML\(_i\),
- \( n \) refers to the total number of readings = \( n_1 + n_2 + \ldots + n_i + \ldots + n_n \), and
- ML\(_i\) is the \( i \)-th assumed mean sound pressure level [dB(A)].

### 2.5.5 Illuminance (I)

The illuminance was measured using a luxmeter from Akrom brand, KR500 model. Readings were taken at 30-minute intervals throughout an eight-hour workday, with the sensor positioned horizontally at eye level and 20 cm above the ground, following the guidelines of SkogForsk (1999).

Due to the lack of regulations for outdoor environments, the data were compared with the recommended minimum illuminance values for precision tasks in indoor environments, as stipulated by the Occupational Hygiene Standard NHO 11 (FUNDACENTRO, 2018).

### 2.5.6 Integrated analysis of urgency in ergonomic intervention

To proceed with the integrated analysis of urgency in ergonomic intervention, considering Equation 13 for standards that determine a maximum permissible value, Equation 14 for standards that determine a minimum value for a specific variable, and Equation 15 for standards that delimit a permissible conformity range, the variables of physical workload, hand and arm vibration, thermal comfort, noise, and illuminance were standardized based on the degree of conformity.

\[ V = 1 - 0.69 \times \left( \frac{X}{X_{\text{max}}} \right)^4 \] \tag{13}

where:
V is the degree of conformity, X is the value of the measured ergonomic variable, and $X_{\text{min}}$ and $X_{\text{max}}$ are the possible minimum and maximum values according to the standards.

$$V=1 - 0.69 \times \left( \frac{X_{\text{min}}}{X} \right)^4$$  \hspace{1cm} (14)

where:

V is the degree of conformity, X is the value of the measured ergonomic variable, and $X_{\text{min}}$ and $X_{\text{max}}$ are the possible minimum and maximum values according to the standards.

$$V=1-0.69 \times \left( \frac{X-0.5 \times (X_{\text{max}}+X_{\text{min}})}{0.5 \times (X_{\text{max}}+X_{\text{min}})} \right)^{0.5}$$  \hspace{1cm} (15)

where:

V is the degree of conformity, X is the value of the measured ergonomic variable, and $X_{\text{min}}$ and $X_{\text{max}}$ are the possible minimum and maximum values according to the standards.

The critical limits considered for calculating the degree of conformity are indicated in Table 3, established according to the respective standard.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Limit</th>
<th>Value</th>
<th>Standard or method</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PW</td>
<td>Max</td>
<td>40% of the frequency limit</td>
<td>Apud (1989)</td>
<td>-</td>
</tr>
<tr>
<td>HAV</td>
<td>Max</td>
<td>5.0 m. s$^{-2}$</td>
<td>NR 15</td>
<td>-</td>
</tr>
<tr>
<td>CT</td>
<td>Max</td>
<td>WBGT = 30</td>
<td>NR 15</td>
<td>Metabolic rate</td>
</tr>
<tr>
<td>R</td>
<td>Max</td>
<td>85 dB (A)</td>
<td>NHO 01</td>
<td>Eight-hour work shift</td>
</tr>
<tr>
<td>I</td>
<td>Min</td>
<td>1,000 lux</td>
<td>NHO 11</td>
<td>-</td>
</tr>
</tbody>
</table>


The conformity degree (V) can range from zero to one, and the higher the value, the greater the conformity of the variable to the standard or reference method. Thus, a color scale was used to facilitate the visual identification of ergonomic conformity, according to de Oliveira et al. (2020) (Table 4).
Table 4. Color classification of the need for ergonomic intervention according to the Conformity Degree.

<table>
<thead>
<tr>
<th>Conformity Degree (V)</th>
<th>Color</th>
<th>Need for ergonomic intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9 &gt; V ≥ 1.0</td>
<td>Green</td>
<td>No need</td>
</tr>
<tr>
<td>0.8 &gt; V ≥ 0.9</td>
<td>Yellow</td>
<td>Low urgency</td>
</tr>
<tr>
<td>0.6 &gt; V ≥ 0.8</td>
<td>Orange</td>
<td>Urgency</td>
</tr>
<tr>
<td>0 ≥ V ≥ 0.6</td>
<td>Red</td>
<td>Emergency</td>
</tr>
</tbody>
</table>

Source: Adapted from de Oliveira et al. (2020).

3 RESULTS

3.1 PROFILE AND WORKING CONDITIONS

The results regarding the profile and working conditions of the three evaluated collaborators are presented in Table 5.

Table 5. Profile and working conditions of the surveyed population.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>1: Leader</th>
<th>2: Assistant/Leader</th>
<th>3: Assistant</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>38.00</td>
<td>31.00</td>
<td>22.00</td>
<td>30.00</td>
</tr>
<tr>
<td>Body mass (kilograms)</td>
<td>73.00</td>
<td>75.00</td>
<td>69.00</td>
<td>72.30</td>
</tr>
<tr>
<td>Height (meters)</td>
<td>1.68</td>
<td>1.75</td>
<td>1.67</td>
<td>1.70</td>
</tr>
<tr>
<td>Body mass index (BMI)</td>
<td>25.80</td>
<td>24.40</td>
<td>24.70</td>
<td>24.90</td>
</tr>
<tr>
<td>Education level</td>
<td>CEE</td>
<td>CEE</td>
<td>IEE</td>
<td>-</td>
</tr>
</tbody>
</table>

Where CEE stands for Completed Elementary Education, and IEE stands for Incomplete Elementary Education.

Source: Authors.

3.2 ERGONOMIC ASSESSMENT

3.2.1 Physical Workload (PW)

The results regarding the Physical Workload (PW) for the evaluated activities are presented in Table 6, where it can be observed that stacking was considered the most burdensome step, classified as extremely heavy.

Table 6. Physical Workload (PW) for semi-mechanized cutting and manual extraction activities

<table>
<thead>
<tr>
<th>Partial Element</th>
<th>ATRW (min)</th>
<th>RHR (bpm)</th>
<th>AWHR (bpm)</th>
<th>MHR (bpm)</th>
<th>CVL (%)</th>
<th>LHR (bpm)</th>
<th>RT (min.h⁻¹)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-mechanized cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>61</td>
<td>78</td>
<td>121</td>
<td>186</td>
<td>40</td>
<td>121</td>
<td>--</td>
<td>Moderately heavy</td>
</tr>
<tr>
<td>DS/BS</td>
<td>168</td>
<td></td>
<td>114</td>
<td></td>
<td>34</td>
<td>121</td>
<td>--</td>
<td>Moderately heavy</td>
</tr>
</tbody>
</table>
3.2.2 Hand and Arm Vibration (HAV)

In relation to Hand-Arm Vibration (HAV), it was observed that felling presented higher values of Partial Exposure Resultant Acceleration (12.5 m. s⁻²) compared to delimbing/bucking (10.8 m. s⁻²). However, when evaluating the Normalized Exposure Resultant Acceleration, an opposite behavior was noticed, where delimbing/bucking showed a higher result (6.4 m. s⁻²) than felling (4.4 m. s⁻²), as presented in Table 7.

Table 7. Hand-Arm Vibration (HAV) for semi-mechanized cutting activity.

<table>
<thead>
<tr>
<th>Partial element</th>
<th>Coordinates</th>
<th>ARPE (m.s⁻²)</th>
<th>ANRE (m.s⁻²)</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felling</td>
<td>X. Y and Z</td>
<td>12.5</td>
<td>4.4</td>
<td>Exposure</td>
</tr>
<tr>
<td>Delimbing/Bucking</td>
<td>X. Y and Z</td>
<td>10.8</td>
<td>6.4</td>
<td>Fatigue</td>
</tr>
</tbody>
</table>

Source: Authors.

3.2.3 Thermal Comfort (TC)

The thermal comfort (TC) of the activities exhibited a non-linear behavior during the workday, with maximum indices occurring between 12:00 PM and 1:00 PM and the minimum at the beginning of the shift, at 9:00 AM (Figure 3).

Figure 3. Thermal comfort for semi-mechanized cutting and manual extraction activities.

Source: Authors.
3.2.4 Noise (N)

The highest average values of Noise (R) were identified in the Delimbing/Bucking stage, reaching levels exceeding 100 dB A, while in the felling stage, although lower (97 dB A), they also surpassed the predetermined safety standards limits (80 dB A), as seen in Figure 4.

Figure 4. Noise recorded for partial elements of semi-mechanized cutting.

3.2.5 Illuminance (I)

The Illuminance (I) followed an expected pattern due to solar exposure, meaning that the times with the greatest availability of light from the natural source (sun), which is between 11:30 AM and 12:30 PM, had the highest values of illuminance recorded (Figure 5).

Figure 5. Illuminance during semi-mechanized cutting and manual extraction activities.
3.2.6 Urgency in Ergonomic Intervention (UEI)

Table 8 presents the results regarding the urgency classification of ergonomic intervention in the evaluated activities.

Table 8. Color-coded classification of the need for ergonomic intervention in relation to the degree of compliance for semi-mechanized cutting and manual extraction.

<table>
<thead>
<tr>
<th>Partial element</th>
<th>Workload</th>
<th>Hand-arm vibration</th>
<th>Thermal comfort</th>
<th>Noise</th>
<th>Illuminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Felling</td>
<td>0.3</td>
<td>0.6</td>
<td>0.8</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Delimbing/Bucking</td>
<td>0.6</td>
<td>0.0</td>
<td>0.8</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Extraction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tipping</td>
<td>0.2</td>
<td></td>
<td>0.8</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>Stacking</td>
<td>0.0</td>
<td></td>
<td>0.8</td>
<td>-</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Source: Authors.

4 DISCUSSION

4.1 PROFILE AND WORKING CONDITIONS

As seen in Table 5, the average age of the workers involved in the analyzed activities was 30 years old. The assistant, aged 22, is the youngest collaborator, reflecting the less demanding nature of previous experience in this role. On the other hand, the leader, aged 38, represents the opposite extreme, indicating that this position requires greater responsibility and, consequently, favors prolonged experience in the role.

The average BMI of 24.9 among the evaluated workers (Table 6), considered ideal by the World Health Organization (LÓPEZ et al., 2018), can be explained by the intense energy expenditure associated with the demanding physical activities of the profession. The muscular and cardiovascular effort involved in forestry work contributes to calorie burning and muscle development, positively influencing BMI.
4.2 ERGONOMIC ASSESSMENT

4.2.1 Physical Workload (PW)

Upon evaluating the results presented in Table 6, it is noticeable that only the activities of felling and stacking, related to the manual wood extraction stage, exceeded the 40% limit of cardiovascular load, therefore requiring rest time calculation. Among the activities comprising extraction, stacking required more rest time, requiring 27 minutes per hour, as it was the only activity classified as extremely heavy. These results were like Schettino et al. (2021, 2017).

Although they did not exceed the maximum value stipulated by Apud (1989), the cutting activities approached this mark, with a minimum value of 34% (delimbing/bucking) and a maximum of 40% (felling). The authors Schettino et al. (2021) explain that the CVL close to or exceeding the pre-established limits commonly occurs in forestry activities, especially non-mechanized ones, due to heavy work, high energy consumption, and physical overload, since the processes are still rudimentary and rely on minimal technology.

Similarly to the CVL, the MHR was also higher in manual wood extraction activities, reaching an average value of 194 bpm. However, following the values indicated by Schettino et al. (2021), who stated that in an 8-hour workday, the average heart rate should not exceed 110 bpm, as otherwise, employees become more susceptible to stress, mental fatigue, cardiovascular problems, and other pathologies, thus compromising their health integrity.

Some authors, such as Barbosa et al. (2014), Heck Junior and de Oliveira (2015), and Schettino et al. (2021, 2020a), discuss the relationship between quality of life and physical demands in forestry activities and explain that heavy work is still common in the sector, where concepts of ergonomics and occupational health have generally been ignored. These scenarios, especially physical overload, as found in the present study, may be responsible for illnesses in employees' bodies, thus reducing productivity, performance, and attendance, as well as causing absences or permanent disability (Schettino et al., 2021).

Considering the results found, except for the felling and delimbing/bucking activities, it is necessary to restructure the activities, with the adoption of scheduled breaks for worker recovery and maintenance of work pace. Breaks represent assistance to the physiological mechanism of worker compensation and recovery, allowing for the irrigation of muscles used in
the activity, providing nutrition to the tissues being solicited, thus avoiding fatigue (Smith; Gallagher, 2018). Additionally, the intake of larger volumes of fluids, periodic consumption of energy foods during work, and the use of hats and shirts for protection against the elements by employees are alternatives to be implemented in the work process.

4.2.2 Hand and Arm Vibration (HAV)

According to the Table 7, the partial elements of semi-mechanized cutting activity show indicators higher than the action level proposed for a normalized exposure root mean square acceleration (ANRE) of 2.5 m. s², with average partial exposure (ARPE) and average ANRE of 11.65 m. s² and 5.4 m. s², respectively. It was noticed that felling presented higher values of A-weighted equivalent root mean square acceleration (ARPE) (12.5 m. s²) than delimbing/bucking (10.8 m. s²). However, the A-weighted normalized root mean square acceleration (ANRE) of the delimbing/bucking stage (6.4 m. s²) was higher than the acceleration found in felling (4.4 m. s²). Therefore, it is necessary to alert that although the level found did not exceed the maximum recommended limit for work (5.0 m. s²), it exceeded the action level (2.5 m. s²) proposed by the NHO 10 of FUNDACENTRO, requiring attention and preventive measures to avoid future damages.

The fact that the delimbing/bucking stage presents the highest normalized vibration can be explained by the fact that the chainsaw operator spends much more time in processing activities than felling and has a higher frequency of contact of the bar with trees, with the chainsaw at maximum acceleration. On the other hand, during the felling activity, the operator spends a large part of the time making movements to locate and fell trees, sharpening the chain, lubricating, and performing other maintenance tasks, keeping the chainsaw at lower acceleration.

Prolonged exposure to hand-arm vibration during extensive hours of work can result in adverse health effects for operators, such as tingling sensations, white finger syndrome, alterations in motor and sensory functions of the hands, reduced blood flow, difficulty in handling small objects, physical stress, transient numbness, osteoarticular effects, lower back pain, and sciatica, influencing operator performance and early degeneration of the lumbar region (Witte et al., 2023). For these reasons, when establishing tolerance limits for exposure to vibration levels, legislation seeks to provide a work environment within acceptable limits.
In this context, the best alternative to reduce vibration levels from these machines is to perform maintenance and adjustments regularly, replacing worn, damaged, and defective parts. Additionally, it is crucial to implement a work plan that allows for worker rotation at least every hour of continuous activity (Mendes et al., 2019). Another strategy to reduce workers' exposure to vibration is associated with work reorganization with scheduled breaks and the use of personal protective equipment such as appropriate gloves.

4.2.3 Thermal Comfort (TC)

According to the Figure 3, when it comes to the variable of thermal comfort, it's important to note that NHO 06 recommends that the tolerance limit for heat exposure, in intermittent work regimes with rest periods at the workplace, for heavy activity such as standing work, moving, lifting, pushing, or dragging weights should be a maximum of 25.4 °C. Consequently, employees exposed to higher temperatures become more susceptible to health risks and loss of concentration in their activities, requiring rest breaks to alleviate this issue.

The average index recorded at the beginning of the workday was 18.9 °C, with an increase until 12:00 PM, where it peaked at 23 °C, and then gradually declined until 3:00 PM, reaching 20.7 °C. Comparing the values obtained with the standards established by NHO 06 from FUNDACENTRO, it is observed that the area is in compliance, with no need for correction or mitigation measures regarding the environmental factor.

Heat exposure is an important safety and productivity issue and can even lead to fatalities. When thermal overload occurs, it is necessary to reduce the worker's time spent at the workplace, adjust workload, adapt functions, and take frequent breaks in a cooler area for hydration and restorative rest, as advocated by NR 24 (Couto, 2002; Tustin et al., 2018).

When evaluating thermal overload in areas of forest harvesting with wind-damaged wood, (Schettino et al., 2018) observed that the values for the thermal environment exceeded legal limits. Other authors such as Fiedler et al. (2007), Lundgren et al. (2014), and Schettino et al. (2021) also noted non-compliance with regulations when assessing heat exposure in forestry activities, highlighting the importance of adopting appropriate control measures for work.

When comparing the values to the standards established by regulations, it is observed that there is no need for corrective or mitigation measures regarding thermal comfort for semi-
mechanized cutting and manual extraction activities, like findings by Nascimento and Catai (2017). These results may be due to data collection occurring between the autumn and winter seasons, which significantly affects the average temperature and relative humidity (Dereczynski et al., 2019). In this context, further studies are recommended to cover spring and summer, where heat and humidity are intense.

4.2.4 Noise (N)

According to Figure 4, the noise exposure levels exceeded the regulatory exposure limit for an 8-hour shift in the semi-mechanized cutting activity. These results may be associated with the specificities of chainsaw use, as well as wear and inadequate lubrication of the cutting assembly, along with prolonged exposure time.

According to Czúni and Varga (2017), chainsaws with internal combustion or electric drive have shown high noise levels during use, indicating the need for ergonomic design measures in machine design, as well as corrective measures such as mandatory use of noise-attenuating ear protectors. Additionally, it is recommended to have efficient operation planning to minimize noise exposure time, thus reducing auditory damage for the workers involved.

4.2.5 Illuminance (I)

According to Figure 5, illuminance recorded throughout the workday averaged 22,701 lux, with a maximum of 47,383 lux at 10:30 AM and a minimum of 7,776 lux at 3:00 PM, thus exceeding the minimum determined by NHO 11, like the findings of de Jesus et al. (2020).

These results may primarily be associated with the daily time interval for performing activities, which favors tasks requiring a high degree of precision. However, Iida and Guimarães (2016) emphasize that illuminance values above 1,000 lux do not significantly improve the performance of precision activities while exposing the body to visual fatigue. In this context, it is recommended to use sunglasses to protect against excessive illuminance and to reduce individual worker exposure by alternating tasks among employees.
4.2.6 Integrated analysis of urgency in ergonomic intervention

The color-coded classification of the need for ergonomic intervention related to the degree of compliance (V) for semi-mechanized cutting and manual extraction is presented in Table 8. For both activities, the physical workload variable showed the lowest degree of compliance, 0.27, while the illuminance variable showed the highest compliance index, averaging 1.00. For the partial elements of semi-mechanized cutting, the noise variable showed the lowest degree of compliance, averaging 0.00, while hand and arm vibration showed a compliance level of 0.30, on average.

The partial elements of semi-mechanized harvesting and manual extraction present a sense of urgency for ergonomic intervention in at least one variable of interest, a problem reported by De Oliveira et al. (2020) when comparing forest machinery in wood harvesting by mechanized methods. The classification by compliance level on a color scale can facilitate decision-making for interventions in forestry activities, compared to conventional methods of point analysis reported in Iftime et al. (2022), Masioli et al. (2020), and Schettino et al. (2021), for example. In this case, it is possible to visually classify which variables, activities, or partial elements are most relevant in terms of ergonomic non-conformities, to rationalize interventions of design, correction, awareness, and participation.

When evaluating the Urgency in Ergonomic Intervention (UEI) based on the compliance level (V), it was noticed that the stacking (0), manual felling (0.2), and Delimbing (0.3) activities had the lowest PW values, thus being classified as the most critical activities for intervention. The Delimbing/Bucking stage, on the other hand, showed the lowest indices (0.0) for both the HAV and N variables (together with felling), also requiring intervention and emergency. Regarding illuminance, none of the activities showed an urgent need for intervention. However, for TC, all activities showed a value indicating an urgent need for ergonomic intervention (Table 9).

5 CONCLUSION

The manual tilting and wood stacking activities showed a high level of physical workload, highlighting the need for breaks of up to 27 minutes per hour for the workers. On the other hand,
the debarking and trimming elements presented non-conformities related to the level of vibration in the hand-arm system, requiring the adoption of control measures to preserve the health of the employees. Regarding the semi-mechanized cutting activity, there was a non-conformity regarding the noise level during its execution, requiring immediate interventions to mitigate the health damage to the workers. However, the levels of thermal comfort and illuminance were found to be acceptable for the performance of both semi-mechanized cutting and manual extraction activities. Nonetheless, these activities presented emergency non-conformities for ergonomic intervention in at least one variable of interest. The integrated analysis of the urgency in ergonomic intervention indicated that noise is the priority variable for corrective action, due to the degree of non-conformity established by the regulatory standard.

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