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ERGONOMIC RISKS IN SEMI-MECHANIZED CUTTING OPERATIONS IN THE SOUTHERN AMAZON

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Resumo

Riscos ergonômicos na operação de corte semimecanizado na Amazônia Meridional. O manejo florestal sustentável na Amazônia deve ser realizado de forma a garantir a manutenção dos recursos florestais e a segurança e saúde dos trabalhadores, em uma região em que os trabalhadores estão sujeitos a diversos riscos ergonômicos que comprometem a qualidade de vida. Nesse contexto, objetivou-se realizar uma avaliação dos riscos ergonômicos aos quais os trabalhadores estão expostos na operação de corte de árvores de diferentes densidades. Foram realizadas avaliações dos níveis de exposição ocupacional ao calor e da carga de trabalho físico, usando termômetro digital portátil IBUTG e monitor de frequência cardíaca, respectivamente. Os limites de IBUTG indicaram a exposição dos trabalhadores à sobrecarga térmica acima dos níveis estabelecidos pela NHO 06. A operação de corte de árvores não indicou carga de trabalho físico elevada, sem a exigência de uma ação imediata de mudanças na rotina de trabalho. A densidade da madeira não influenciou a carga de trabalho físico do trabalhador florestal na operação de corte semimecanizado.
Palavras-chave: exploração florestal, floresta nativa; ergonomia; saúde; segurança.

Abstract

Sustainable forest management in the Amazon must be carried out to guarantee the maintenance of forest resources and the safety and health of workers. In this region, workers are subject to various ergonomic risks that compromise their quality of life. In this context, the objective was to assess the ergonomic risks to which workers are exposed when cutting trees of different densities. Assessments of occupational heat exposure levels and physical workload were performed using a portable digital IBUTG thermometer and heart rate monitor, respectively. The IBUTG limits indicated the workers' exposure to thermal overload. The tree-cutting operation did not indicate a high physical workload or potential postural risks, without the requirement for immediate action to change the work routine. Thermal overload is a factor that requires the adoption of mitigating ergonomic measures to preserve the health of workers in the Amazon region.
Keywords: forestry exploitation, native forest; ergonomics; health; security.

INTRODUCTION

The Brazilian Amazon, known as the largest tropical rainforest in the world, possesses a variety of natural resources derived from different plant communities that develop under the influence of this biome's intrinsic environmental factors. Due to the need to curb deforestation in the Amazon, the Brazilian government established, through Ordinance No. 332 of August 25, 2011, the Southern Amazon Mosaic, covering areas located in the border region between the states of Amazonas, Mato Grosso, and Rondônia (Brazil, 2011). The predominant vegetation in this biome is composed of Open and Dense Ombrophilous Forests (IBGE, 2012), and forest resources can be utilized through sustainable forest management.

Forest management aims to use forest resources wisely and sustainably, so that future generations can enjoy at least the same benefits as the current generation (Scolforo, 1998). It is possible to manage natural forests in legal reserve areas of rural properties to enable timber production. In this way, it allows producers to use legally authorized timber through forest management plans, approved by regulatory environmental agencies with the issuance of the Exploration Authorization (AUTEX).

According to Nogueira et al. (2011), exploiting natural forests through management should ensure the sustainable production of forest products without compromising the forest's quality, composition, or long-term diversity, including its essential ecological processes and services. During forest exploitation, tree-cutting activities are carried out in a semi-mechanized system using chainsaws, with techniques applied to guide the trees' fall. Amaral et al. (1998) highlight that these techniques should be applied to prevent errors, reduce wood waste, minimize forest damage, and prevent work-related accidents.

Ergonomics is defined as the science that studies factors influencing the performance of the production system, aiming to reduce harmful effects on workers by providing safety, health, and satisfaction (Iida; Guimarães, 2016). Its application is essential in forestry activities, as in this environment, workers frequently use equipment

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and machines that generate noise and vibration and perform tasks that can alter heart rate and caloric expenditure, often requiring physical effort and being considered strenuous.

Sustainable forest management in the Amazon must meet environmental and legal requirements while ensuring the safety and health of forest workers, who are subject to various unknown ergonomic risks that compromise their quality of life. Workers are exposed to numerous ergonomic risks in logging operations in the southern Amazon, where wood density is a variable that may influence these ergonomic risks, yet studies addressing this topic are lacking. In this context, this study aimed to evaluate ergonomic risks related to heat exposure and physical workload to which workers are exposed in the semi-mechanized tree-cutting operation involving woods of varying densities.

MATERIALS AND METHODS

Study area

The research was conducted in an area of native vegetation within the Amazon biome under a sustainable forest management (SFM) regime, located in the northern region of the state of Mato Grosso (MT), with data collected between August and September 2022 (Figure 1).

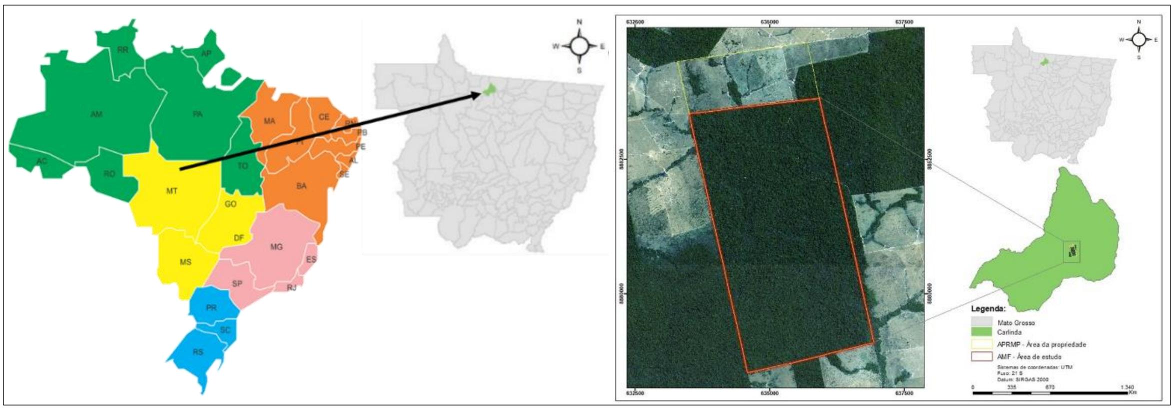

Figure 1. Location map of the study area.
Figura 1. Mapa de localização da área de estudo.

The region's climate is classified as Am, tropical rainforest with a dry season from June to September and rainfall occurring from October to May, with an average annual precipitation of 2,500 to 2,800 mm, while the average annual temperature ranges from 22 to 24°C. The soils in the area are classified as Red-Yellow Dystrophic Latosol, with medium texture, low to moderate clay content, and the dominant vegetation is Open Ombrophilous Forest. The research area is located in the Teles Pires River sub-basin, part of the larger Amazon River Basin (Moreira; Vasconcelos, 2007; IBGE, 2012; Alvares et al., 2013). The region's precipitation and temperature data for 2022 were collected at the meteorological station of the State University of Mato Grosso (UNEMAT), Alta Floresta/MT Campus.

The sample consisted of one chainsaw operator, given the limited number of personnel involved in field operations and because the primary focus of this study was to evaluate the influence of wood density on cutting activity. The evaluated operator was a 40-year-old male with a Body Mass Index (BMI) of 22.86. Before starting the activity, his resting heart rate was 69 bpm, and his maximum heart rate reached 144 bpm. The operator reported being a non-smoker, not engaging in regular physical activities, not using continuous medication, occasionally consuming alcoholic beverages, with over 10 years of experience in tree-cutting activities, and possessing certification as a chainsaw operator.

This study was submitted to the Research Ethics Committee (COMEP) of the State University of the Midwest (UNICENTRO) and was approved under opinion number 5,594,876. Participation in the study was voluntary, with participants receiving clarifications on the study's objectives and methods through the reading and signing of the Informed Consent Form, by Resolution No. 196/1996 of the National Research Ethics Committee of the Ministry of Health.

Characterization of forestry operations

The tree felling was carried out using Stihl chainsaws, model MS 651. The tree-cutting cycle involved opening the directional notch or “cutting mouth” with a horizontal cut in the tree’s falling direction at 20 cm from the ground, followed by a diagonal cut at a 45º angle to meet the horizontal cut line. This was followed by a back cut, made horizontally on the opposite side of the directional notch, approximately 30 cm from the ground. Subsequently, topping (separating the crown from the trunk) and bucking (sectioning the stem into logs) were performed as needed.

Operational scenario

The evaluated operational scenario was the tree-cutting operation involving woods of different densities, classified according to the Institute of Technological Research (IPT) (IPT, 2021), as follows: low density = d < 0.50 g/cm³ (Scenario 1); medium density = 0.50 ≤ d < 0.72 g/cm³ (Scenario 2); and high density = d ≥ 0.72 g/cm³ (Scenario 3).

Ergonomic risk assessment

The assessment of the worker's occupational heat exposure was conducted using the Wet Bulb Globe Temperature Index (WBGT), according to the procedure described by Occupational Hygiene Standard No. 06 (NHO 06), which establishes guidelines for evaluating occupational heat exposure (FUNDACENTRO, 2017).

A portable digital WBGT thermometer by Highmed, model TGD–1800, was installed at the log storage site at a height of 1.60 m from the ground (Figure 2A). Data were recorded and stored at one-minute intervals throughout the work shift, with the WBGT average subsequently calculated, including a one-hour meal break. The WBGT is calculated for outdoor environments with solar load, as per Equation 1:

$$IBUTG = 0{,}7tbn + 0{,}2\ tg + 0{,}1\ tbs \qquad (1)$$

In which: IBUTG = wet bulb globe temperature index; Tbn = natural wet bulb temperature; Tbs = dry bulb temperature; and Tg = globe temperature.

For the evaluation of physical workload, data were collected using a POLAR heart rate monitor, model M600 9715, which is equipped with an optical heart rate sensor. The monitor was installed on the worker's wrist at the beginning of the work shift and removed at the end, with data collected after the felling of each tree in the three evaluated wood densities (Figure 2B). Heart rate data were recorded at 1-second intervals and, at the end of each work shift, transferred and analyzed using POLAR® *software*, following the methodology proposed by Apud (1989).

Figure 2. A: IBUTG portable digital thermometer installed on the banks of the storage yard. B: Heart rate meter installed on the chainsaw operator's wrist.

Figura 2. A: Termômetro digital portátil IBUTG instalado às margens do pátio de estocagem. B: Medidor de frequência cardíaca instalado no pulso do operador de motosserra.

The determination of cardiovascular load was based on the equations proposed by Apud (1989), where the cardiovascular load of the work corresponds to the percentage of the heart rate during work concerning the maximum heart rate supported by the worker, as shown in Equation 2.

$$CCV = \frac{FCT - FCR}{FCM - FCR} X\ 100 \qquad (2)$$

The limit heart rate (FCL) in beats per minute (bpm) corresponds to 40% of the maximum cardiovascular load, as shown in Equation 3.

$$FCL = 0{,}40 * (FCM - FCR + FCR) \qquad (3)$$

In cases where the cardiovascular load exceeds the 40% threshold, it is necessary to reorganize the work-rest schedule, using the calculation provided by Equation 4.

$$Tr = \frac{Ht(FCT - FCL)}{(FCT - FCR)} \quad (4)$$

Em que: CCV = cardiovascular load, in %; FCT = average heart rate during work; FCM = maximum heart rate (220 - age); FCR = resting heart rate; FCL = limit heart rate; Tr = rest time, breaks or pauses, in minutes; and Ht = work duration, in minutes.

For the classification regarding the characterization of work, reference values were used according to Table 1, as proposed by Apud (1989).

Table 1. Reference values for classification regarding work.
Tabela 1. Valores de referência para classificação quanto a classificação do trabalho.

Average Heart Rate (Batimentos por minuto, bpm)	**Work Classification**
< 75	Very light
75 a 100	Light
100 a 125	Moderately heavy
125 a 150	Heavy
150 a 175	Very heavy
> 175	Extremely heavy

Source: Adapted from Apud (1989).

Data Analysis

To evaluate the thermal overload, the data were analyzed using Highmed® software, obtaining the average WBGT value per hour and comparing it with the occupational heat exposure limits for unacclimatized workers, according to the NHO 06 standard (FUNDACENTRO, 2017).

For the evaluation of physical workload, a completely randomized experimental design (DIC) was used, where the treatments were the three wood densities, and the repetitions were composed of 24 trees with low density, 21 trees with medium density, and 15 trees with high density, totaling 60 sampled trees. The statistical analyses were conducted using the original data, as they met the assumptions of homoscedasticity. To verify the homogeneity of the data variances, Bartlett's test was used, and homogeneous variables had their treatments tested using the F-test, with treatment means compared by Tukey's test at the 5% significance level. The statistical analyses were performed using the Assistat software, version 7.7 (SILVA; AZEVEDO, 2016).

RESULTS

Heat Exposure

During the data collection period, the average temperature was high and the relative humidity was low (Figure 2), with average temperatures ranging from 28.01ºC to 27.5ºC and rainfall between 29.1 mm and 56.1 mm for August and September, respectively, resulting in a hot and moderately dry environment.

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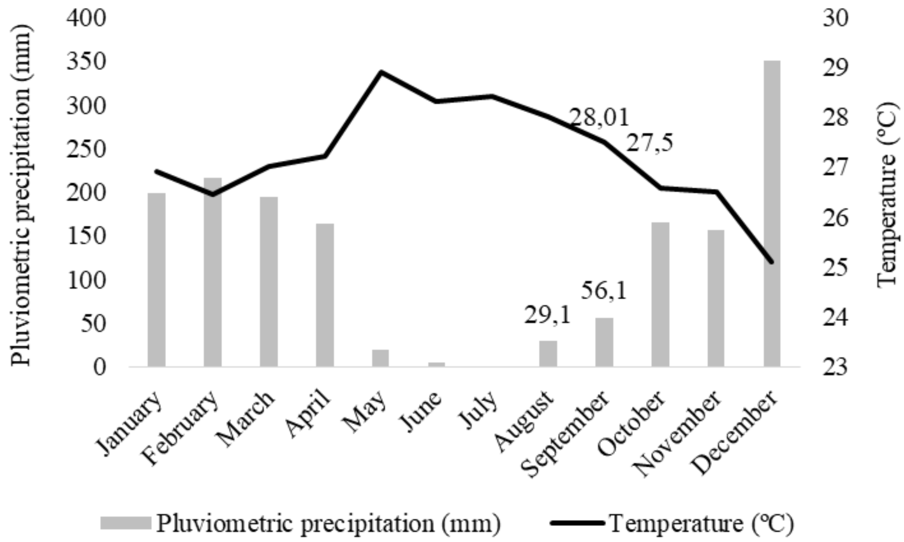

Figure 2. Temperature and pluviometric precipitation mean during the study period.
Figura 2. Médias de temperatura e precipitação pluviométrica no período do estudo.

It was observed that the tree-cutting operation exceeded the limits established by NHO 06, with an average WBGT of 26.07°C (Figure 3). NHO 06 establishes that the action level and exposure limit of WBGT are related to the worker's metabolic rate during the activity. In this study, the job characteristics were considered as described: the cutting operation was classified as moderate work with the body, establishing a metabolic rate of 468 W/h, and the exposure limit and action level were set at 22.3ºC. The exposure limit of 22.3°C was exceeded in the early morning, starting at 9 a.m., and remained above this threshold throughout the workday. The workers were exposed to heat, meaning there was thermal overload between 11 a.m. and 5 p.m., being 21% above the exposure limit, demonstrating the need to alternate tasks or interrupt activities for a certain period.

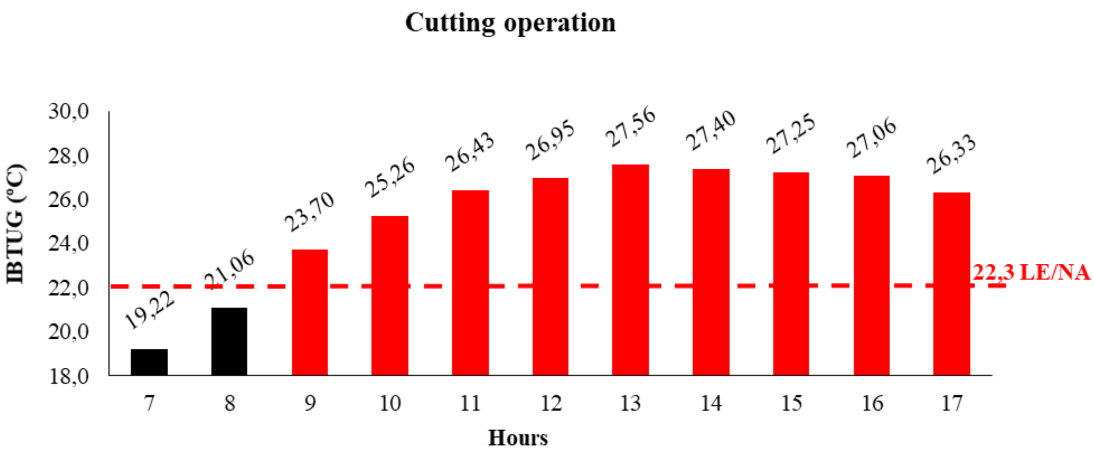

Figure 3. Wet bulb index and globe thermometer (IBUTG) in the tree felling operation in a tropical forest.
Figura 3. Índice de bulbo úmido e termômetro de globo (IBUTG) na operação de corte de árvores em floresta tropical.
Legend: LE: Exposure Limit; NA: Action Level.

Physical Workload

There was no statistical difference between the mean CCV values for the tree-cutting operation across different wood densities, thus no association was found between wood density and the operator's cardiovascular capacity at a 5% significance level (Table 2). The tree-cutting operation across the three wood densities was classified as moderately heavy, with average cardiovascular loads below the maximum 40% limit proposed by Apud (1989).

The classification as moderately heavy is related to the high energy consumption due to the physical demands of the task. The results showed that medium and high-density woods had the highest CCV values, with

35% and 36%, respectively. Therefore, it was found that the CCV percentages indicated there was no physical overload during the tree-cutting operation for the three densities evaluated, and no need for rest periods (TR).

Table 2. Physical workload required in tree-cutting operations in tropical forest regions.
Tabela 2. Carga de trabalho físico exigida na operação de corte de árvores em região de floresta tropical.

Operation	**Density**	**CCV** (%)	**FCR** (bpm)	**FCT** (bpm)	**FCM** (bpm)	**FCL** (bpm)	**TR** (min.)	**Classification**
Cutting	Low	33^{ns}	70	106	180	114	-	Moderately heavy
	Medium	35^{ns}		109	180	114	-	Moderately heavy
	High	36^{ns}		109	180	114	-	Moderately heavy

Legend: ns: not significant by Tukey's test at 5% probability; FCR: resting heart rate; FCT: working heart rate; FCM: maximum heart rate (220 – age); CCV: cardiovascular load; FCL: limit heart rate; TR: recommended rest time based on the workday.

Although no association was found between wood density and the chainsaw operator's cardiovascular capacity, the minimum cardiovascular load values were observed for trees with low density, with a gradual increase for medium and high-density trees, respectively (Table 3). For the maximum values, it was observed that the cardiovascular load was highest for medium-density wood, decreasing for low and high-density wood, respectively.

Table 3. Average, minimum, maximum values, standard deviation and coefficient of variation of cardiovascular load (CCV) and average heart rate (FCM) in tree-cutting operations in a tropical forest region.
Tabela 3. Valores médio, mínimo, máximo, desvio padrão e coeficiente de variação da carga cardiovascular (CCV) e frequência cardíaca média (FCM) na operação de corte de árvores em região de floresta tropical.

	CCV			FCM		
Wood density	Low	Medium	High	Low	Medium	High
Mean	32,92	35,06	35,74	106,21	108,57	109,31
Min	12,73	21,82	31,82	84,00	94,00	105,00
Max	45,45	50,91	41,82	120,00	126,00	116,00
Standard Deviation (S)	8,4347	8,4968	2,7588	9,2782	9,3465	3,0923
Coefficient of Variation (%)	25,6245	24,2317	7,7195	8,7359	8,6086	2,8289

DISCUSSION

In the studied area, two distinct seasons are defined, a dry winter and a rainy summer. The tree-cutting period in the region occurs from the beginning of April until the end of January. During the dry season, the climate presents high temperatures and low relative humidity, due to the absence or low precipitation. These environmental conditions expose the forestry worker to the heat risk factor. The thermal overload in the work environment demands greater hydration from the tree-cutting operator, as it increases the loss of water and minerals through perspiration, thus requiring replenishment.

The IBUTG values were higher than those recommended by NHO 06, potentially causing harm to the health of the chainsaw operators, highlighting the need for ergonomic measures to minimize the discomfort caused by the work environment. Recovery breaks for the hydration of tree-cutting operators may promote greater comfort during work execution. Thermal overload was identified as a factor that requires the adoption of mitigating ergonomic measures to preserve the health of workers in the Amazon region.

Iida and Guimarães (2016) state that prolonged exposure to heat, besides raising body temperature, can cause skin diseases, thermal overload, and increase accident risks. The results observed in this study corroborate other research conducted in regions with native vegetation forestry operations. Bermudes and Minette (2019) evaluated occupational heat exposure during a daily chainsaw operation in the state of Pará, finding IBUTG values above the tolerance limits. They highlighted the need for appropriate control measures, including scheduled work intervals and even stopping work during certain hours.

The physical workload can be affected by the level of physical conditioning of the worker involved in the operation. In this study, the chainsaw operator assessed had good conditioning, being able to perform their duties with greater efficiency and less physical wear, meaning less fatigue compared to operators with lower fitness levels, who would require more rest time during the operation.

Although the results indicated no physical overload in the chainsaw cutting activity under the conditions in which this study was conducted, ergonomic reorganization of the work is necessary to define recovery breaks, due to the need for alternation between effort and rest. This is important because the human body requires a recovery period to maintain its functional capacity. Thus, breaks are necessary to avoid work overload when excessive physical load is detected (APUD, 1989). It is also essential that workers in forestry activities have good physical conditioning, as the physical load of the work is estimated based on the average heart rate. This variable represents the worker's physical and aerobic condition (NASCIMENTO et al., 2018).

Other authors support this study by reporting similar results regarding physical workload in forestry activities. Nascimento et al. (2021) assessed heart rate to estimate physical workload in forest exploitation, observing significant variation in cardiovascular load, ranging from 33.6% to 52.7%, resulting in a physical workload classified as heavy for a less fit worker and moderate (without the need for breaks) for another better adapted. Minette et al. (2018), in an evaluation of physical load during wood harvesting, found that activities such as felling, delimbing, and bucking exceeded the recommended cardiovascular load limits, with values of 47%, 42%, and 44%, respectively. These activities were classified as moderately heavy, indicating the need for work reorganization.

CONCLUSION

- The chainsaw operator was exposed to heat during the tree-cutting operation, exceeding the limits established by NHO 06, resulting in thermal overload and requiring the adoption of mitigating ergonomic measures to preserve the workers' health in the Amazon region.
- The tree-cutting operation under the studied conditions did not result in physical overload for the chainsaw operator. However, this ergonomic risk should be monitored, and preventive and corrective measures should be taken when necessary.
- The density of the wood did not directly influence the physical overload of the chainsaw operator during the semi-mechanized cutting operation.

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