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VISIBILITY AND POSTURE OF OPERATORS IN HARVESTERS WITH LATERAL AND FRONT COUPLING CRANES

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Resumo

Visibilidade e postura de operadores em harvester com lanças de acoplamento lateral e frontal. Nas operações mecanizadas de colheita de madeira é possível verificar inadequações ergonômicas, como má visibilidade e posturas inadequadas, que podem causar riscos à segurança e à saúde dos trabalhadores, com efeitos no desempenho operacional das máquinas. Nesse contexto, o objetivo deste trabalho foi avaliar os efeitos dos posicionamentos da lança de acoplamento em *harvesters* na visibilidade e nas posturas de operadores florestais. Para isso, o estudo foi conduzido em operações de corte raso em povoamentos de eucalipto, sendo avaliados um *harvester* com lança de acoplamento frontal e outro com acoplamento lateral e quatro operadores por máquina. Para determinação de tempos efetivos e posturas típicas foram realizadas filmagens e congelamento das imagens. Em seguida, foram empregados os métodos *Skogforsk* e *Rapid Upper-Limb Assessment* (RULA), para avaliação de visibilidade e postura, respectivamente. Os dados de angulação e postura foram comparados entre máquinas pelo teste t de *Student*. As visibilidades frontal e lateral permaneceram dentro dos limites aceitáveis, mas o *harvester* com lança lateral exigiu dos operadores um ângulo médio de 15º de inclinação frontal de cabeça, 50% superior ao com lança frontal. Consequentemente, na avaliação postural, o com lança lateral, em 86% do tempo apresentou escore 3 e nível de ação 2, sugerindo mais investigações, enquanto o outro em 81% do tempo apresentou escore 2 e nível de ação 1, sendo aceitável se não for mantida ou repetida por longos períodos. Portanto, o posicionamento do acoplamento da lança na máquina requer uma reorganização do posto de trabalho, principalmente do visor da máquina.
Palavras-chave: Colheita de madeira; ergonomia; máquinas florestais; posto de trabalho.

Abstract

Operator visibility and posture in harvesters with side and front coupling crane. In mechanized timber harvesting operations, it is possible to verify ergonomic inadequacies, such as poor visibility and inappropriate postures, which can cause risks to the safety and health of workers, with effects on the operational performance of the machines. In this context, the objective of this work was to evaluate the effects of the positioning of the coupling crane in *harvesters* concerning the visibility and postures of forestry operators. For this, the study was carried out in clear-cutting operations in eucalyptus stands, evaluating a harvester with a frontal coupling crane and another with lateral coupling, as well as operators per machine. To determine effective times and typical postures, filming and freezing of images were performed. Then, the *Skogforsk and Rapid Upper-Limb Assessment* (RULA) methods were used to assess visibility and posture, respectively. Angulation and posture data were compared between machines by the Student's t test. Front and side visibility remained within acceptable limits, but the side crane harvester required operators to have an average head tilt angle of 15º, 50% higher than with the front crane. Consequently, in the postural evaluation, the one with the lateral crane presented score 3 and action level 2 86% of the time, suggesting further investigations, while the other presented score 2 and action level 1 81% of the time, being acceptable if not maintained or repeated for long periods. Therefore, the positioning of the crane coupling on the machine requires a reorganization of the workstation, mainly the machine's display.
Keywords: Wood harvesting; ergonomics; forest machines; workstation.

INTRODUCTION

Harvesting wood from planted forests is very important in the production process, with a significant share in the composition of the final costs of wood placed in the factory, in addition to being influenced by various technical, economic, social, environmental and ergonomic factors. In Brazil, one of the most used machines for forestry cutting operations in pine and eucalyptus plantations is the *harvester*, which performs felling activities, delimbing, stripping, tracing and stacking the wood in the form of logs, which can be of different lengths. The *harvester* is made up of a base machine with wheeled tires or tracks, mounted on an articulated chassis that rotates around its own axis, equipped with an arm and coupled hydraulic crane and a processor head. This hydraulic crane can be located at the front, side or rear of the machine.

Even in wood harvesting activities carried out with technologically modern machines, such as the *harvester*, it is possible to have problems with the ergonomic aspect of seats, controls, components or workstations, related both to the anthropometric characteristics on which the machines were designed, as with construction characteristics (*purpose-built* or *adapted*). Such situations can cause the operators to adopt inappropriate postures and visibility difficulties, compromising comfort, safety and health in the execution of the work. (GERASIMOV; SOKOLOV, 2014; SCHETTINO *et al*., 2016; MARTINS *et al.*, 2020).

Therefore, ergonomics as an applied science can contribute to the identification of problems in relation to machine designs and operational procedures in the search for greater comfort, well-being, safety and health of operators in their relationship with production systems. This can be done by assessing posture and visibility at the machine operators' workstations.

Inadequate design of seats, commands and workstations on machines can force workers to adopt incorrect postures when carrying out their activities (IIDA e GUIMARÃES, 2016). The results of postural analyzes have great practical applicability in solving ergonomic problems, with a consequent reduction in productivity loss and improvement in working conditions (PAINI *et al*., 2019; LANDEKIC *et al*., 2019). In this sense, a situation that influences the postural condition of the harvester operator in wood harvesting is the inadequate location of the crane, hydraulic arm, hoses, columns and cabin protection rails, which vary according to the brand and model of the machine. (MARTINS *et al*., 2020).

Typical postures of forest machine operators can present ergonomic risks that cause damage to health and affect work performance (PAINI *et al*., 2020). As the work of *harvester* operators requires greater use of the upper limbs and maintenance of a more static posture at the workstation, a method that can be used for postural assessment is the *Rapid Upper-Limb Assessment* (RULA), focusing on overload of such members (McATAMNEY; CORLETT, 1993). Through it, it is possible to evaluate: the muscular work in a static way, the forces applied in the segments of the human body and the recognition of the angles of the movements in the different members of the body, in addition to encompassing analysis of repetitiveness and handling of loads.

Thus, given the already evidenced postural needs, the importance of evaluations in wood harvesting machines is shown to verify the actual conditions of health and postural safety. At the same time, the visibility of wood harvesting machines is an ergonomic problem that can be related to deficiencies in machine designs.

On the other hand, the forest area managers also reported on the importance of the need for improvements in the visibility of the machines, especially when the work is carried out on land with adverse conditions in relation to the slope, presence of hills and obstacles. (BAYNE; PARKER, 2012). Furthermore, the conditions for maintaining good visibility conflict with the design of the machines, depending on the height, width and length of the booths.

A method to evaluate visibility conditions through ideal and maximum acceptable limits for the operator's head movements is the one developed by the Forestry Research Institute of Sweden (SKOGFORSK, 1999). The closer to the neutral position, the better the visibility. Furthermore, the maximum angles should only be used during short breaks and in isolated situations on the job.

It is important to mention that the design of machine booths must be done considering the maximum reduction of supports that hinder the operator's field of vision concerning the workplace (SCHLOSSER *et al*., 2011). It should also be noted that there are machines with different design features in terms of the hydraulic crane, which can be located at the side, front or above the booth. Considering that the operator is in a sitting position and performing repetitive activities at the workstation, this crane positioning can negatively influence the postures adopted throughout the working day, which may harm the worker's health.

Therefore, the objective of this work was to evaluate the effect of positioning the coupling crane in two *harvester* models, considering the posture and visibility of operators in wood harvesting in planted forests, and aiming to identify possible problems and propose ergonomic solutions.

MATERIAL AND METHODS

Study area and operations studied

The experiment was carried out in areas with planted forests belonging to a forestry company located in the Central Eastern mesoregion of the state of Paraná, Brazil. The stands consisted of 8-year-old *Eucalyptus urophylla* × *E. grandis* hybrid clones, planted in gently undulating terrain, with a slope of 3 to 8%, initial spacing of 3 m x 2 m, without thinning and with volume individual tree average of 0.4 m³ at harvest. The assortments of logs produced were: (1) 2.40 m long and 15 to 17 cm in diameter at the thin end; (2) 2.60 m in length and between 18 and 22 cm in diameter at the fine point; and (3) 2.55 m in length and over 22 cm in diameter at the fine point.

The harvesting system in which the *harvesters* worked was short logs. The study included two models of *harvesters*, one with a lateral hydraulic crane and the other, a frontal one. Both machines carried out the activities of felling, delimbing, processing (torching), cutting and stacking the logs from the trees inside the stand. The width of the work lane was 9 meters, with the machines working in one direction.

Eight duly trained operators with an average experience of 6.2 years in the function were studied, four in each machine model. The research was submitted and approved by the Research Ethics Committee (COMEP) in compliance with the National Health Council of the Ministry of Health.

The characteristics of the machines and operators are shown in Table 1.

Table 1. Characteristics of harvesting machines and their operators.
Tabela 1. Características das máquinas de colheita e de seus operadores.

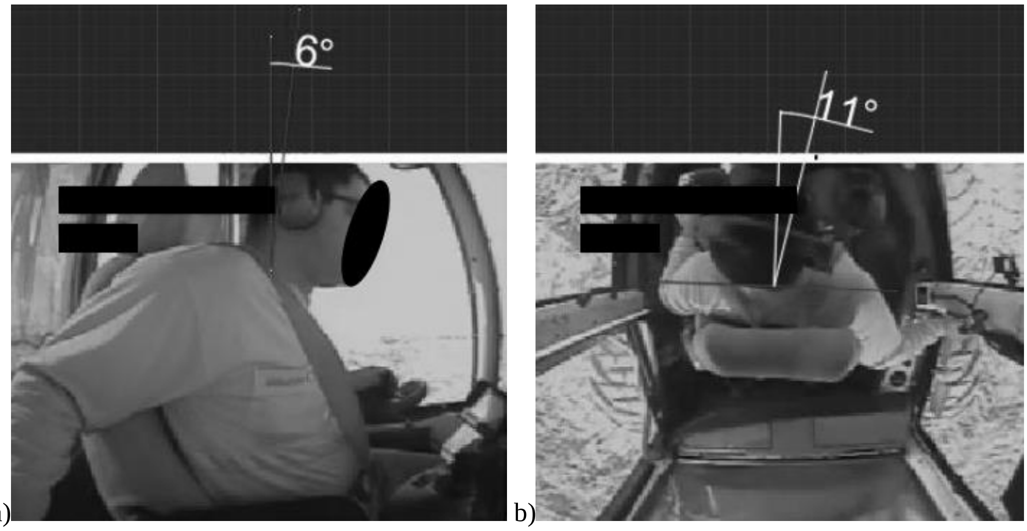
Item	Technical characteristic	*Harvester* with side coupling crane	*Harvester* with front coupling crane
Machine	Visual representation		
	Internal view		
	Length (m)	7,6	7,9
	Width (m)	2,9	2,9
	Height (m)	3,9	4,2
	Motor power (kW)	193	200
	Traction	6×6	8×8
	Lifespan (h)	13.000	3.500
Booth	Rotation and leveling	sim	sim
	Length (m)	1,1	2,0
	Width (m)	1,1	1,5
	Height (m)	2,0	2,1
Operators	Age (years)	38,7 ± 6,4	38,0 ± 2,6
	Stature (m)	1,75 ± 0,1	1,67 ± 0,1
	Body mass (kg)	79,0 ± 5,7	76,3 ± 5,9

Source: Machine catalogs and field measurements.

Data collection and analysis

The body postures and the visibility angles of the operators at the workstations on both machines were collected simultaneously in a real work situation. In order to do this, footage was taken of the operators during the execution of the wood harvesting operations, with the images being obtained using two DVR-type cameras, ACTIA brand, equipped with a recording unit with four channels, which were installed inside the cabins of the machines. The first camera was fixed on the side, to capture the image of the operator in profile position and the second on the cabin roof, to capture the top image.

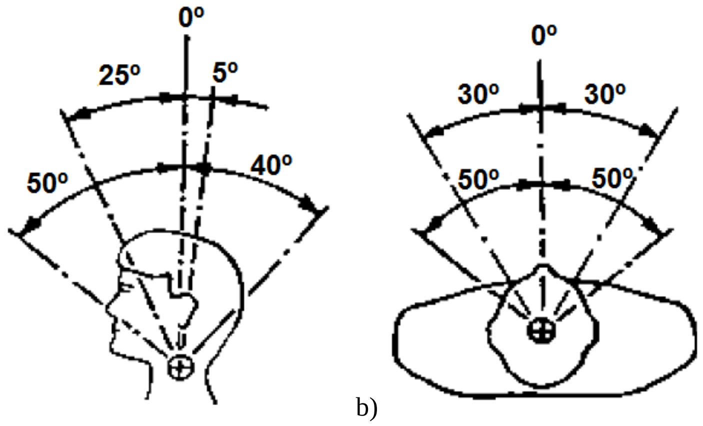
To evaluate the operators' visibility angles at the machines' workstations, images were obtained from the cameras installed in the interior spaces of the cabin, acquiring the horizontal and vertical movements of the head during the working day, and then comparing the data with the method proposed by *Skogforsk* (1999). To measure the visibility angles, the images were "frozen" and inserted into the Autodesk® AutoCAD® 2016 educational *software*, with the angles measured directly by the programming tool, as shown in Figure 1.



a) b)

Figure 1. Determination of visibility angles. Note the frontal (a) and lateral (b) angulation of the head.
Figura 1. Determinação dos ângulos de visibilidade. Observar a angulação frontal (a) e lateral (b) da cabeça.

The average angles in the sagittal and superior planes of the typical postures identified during the effective time of the operational cycles were calculated, with the ideal and maximum angles of the head and neck movements during the performance of the work having been evaluated according to Figure 2.



a) b)

Figure 2. Ideal and maximum limits for head and neck angulation to assess visibility angles. Note the head flexion forward and backward (a) and left and right (b) (SKOGFORSK, 1999).
Figura 2. Limites ideais e máximos para angulação de cabeça e pescoço para avaliação dos ângulos de visibilidade. Observar a flexão da cabeça para frente e para trás (a) e para a esquerda e a direita (b) (SKOGFORSK, 1999)

To identify the typical postures, a study of times and movements was carried out using the multimoment method, in which five-second intervals were defined and, based on the adopted posture frequency, it was possible to define such postures. Two hours of operation were evaluated (from 9:00 am to 11:00 am), where 1,440 postural records were recorded, being extrapolated to the 8-hour working day.

Then, the images collected at the workstation of both machines were analyzed in the laboratory. Typical postures were then evaluated using the RULA method. Scores were obtained for each body segment of operators' groups A (arms, forearms, wrists and wrist rotation) and B (neck, trunk and legs), shown in Figure 3.

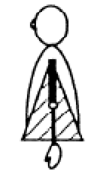
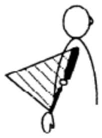
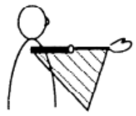
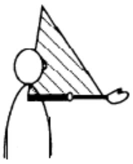
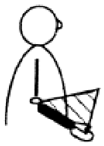
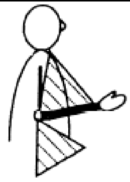
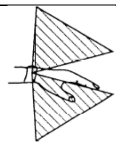
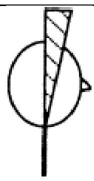
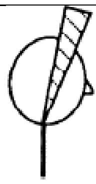
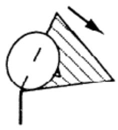
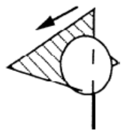
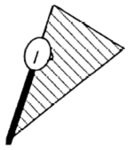
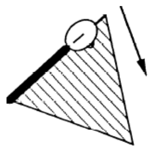
Scores	1	2	3	4	Adjustments
Group A					
Arms	 20° extension to 20° flexion	 > 20° extension  20 to 45° flexion	 > 45 to 90° flexion	 ≥ 90° flexion	+ 1 raised shoulder + 1 arm abducted - 1 arm supported
Forearms	 60 to 100° flexion	 < 60° flexion or > 100° flexion			+ 1 forearm crosses the sagittal plane + 1 forearm rotated externally to trunk
Fists	 0° neutral or half-tilt pronation or supination	 15° flexion to 15° extension or full pronation or supination	 ≥ 15° flexion or extension		+1 ulnar or radial deviation
Group B					
Neck	 0° to 10° flexion	 10 to 20° flexion	 > 20° flexion	 in extension	+ 1 twisted or rotated neck + 1 neck tilted sideways
Trunk	 0° or well-supported when sitting	 0 to 20° flexion	 20 to 60° flexion	 > 60° flexion	+ 1 twisted or rotated log + 1 log leaning sideways
Legs	pernas e pés bem apoiados e equilibrados	pernas e pés não estão corretamente apoiados e equilibrados			

Figure 3. Scores of body segments in the RULA method (McATAMNEY; CORLETT, 1993).
Figura 3. Escores dos segmentos corpóreos no método RULA (McATAMNEY; CORLETT, 1993).

Each evaluated factor of groups A and B received a score, the results of which were crossed, adding different scores to the use of muscles, that is, if the posture was static and maintained for a period longer than one minute; if repetitive movements were occurring for more than four minutes; or the workload itself. The final score for each typical posture adopted by the operator was compared with the action levels defined by the method, in order to adapt to the respective diagnosis:

- Score 1 or 2 (action level 1): Acceptable posture if not maintained or repeated for long periods.
- Score 3 or 4 (action level 2): Further investigation needed and possible need for changes.
- Score 5 or 6 (action level 3): Investigations and changes needed quickly.
- Score 7 or more (action level 4): Immediate investigations and changes are needed.

Sampling and statistic

Initially, a pilot study was carried out to obtain the sampling intensity, that is, the minimum number of repetitions (average of the values sampled for two hours of data collection) necessary for the evaluation of each ergonomic variable at the level of 95% probability of limit of permissible error of 10%, using the formula proposed by Barnes (1977).

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

In which: n = minimum number of repetitions (samples) required; t = value of t, for the desired level of probability and (n-1) degrees of freedom; CV = coefficient of variation, in percentage; and E = permissible error limit, in percentage.

Following a completely randomized design, two treatments were tested (*harvester* with side-mounted crane × *harvester* with front-coupled crane) with 24 replications (sample averages of 2 hours, with 6 replications for each of the 4 operators). The results were submitted to the Kolmogorov-Smirnov normality test and to the analysis of variance using the F test. Means of visibility angles were also compared by Student's t test at the 5% error probability level.

RESULTS

The average values of the front and side visibility angles of the operators in the execution of the work are present in Figure 4, and it is possible to verify that none of the values obtained exceeded the maximum limits according to the evaluation criteria.

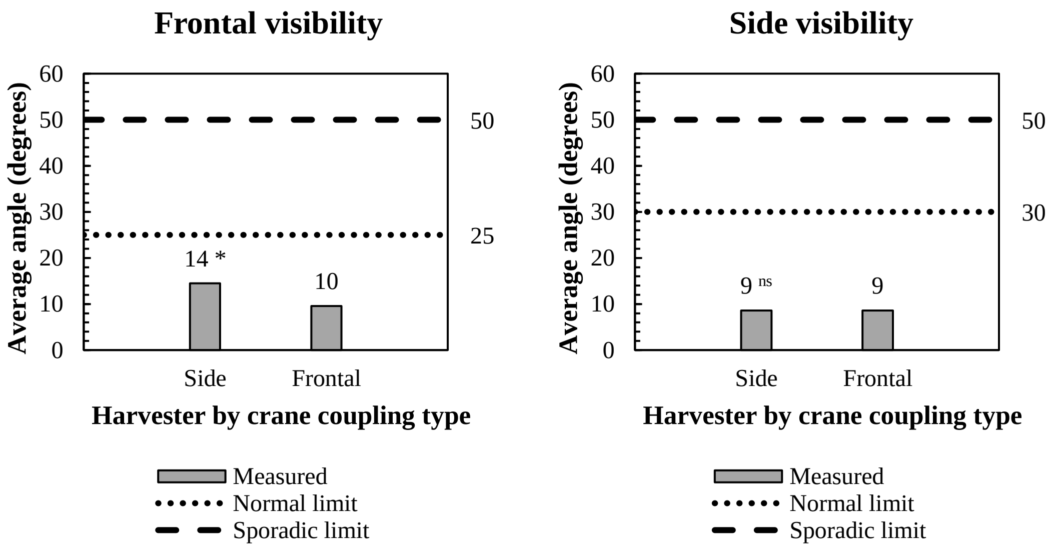


Figure 4. Average angulations in the frontal and lateral planes obtained in the assessment of visibility angles. Significant at 5%.

Figura 4. Angulações médias nos planos frontal e lateral obtidas na avaliação dos ângulos de visibilidade. Significativo a 5%.

The *harvester* with side-coupled crane required operators to have a greater mean angle of forward inclination, 15 degrees ± 4, statistically different from the *harvester* with front-coupled crane, which presented 10 degrees ± 3. In the evaluation of lateral visibility, both *harvesters* presented statistically homogeneous angulations, given that the *harvester* with the lateral coupling crane presented 9 degrees ± 4, while the *harvester* with the front coupling crane showed 10 degrees ± 3.

The postural assessments of the operators at the workstations on both machines performed by the RULA method are shown in Table 2. The score and diagnosis were similar for the same postures between the machines.

Table 2. Postural assessment of operators at harvesting machines.
Tabela 2. Avaliação postural dos operadores nas máquinas de colheita.

Machine	Typical Posture	Image	Effective time (%)	Average score ± s	Action level	Diagnosis
Harvester with side coupling crane	1		86	3 ± 0,38	2	More investigations needed and possible changes
	2		14	3 ± 0,41	2	
Harvester with front coupling crane	1		81	2 ± 0,44	1	Acceptable if not maintained or repeated for long periods
	2		9	3 ± 0,78	2	More investigations needed and possible changes
	3		10	4 ± 0,51	2	

In the *harvester* model with the lateral coupling crane, two typical postures adopted by operators with a score of 3 were identified, indicating that the adopted postures require further investigation and possible changes. In both postures, the operators remained with their arms lowered, varying from 20º of extension to 20º of flexion, and with their forearms flexed varying from 60 to 100º, being supported by the supports of the machine seats. In addition, a minimum inclination and rotation of the wrists were identified, and without the occurrence of rotation and lateral inclination of the trunk, it should be noted that the trunk, legs and feet were well supported on the seats and platform of the machine, not causing excessive effort to activate the controls and drive pedals of the machines.

Posture 1 adopted in this machine occurred in 86% of the effective working time. In posture 2, with 14% of the effective time, the neck presented a more accentuated slope. For both typical postures adopted by operators, the action level recommended by RULA was 2, with a demand for further investigation and possible changes in work from an ergonomic point of view.

In the front coupling crane *harvester*, it was possible to identify three typical postures adopted by the operators. It was identified that the operators' arms were lowered, between 20º of extension and 20º of flexion, with the forearms varying from 60 to 100º of flexion and being supported by the seat supports. It was also possible to identify the occurrence of mild inclination and rotation of the wrists. The neck inclination was between 0 and 10º, without the occurrence of rotation and lateral or frontal inclination of the trunk, with the legs and feet well supported on the floor of the machine, without excessive effort for activating the controls.

Posture 1 adopted by the operators occurred in 81% of the effective working time, generating score 2 and action level 1 by the RULA method. However, it should be noted that such a posture can be harmful to the operator if maintained or repeated for long periods. Therefore, preventive measures must be observed from the ergonomic point of view, and pre-established breaks can be introduced in order to maintain the proper posture during the journey. In this way, the operator reduces the time of adoption in the same posture, as well as the level of concentration on the task performed.

Regarding posture 2, its occurrence was verified in only 9% of the actual working time, being similar to posture 1, however, with the aggravating factor of the need for frontal neck tilt. This situation resulted in a score of 3 by the RULA method with action level 2, thus indicating the need for further investigations and possible changes in the work.

Posture 3 adopted by the operators, with the head rotated, was considered the most harmful among the postures, with a score of 4 points. Although this posture occurred in only 10% of the effective working time, it can be considered more serious in relation to the other postures due to the occurrence of rotation and lateral inclination of the neck.

DISCUSSION

Posture 1 adopted by the operators occurred in more than 80% of the effective working time on both machines, with such inclination being smaller due to the need for the operator to maintain visual contact with the machine head, which was always close to the ground level to carry out the search and felling of the tree. This posture was considered the most appropriate for workers among all those identified.

The most unfavorable postural condition for the operator was verified in the harvester with frontal coupling crane, having occurred, on average, in 10% of the effective working time. It was caused by greater rotation and lateral inclination of the neck and may be related to the need to visualize the work field, especially close to the machine head. Visual difficulties in the quality of the operation have already been observed by Nadolny et al. (2019) when measuring post-felling stump heights (stumps) in two thinning models.

Even though the machine had activated cabin rotation and leveling devices, the position of the crane in front of the machine obstructed the operators' view at certain times, especially when they needed to perform the task with greater precision, such as coupling the head to the base of the tree to be felled and the organization of piles of logs on the land. Therefore, the use of a machine with a side coupling crane would be the best alternative due to its coupling position and simultaneous rotation of the cabin and crane.

Although the front coupling crane *harvester* provided the worst postural condition for the operators among the studied machines, it provided the best visibility conditions for carrying out the operation at the level of the forest floor, possibly due to the greater height of the cabin, which provides a better view towards the workplace (SKOGFORSK, 1999). In addition, it enabled better visibility of information on the on-board computer screen, as it is located above the panel in front of the operator and below the line of sight of the operation.

Regarding the need to visualize information on the on-board computer screen, a problem found in both machines studied and observed in posture 2 was the greater occurrence of frontal neck tilt by the operators. It was identified that this posture occurred due to the need to view information on the machine's on-board computer screen. This fact may have occurred due to the distribution and size of the information on the machines' screens, which, due to the observation distance, may have required the operator to tilt his head in search of greater proximity and better observation of the screen.

In this sense, anthropometric adjustments in the seats of both machines would not allow the correction of inadequate postures when operators needed to view information on the onboard computer screen. As an alternative, one can cite changing the positioning of the onboard computer screen to a greater height in relation to the machine panel, with the possibility of lateral displacement, as long as it does not obstruct the operator's field of vision. Another alternative is the use of *Head-Up Display* (HUD) technology, which consists of a digital panel that projects information directly onto the windshield, to avoid both neck tilt and maintain the operator's view in the direction of the operation.

Among the most common ergonomic problems, the improper posture maintained by workers can be cited, which stands out and often occurs as a result of inadequate machines that do not meet the anthropometric measurements for the user population. (LIMA; OLIVEIRA, 2019). It should be noted that these machines are designed based on the population anthropometric profile of European countries, that is, the average body dimensions are considerably different from the Brazilian population.

Other suggestions for improving the postures adopted by forestry operators are: installing cameras to monitor operators during the working day, scheduling recovery breaks and labor gymnastics distributed during the working day (FIGUEIREDO *et al.*, 2017), reducing the working day and job rotation alternating other muscle groups, for example.

Even with posture and visibility conditions not having reached critical levels, observations of changes in the location of the screen or information projection system made for harvesters with lateral and frontal coupling cranes are suggested, given the need to reduce, whenever possible, postures in uncomfortable and possibly injurious angulations.

In New Zealand, professionals also reported the importance of improvements in the visibility and control of operators of forest harvesting machines, especially in steeper terrain, avoiding potential risk situations (BAYNE; PARKER, 2012). As observed both in this study and in similar research, even with the mechanization of forest harvesting operations, there are still improvements that can be implemented in terms of posture and visibility in operations, allowing for better visualization of the operation and the information generated on the computer screen onboard the machines. Furthermore, it is recommended to carry out studies that investigate the possibility of injury at different angles, the determination of time limits for permanence in different postures and also the evaluation of *harvesters* with cranes located at the rear of the machine.

CONCLUSIONS

- Both front and side visibility at the workstations of both machines did not show significant differences in terms of inclination and remained within acceptable limits. However, in frontal visibility, the average degree of slope in the *harvester* with side-coupling crane was higher than the *harvester* with front-coupling crane.
- The front crane *harvester* provided the operators with more adequate postural conditions when compared to the side crane *harvester* according to the results of the RULA method, but its workstation generated a greater number of typical postures and the indication of further investigations.
- Therefore, the lateral or frontal positioning of the crane coupling on the machine does not significantly influence the ergonomic conditions in terms of posture and visibility at *harvester* workstations. However, due to some negative indications found in this study, the reorganization of the workstation is recommended, especially the machine's display, being fundamental to providing better comfort conditions to the operators.

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