

EFFECT OF WORK SHIFT ON ERGONOMIC VARIABLES IN WOOD HARVESTING MACHINE WORKSTATIONS

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Resumo

Efeito do turno de trabalho em variáveis ergonômicas nos postos de trabalho de máquinas de colheita da madeira. Para aumentar a produtividade, empresas florestais brasileiras têm adotado o trabalho em turnos, incluindo operações noturnas, muitas vezes sem compreender plenamente os riscos ergonômicos em condições reais de operação. Este estudo avaliou o efeito dos turnos de trabalho sobre variáveis ergonômicas em postos de trabalho de máquinas, em povoamentos de eucalipto na região Sul do Brasil. Os dados foram coletados durante operações de corte, extração e processamento da madeira, utilizando *feller buncher*, *grapple skidder* e processador *harvester*, nos turnos diurno e noturno. A vibração de corpo inteiro foi avaliada conforme a NHO 09, o ruído e o conforto térmico com base nas NR 15 e NR 17, e a visibilidade segundo a diretriz ergonômica da *Skogforsk*, com comparação aos limites da legislação brasileira. Os resultados mostraram que os riscos ergonômicos foram mais influenciados pelo tipo de máquina e pelas condições operacionais do que pelo turno isoladamente. Diferenças entre turnos estiveram relacionadas a variações na condução da máquina, influenciadas pela visibilidade, velocidade de deslocamento e condições do terreno. O *grapple skidder* apresentou as condições mais críticas, com vibração de até 1,62 m/s² e ruído de até 89 dB(A), acima dos limites recomendados. Além disso, maiores movimentos laterais da cabeça indicaram redução da visibilidade, especialmente à noite. Conclui-se que os riscos ergonômicos na colheita mecanizada da madeira são determinados principalmente pelas exigências operacionais, reforçando a necessidade de melhorias no projeto das máquinas, na manutenção e na organização do trabalho.

Palavras-chave: exposição ocupacional; mecanização; fatores humanos; segurança do operador; operações florestais.

Abstract

Brazilian forestry companies have increasingly adopted shift work to increase productivity, including night operations, often without fully understanding the associated ergonomic risks under real operating conditions. This study evaluated the effect of work shifts on key ergonomic variables at machine workstations in eucalyptus plantations in southern Brazil. Data were collected during cutting, extraction, and processing operations using a feller buncher, grapple skidder, and landing processor, in both day and night shifts. Whole-body vibration was assessed according to NHO 09, noise and thermal comfort were evaluated based on NR 15 and NR 17, and operator visibility was analyzed using the Skogforsk ergonomic guideline, with results compared to Brazilian regulatory limits. The results showed that ergonomic risks were more strongly influenced by machine type and operational conditions than by work shift alone. Differences between shifts were associated with changes in machine operation caused by visibility, travel speed, and terrain conditions, which affected vibration and noise exposure. The grapple skidder consistently presented the most critical situation, with vibration levels reaching 1.62 m/s² and noise levels up to 89 dB(A), exceeding recommended limits. In addition, greater lateral head movements indicated reduced visibility, particularly during night operations. These findings indicate that ergonomic risks in mechanized timber operations are primarily driven by operational demands rather than shift schedules, emphasizing the need for targeted interventions in equipment design, maintenance, and task organization to improve worker safety and performance.

Keywords: occupational exposure; mechanization; human factors; operator safety; timber operations.

INTRODUCTION

The use of fully mechanized systems in wood harvesting operations has increased among forestry companies, driven by the greater production capacity of machines, reduction of physically demanding labor, and improved comfort, safety, and health conditions provided to operators (OLIVEIRA *et al.*, 2021; SLÁMA *et al.*, 2023). Many Brazilian forestry companies have implemented shift work, including night work, in their forestry operations to increase work productivity and reduce production costs. However, this has often been done without considering the ergonomic risks associated with these working conditions.

The operator is the main component of the human-machine system, capable of utilizing the full production capacity of forestry machinery through their skills (MALINEN *et al.*, 2018; PAGNUSSAT *et al.*, 2021). Despite the improvements and numerous ergonomic features for comfort and safety in modern wood harvesting machines,

operators still spend extended work periods seated inside the workstations, often adopting improper postures, exposed to whole-body vibration, and performing repetitive movements (MARTINS *et al.*, 2020a, MARTINS *et al.*, 2020b; OLIVEIRA *et al.*, 2021). Night shift work may additionally reduce alertness and visual perception while increasing operator fatigue, potentially influencing machine handling and exposure to ergonomic stressors during forestry operations (YANG *et al.*, 2024). Therefore, shift schedules should be organized to minimize fatigue and improve operator safety and working conditions.

The extension of work hours and adoption of various work shifts have become common practices among large Brazilian forestry companies, driven by the need to increase production, reduce machine obsolescence, enhance operational efficiency, and improve market competitiveness. However, ergonomic working conditions differ between day and night shifts, are influenced by operational conditions and may disrupt operators' sleep patterns and circadian rhythms. In this regard, recent studies have evaluated the effects of work schedules on productivity, as well as sleep and recovery in relation to shift work (KYMÄLÄINEN *et al.*, 2023).

Operator comfort has a significant impact on productivity and safety in wood harvesting machines (HÄGGSTRÖM; LINDROOS, 2016). It is essential to adhere to ergonomic principles which help reduce physical and mental stress, and consequently the likelihood of operator errors. Key factors include thermal comfort, vibration, noise, and lighting (MARZANO *et al.*, 2017; OLIVEIRA *et al.*, 2021). Visibility is also crucial for night shift machine operations; if the operator's view is insufficient, safety and health are at risk, increasing the chances of errors and accidents. Ergonomics can help identify issues related to machine design and operational procedures, aiming to enhance comfort, well-being, safety, and health for operators in productive systems. Ergonomic variables related to thermal comfort, vibration, noise, lighting, and visibility should be well understood for forestry machine workstations across different shifts.

Thermal comfort is directly linked to productivity, as productivity, work pace, and concentration decrease when operators are exposed to high temperatures and intense radiation, leading to more frequent breaks and higher risks of errors and accidents (IIDA; GUIMARÃES, 2016). Exposure to vibration is associated with a range of health issues, including those affecting the spine, reproductive organs, digestive, circulatory, and nervous systems, with various studies highlighting its negative health impacts on forestry machine operators (HÄGGSTRÖM; LINDROOS, 2016; MARTINS *et al.*, 2020b). Noise can impair an operator's concentration and negatively affect their hearing and overall health over time (IIDA; GUIMARÃES, 2016).

As already mentioned, visibility is particularly important during night shift work, as it can directly affect the quality and productivity of harvesting operations. Limitations in the operator's field of view in forestry machines are often associated with cabin design, external lighting quality, and implement positioning, which may partially obstruct the work area (SCHETTINO *et al.*, 2017). Operators may adopt repeated head and neck movements to compensate for restricted visibility under these conditions, increasing postural demands and potentially compromising comfort and safety during operation.

Therefore, the objective of this study was to evaluate the variation of selected ergonomic variables in the workstations of wood harvesting machines during day and night shifts, aiming to support improvements in working conditions.

MATERIALS AND METHODS

Study area and forestry operations

This study was conducted in a forestry company located in the southern region of Brazil, in clonal plantations of *Eucalyptus urophylla* × *Eucalyptus grandis* at 8 years of age, in gentle to undulating terrain with an average slope between 3% and 8%, spacing of 3 × 2 meters, and average volume per tree (AVT) of 0.4 m³. Data were collected from the wood harvesting machines in the whole tree (Full Tree - FT) system, where cutting operations were performed by the feller buncher, which felled and stacked tree bundles inside the plantation. These bundles were then removed to the field edge by the grapple skidder and later processed into logs by the processor. The technical characteristics of the machines studied are presented in Table 1.

The operators who participated in the study received training and had experience in the role, with two operators being evaluated for each machine model in each work shift. The study was submitted to and approved by the Research Ethics Committee (COMEP) in compliance with the National Health Council of the Ministry of Health, under protocol No. 2.645.278.

Table 1. Wood harvesting machine characteristics in the full tree system.
Tabela 1. Características das máquinas de colheita da madeira no sistema *full tree*.

Characteristics		Feller Buncher	Grapple Skidder	Landing Processor
				
Machines	Operation	Cutting	Extraction	Processing
	Undercarriage	Tracks	Tires	Tracks
	Traction	Tracks	6 X 6	Tracks
	Hour meter (h)	15,000	25,000	18,000
	Machine length (m)	5.3	9.3	5.1
	Machine width (m)	3.4	3.3	3.7
	Machine height (m)	3.7	3.6	3.1
	Engine power (kW)	298	194	119
	Cabin dimensions C×L×A (m)	1.8×1.0×1.9	1.6×1.0×1.8	3.3x1.0x1.9
	Cabin rotation	Yes	No	Yes
	Implement	Accumulator head	Claw	Processor head
	Boom coupling	Side	Front	Side
Operators	Age (years)	39.0 ± 13	48.3 ± 10	34.5 ± 2
	Height (m)	1.75 ± 0.1	1.70 ± 0.1	1.77 ± 0.1
	Body mass (kg)	89.7 ± 12	92.0 ± 10	85.0 ± 25
	Experience (years)	8.7 ± 6.7	8.7 ± 2.1	5.1 ± 3.3

Sampling and treatment procedures

The ergonomic assessments of the machines were performed during two work shifts: the day shift from 8:00 AM to 12:00 PM and the night shift from 8:00 PM to 12:00 AM. Data on whole-body vibration (WBV), noise, thermal comfort, and visibility angles were collected using ergonomic instruments and video cameras installed inside the machines (Figure 1). Ergonomic data were recorded for each machine model over 12 repetitions of two-hour periods per shift, resulting in a total sampling effort of 24 hours per machine per work shift.

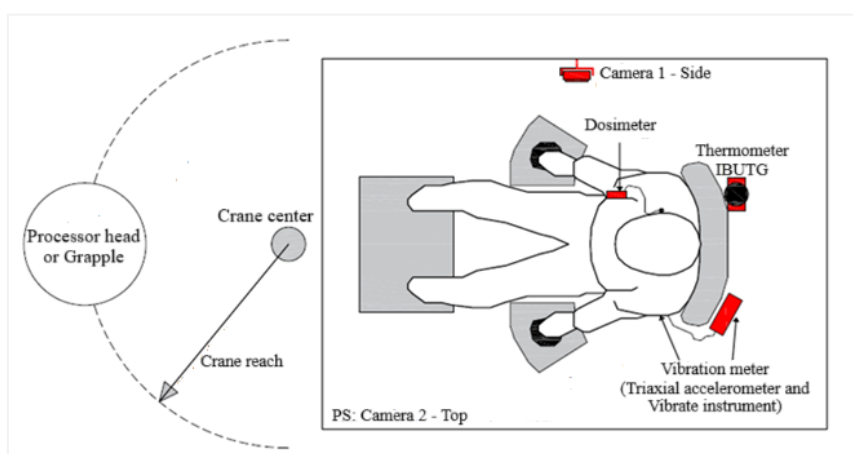


Figure 1. Location of ergonomic instruments and cameras for collecting ergonomic variables.

Figura 2. Localização dos instrumentos ergonômicos e câmeras na coleta das variáveis ergonômicas.

Ergonomic variables

The whole-body vibration (WBV) data were collected using a *Brüel & Kjær* vibration meter (model Type 4447), with a triaxial accelerometer (x, y, and z axes) installed on the machine's seat via a seatpad, in accordance

with the Brazilian Occupational Hygiene Standard NHO 09, proposed by the Jorge Duprat Figueiredo Foundation for Safety and Occupational Medicine (FUNDACENTRO, 2013). The average vibration was obtained through the acceleration resulting from the normalized exposure (in m/s^2) and the vibration dose value (VDVR in $\text{m/s}^{1.75}$) for 8 hours of work:

$$\text{aren} = \text{are} \times \sqrt{\frac{T}{T_0}}$$

in which: aren = acceleration resulting from normalized exposure (m/s^2); are = acceleration resulting from exposure, representative of daily occupational exposure (m/s^2); T = duration of the daily working day expressed in hours or minutes; and $T_0 = 8$ hours or 480 minutes.

$$\text{VDVR} = \left[\sum_j (\text{VDV} \times \exp_j)^4 \right]^{1/4}$$

in which: $\text{VDV} \exp_j$ is Vibration Dose Value of exposure representative of daily occupational exposure on the “j” axis, where “j” is equal to “x”, “y” or “z” ($\text{m/s}^{1.75}$).

The results were compared with the exposure limit or action level defined by NHO 09, where average acceleration values resulting from normalized exposure (aren) above 1.1 m/s^2 or vibration dose values (VDVR) greater than $21 \text{ m/s}^{1.75}$ indicate that the exposure limit has been exceeded, requiring the immediate adoption of corrective measures for exposure control. Meanwhile, aren values between 0.5 and 1.1 m/s^2 or VDVR between 9.1 and $21 \text{ m/s}^{1.75}$ indicate exposure above the action level, necessitating preventive measures to minimize health issues for workers.

The noise data were obtained using an Instrutherm DOS-500 dosimeter (with “A” compensation circuit and slow response, and a criterion level of 85 dB with a 5 dB exchange rate), installed in the operator’s hearing area inside the machine cabin with the door closed. The noise doses were determined by calculating the Average Noise Level (Lavg) over the measurement time:

$$\text{Lavg} = 16.61 \times \log \left(\frac{D}{100} \times \frac{480}{T_m} \right) + 85$$

in which: Lavg (average level) is average level (dB); D is partial noise dose related to the measurement (%); and T_m is Measurement time (min).

Next, the average noise level was converted for an eight-hour workday to determine the average exposure level or dose to compare with exposure limits, so the Normalized Exposure Level (NEL) was calculated as:

$$\text{NEL} = \text{Lavg} + 16.61 \times \log \left(\frac{T_e}{480} \right)$$

in which: NEL is Normalized Exposure Level (dB); Lavg is average level; and T_e is Exposure time.

The permissible maximum limit of 85 dB (A) for an 8-hour workday without the use of hearing protection was considered as 100% of the daily dose by NR 15, the Regulatory Standard 15 - Unhealthy Activities and Operations (BRASIL, 1978b). The action level (prevention) value was 80 dB (A), representing 50% of the daily dose by NR 09, the Regulatory Standard 09 - Environmental Risk Prevention Program (BRASIL, 1978a), and the comfort limit was 65 dB (A), considering that the activities required intellectual effort and constant attention according to NR 17, the Regulatory Standard 17 – Ergonomics (BRASIL, 1978c).

Heat exposure was assessed using the Wet Bulb Globe Temperature (WBGT) index, with data collected using a Digital Thermal Stress Meter (Globe Thermometer) with a datalogger (model TGD-1800), which was installed inside the machines. The WBGT value was obtained at one-minute intervals during the data collection period, with the average values extrapolated for 8 hours and compared to the NR 15 limits (BRASIL, 1978b).

The visibility angles of the operators at the machine workstations were obtained from images generated by the video cameras installed inside the cabin, capturing the head movement angles of the operators in the frontal (vertical) and transverse (horizontal) planes. These angles were then compared with the method proposed by The Forestry Institute of Sweden (SKOGFORSK, 1999). Head movement angles are indicators used to assess visibility at workstations, where the closer to the neutral position, the better the visibility. Maximum angles should only be used for short intervals and in isolated situations during work. The images for measuring visibility angles were paused and inserted into the Autodesk® AutoCAD® 2016 software. The average angles in the sagittal and superior

planes were calculated, considering the typical postures adopted by the operators during their effective working time, and then compared with the ideal and maximum head and neck movement angles (Figure 2).

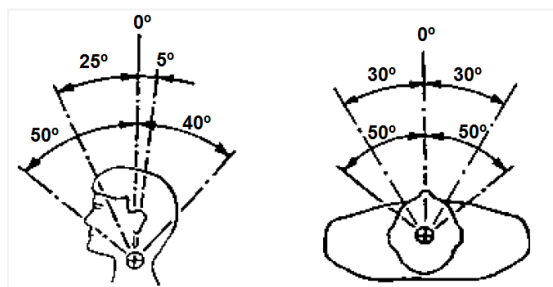


Figure 2. Limits of visibility angles in the frontal and transversal planes (SKOGFORSK, 1999).

Figura 2. Limites dos ângulos de visibilidade nos planos frontal e transversal (SKOGFORSK, 1999).

Statistical analysis

A pilot study was initially conducted to determine the minimum sample size required for evaluating each ergonomic variable at a 95% confidence level (BARNES, 1977).

$$n \geq \frac{t^2 \times CV^2}{E^2}$$

in which: n is minimum number of repetitions (samples) required; t is t-value for the desired probability level and (n-1) degrees of freedom; CV is coefficient of variation, expressed as a percentage; and E is allowable error, expressed as a percentage.

The data were subjected to the Kolmogorov-Smirnov test to verify normality. The results were subsequently analyzed by analysis of variance, and the means between work shifts were compared using the Student's t-test at the 5% significance level.

RESULTS

The average acceleration values (aren) and daily dose (VDVR) for the whole-body vibration variable for 8 hours of work in the feller buncher, grapple skidder and landing processor for both work shifts are shown in Figure 3. The NHO 09 standard states that both indicators should be analyzed together, especially in operations that involve shocks or jolts, which is important to better evaluate the potential impacts on the worker's health (FUNDACENTRO, 2013), and constitutes a situation commonly observed in forestry operations.

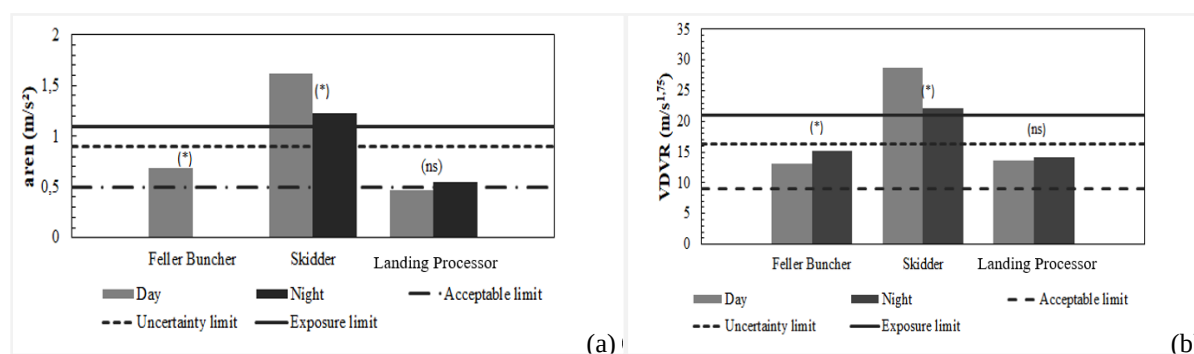


Figure 3. Vibration in relation to (a) the average acceleration and (b) the average daily dose of the machines during day and night shifts.

Figura 3. Vibração em relação a aceleração média (a) e dose diária média (b) das máquinas nos turnos diurno e noturno.

The feller buncher performed tree felling and stacking operations within the forest stand with minimal machine movement, operating in a relatively stationary condition. Whole-body vibration (WBV) presented average acceleration and daily dose values between the action level and exposure limit proposed by NHO 09, with 0.68 m/s² and 13.07 m/s¹.⁷⁵ during the day shift, and 0.77 m/s² and 15.15 m/s¹.⁷⁵ during the night shift, respectively, showing a significant difference between work shifts. The grapple skidder, responsible for transporting trees from the interior of the stand to its edge and operating in continuous motion under both loaded and unloaded conditions,

presented the highest vibration levels in both shifts, with acceleration values of 1.62 m/s^2 and 1.23 m/s^2 and daily doses of $28.71 \text{ m/s}^{1.75}$ and $22.11 \text{ m/s}^{1.75}$ during the day and night shifts, respectively. These values exceeded the exposure limit established by NHO 09, indicating harmful exposure to operators' health and the need for preventive and corrective measures. The landing processor, operating in a stationary manner during tree processing at the stand edge, showed average vibration acceleration of 0.47 m/s^2 during the day shift and 0.55 m/s^2 during the night shift, with a significant difference between shifts. In contrast, daily doses were $13.60 \text{ m/s}^{1.75}$ and $14.12 \text{ m/s}^{1.75}$, with no significant difference, indicating similar exposure to shocks and jolts across both shifts.

The average noise levels during the day and night shifts are shown in Figure 4. This ergonomic variable manifested differently for each machine, with no direct relationship to the work shifts. The feller buncher had an average noise level of 78 dB(A) during the night shift, which was higher than the day shift at 65 dB(A), with a significant difference between the two shifts. The higher noise level observed during the night shift may be associated with changes in machine handling under reduced visibility, requiring more frequent hydraulic movements and engine load adjustments during tree felling. The grappler skidder presented the highest noise levels in both shifts, with average values of 89 dB(A) and 87 dB(A), respectively, but no statistical difference between the shifts. The processor had the lowest noise levels, with 62 dB(A) and 69 dB(A) during the night and day shifts, respectively, with no statistical difference between the evaluated periods.

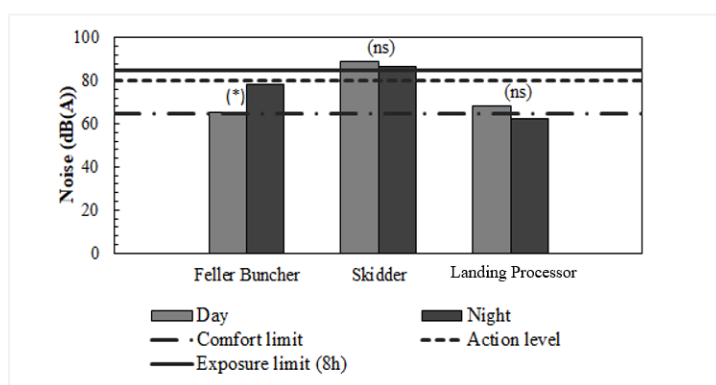


Figure 4. Average noise levels of the wood harvesting machines during day and night shifts.

Figura 4. Níveis médios de ruído das máquinas de colheita da madeira nos turnos diurno e noturno.

Thermal comfort inside the machine workstations, measured by the Wet Bulb Globe Temperature (WBGT) Index, was adequate and below the limit established by the standard (Figure 5). All machines were equipped with a cabin climate control system, with the internal temperature regulated by the operators themselves. Despite this, the highest WBGT values were recorded during the day shift, as the machines worked part of the workday exposed to solar radiation. The feller buncher had an average WBGT of 19.2 and 17.1 during the day and night shifts, respectively, while the grappler skidder, which worked the entire workday exposed to solar radiation, had an average WBGT of 20.5 and 15.5 during the day and night shifts, respectively, showing a significant difference between the two shifts for both machines. The processor showed an average WBGT of 18.1 during the day and 17.1 at night, with no significant difference between the shifts. It should be noted that measurements were conducted during morning and evening operational periods, which are representative of routine production conditions in the company studied.

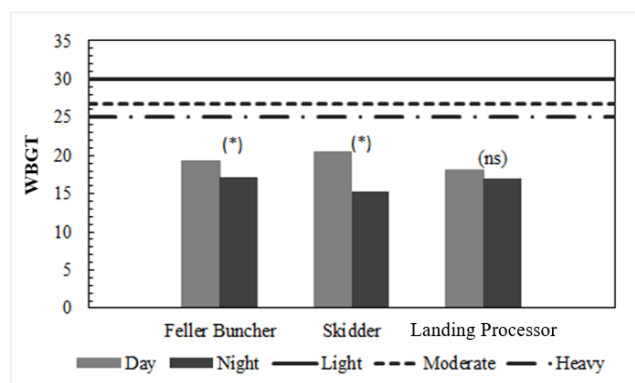


Figure 5. Average WBGT levels of wood harvesting machines during the day and night shifts.

Figura 5. Níveis médios de WBGT das máquinas de colheita da madeira nos turnos diurno e noturno.

The average head angles of the operators and their respective recommended limits for healthy work are presented in Table 2. The recommended average limit for normal work (maximum angle to be respected for most of the workday) was only exceeded in the lateral plane in the grapppler skidder during the wood extraction. The operator had the second-highest average of frontal inclination when cutting trees with the feller buncher during the day shift with 14.3 ± 5.2 degrees, showing a significant difference when compared to the night shift (7.9 ± 2.9 degrees). The averages in the day and night shifts regarding the lateral angle were 7.8 ± 2.4 and 6.2 ± 2.8 degrees, respectively, with no significant difference. It can be noted that the average visibility angles of the operators in the frontal plane were higher than in the lateral plane during both work periods.

Table 2. Average visibility angles of the operators according to the frontal and lateral planes.

Tabela 2. Ângulos médios de visibilidade dos operadores nas máquinas em função dos planos frontal e lateral.

Machine	Shift	Frontal Visibility	Lateral Visibility	Frontal Visibility (Degrees)		Lateral Visibility (Degrees)	
				AV	SD	AV	SD
<i>Feller Buncher</i>	Day			14.3 ^a	5.2	7.8 ^a	2.4
	Night			7.9 ^b	2.9	6.2 ^a	2.8
<i>Grapppler Skidder</i>	Day			11.8 ^a	4.3	38.4 ^a	9.8
	Night			3.3 ^b	0.2	77.2 ^b	9.6
<i>Landing Processor</i>	Day			8.6 ^a	2.0	8.8 ^a	2.0
	Night			8.9 ^a	2.1	7.3 ^a	1.9
Normal limit				25,0	-	30,0	-
Sporadic limit				50,0	-	50,0	-

AV = Average Value; SD = Standard Deviation.

The grappler skidder operator exhibited the highest average lateral angulation values, making it the machine with the greatest head movement demands, and consequently the one which presented the most significant visibility challenges for operators. The vertical movement related to frontal visibility during the day and night shifts was 11.8 ± 4.3 and 3.3 ± 0.2 degrees, respectively, while the lateral movement was 38.4 ± 9.8 and 77.2 ± 9.6 degrees, showing a significant difference between shifts. The wood processing operation with the processor required less head movement from operators in both planes, with frontal visibility averaging 8.6 ± 2.0 degrees during day and 8.9 ± 2.1 degrees at night, while the lateral movement averaged 8.8 ± 2.0 degrees and 7.3 ± 1.9 degrees. This machine was similar to the feller buncher in that it also had a lateral coupling boom in the cabin, helping the operator maintain a forward head position, which was adopted throughout the entire wood processing operation at the edge of the forest stand.

DISCUSSION

Wood extraction with the grappler skidder was the harvesting activity which presented the highest vibration levels, exceeding the exposure limits in terms of acceleration and daily dose during both work shifts, highlighting the clear need for ergonomic measures. The highest vibration occurred during the day shift, with values above the exposure limit. This was explained by the fact that operations are typically conducted in more adverse conditions during the day shift, when visibility is better. It is important to emphasize that the higher vibration in the grappler skidder, regardless of the work shift, was due to the nature of the wood extraction operation, which requires numerous machine movements during work. Additionally, the wood loading and unloading stages, which make up more than 70% of the total operational cycle time, involve higher engine power, while the movements in these stages are slower or only performed by the machine's grapple (PAINI *et al.*, 2020; LIMA *et al.*, 2023). Furthermore, timber extraction was performed on irregular terrain with obstacles such as stumps and forest residues, requiring greater engine power and machine acceleration during skidding, which contributed to higher vibration levels.

Following this, high vibration levels were also observed in the feller buncher during both shifts, being explained by the jolts caused by the impact of tree bundles on the ground. In contrast, no significant vibration issues were observed in the processor due to its greater stability and less machine movement during operation. Therefore, the results reinforce the hypothesis that WBV is directly related to the contact of the machine's wheels with the terrain and the movement speed during wood extraction, as well as the impacts of trees on the ground during felling. Previous studies have reported that operational implements make a limited contribution to vibration (HÄGGSTRÖM; LINDROOS, 2016; OLIVEIRA *et al.*, 2021). As such, adopting preventive and corrective ergonomic measures is essential to provide better comfort and health conditions for machine operators. These measures must include periodic monitoring of WBV exposure, operator training, and medical control (occupational health exams). Studies related to WBV exposure with heavy machinery can also explore different alternatives, such as variations in tire pressure, the use of different seat cushioning materials, reduced travel speed during work, reorganized tasks to reduce worker exposure to vibration, and periodic training or the use of machines with a greater number of wheels to improve stability and homogenize tire impacts with the ground (JI *et al.*, 2017).

The grappler skidder was, once again, the machine which presented the highest noise levels during both work shifts, exceeding the exposure limit of 85 dB(A) established by NR 15. In contrast, the other machines, which operate with low movement and engine rotation, had noise levels below the action level of 80 dB(A) defined by NR 09. More recent evidence from Brazilian forestry operations indicates that a significant proportion of machine operators are exposed to noise levels above regulatory limits, reinforcing the persistence of this occupational risk (CAMARGO *et al.*, 2021). These issues have been associated with machine design characteristics, particularly deficiencies in cabin acoustic insulation due to wear of sealing components over time.

Therefore, routine maintenance programs should include periodic inspection of door seals and cabin insulation systems to reduce operator exposure and preserve adequate acoustic comfort. It is important to highlight that when noise is treated as acoustic comfort, the machines presented noise levels above or very close to the comfort limit defined by NR 17. This standard specifies that activities requiring constant intellectual demand and attention should not have noise exposure above 65 dB(A), which can be considered harmful to operators during wood harvesting operations.

According to NR 15, the operation of wood harvesting machines is classified as light work, where the operator remains seated for most of the workday, with moderate arm and leg movements. All the machines studied presented WBGT values below 30.0 for recommended continuous work, highlighting that thermal comfort not only aims at temperature control (20 to 23°C), but also airspeed (up to 0.75 m/s) and relative humidity (above 40%), indicating that the machines were in compliance with regulatory standards during both work shifts.

It should be noted that door seals may be damaged during operator ingress and egress, progressively compromising cabin thermal comfort. This reinforces the need for preventive inspections and timely corrective

maintenance to preserve adequate sealing conditions. Thus, maintaining cabin seals and mechanical components, taking breaks to relieve fatigue, reducing daily work hours, and rotating operators among different forestry machines are some recommendations which can help mitigate occupational health risks for operators (CAMARGO *et al.*, 2017). It is worth emphasizing that the physiological response to heat varies from person to person, depending on the type of task, exposure duration, skill level, and individual acclimatization. The characteristics of both the machines and operators should be considered in future studies.

In terms of visibility, the worst results were found during the wood extraction process, where the grappler skidder operator showed the highest average lateral head angulation values compared to frontal angulation. The operator's seat in this machine had a restricted rotation angle, which limited visibility and required frequent head movements, especially during maneuvering activities associated with loading and unloading. Skogforsk (1999) states that the visibility problem becomes severe when the operator has to follow the boom's movement from a fixed cabin, and it is worsened when the operator has to turn their head extensively for better visibility of the work area. The machines which showed the best visibility conditions were those equipped with a rotation system around their own axis and a lateral coupling boom, allowing for an unobstructed frontal view, as was the case with the feller buncher and landing processor.

CONCLUSIONS

- Work shift influenced ergonomic variables, with differences observed in vibration, noise, thermal comfort, and visibility, although not consistently across all machines.
- Ergonomic risks were mainly driven by machine type and operational function, with the grappler skidder showing the most critical conditions, including vibration above exposure limits and high noise in both shifts.
- Environmental and operational factors, such as terrain conditions and solar radiation, had a stronger influence than work shift itself, indicating that effects are context dependent.
- Visibility constraints were most pronounced in the grappler skidder due to limited cabin rotation, requiring increased head movement, particularly during night operations. Improvements in machine design and operational planning are essential to reduce risks.

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