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REPETITIVE MOTION AND POSTURAL ANALYSIS OF MACHINE OPERATORS IN MECHANIZED WOOD HARVESTING OPERATIONS

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HIGHLIGHTS

Feller buncher operators have adopted only one posture during the entire working day.

Difficult visibility of the operation contributed to the adoption of improper posture at work.

Repetitive motions may contribute to the RSI/MSDs.

Ergonomic measures should be adopted to improve operators' comfort and health.

ABSTRACT

The objective of this study was to evaluate operators' posture and repetitive motions in the mechanized wood harvesting operations, aiming comfort, safety, and health of forest operators. The study was carried out in the clearcutting of pine stands located in Paraná State, Brazil. Data were obtained in tree cutting operations with feller buncher and wood processing with harvesters, in which three operators in each machine were filmed during their workday. The typical postures were evaluated by Rapid Whole-Body Assessment (REBA) and Rapid Upper-Limb Assessment (RULA) methods, while repetitive motions were evaluated by Latko, Silverstein and Strain Index (SI) methods. The results showed the feller buncher operators remained long period seated in static position, with fists turning outside the neutral line and without pauses for recovery, although REBA and RULA methods had identified low postural risk. In wood processing operation, the spinal column and neck were the most affected body parts, presenting medium postural risk and the need for investigations and quickly changes by REBA and RULA methods, respectively. Besides that, wood harvesting operations with feller buncher and harvester were classified as high repeatability, showing more than 30 thousand repetitive motions in a workday, indicating high risk of Repetitive Strain Injuries (RSIs) and Musculoskeletal Disorders (MSDs) in the operators. Therefore, it is concluded the ergonomic measures are necessary to improve operators' comfort and health.

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INTRODUCTION

The planted trees sector is of great importance to Brazilian society, being responsible for supplying raw material for a wide wood products variety, as well as contributing to job creation and environmental sustainability (IBÁ, 2017). In this context, wood harvesting and transportation are the important stages in the forest production process, which represent the major part of wood final cost, besides being activities with risks to health and safety of the workers (Machado et al., 2014).

Currently, even with the latest machine and equipment technologies applied in wood harvesting operations, the forestry sector continues to demand a large contingent of labor, with a direct dependence on the human to perform forest operations. However, despite technological advances and improvements in working conditions, ergonomic problems are still common in forest machines (Phairah et al., 2016).

Increased mechanization in forest operations has caused changes in working conditions, resulting in modification at man-machine interaction (Schettino et al., 2016). In addition, there are impacts on the management and execution of work, evidencing the need of forest workers to learn new mechanized harvester system (Bayne and Parker, 2012). Thus, the industry has been working for improving ergonomic designs of forestry machines and equipment to reduce physical effort and occupational accident (Gerasimov and Sokolov, 2009).

Operators' body posture on the workday is an important aspect to be observed for designing workstations on forestry machine (Thun et al., 2011), due to the improper posture and visibility problems or lack of training. In this context, Gerasimov and Sokolov (2009) affirm that inadequate posture influence on operators' performance, while Silva et al. (2014) report this is a cause of pain and discomfort, especially in wrists, hands, back, lower back, shoulders, and neck.

Besides the operators' improper postures, repetitive motions of the upper limbs are also common in mechanized wood harvesting, due to the joysticks used for operating machines, which can lead to Repetitive Strain Injuries (RSIs) and Musculoskeletal Disorders (MSDs) (Phairah et al., 2016). These motions can cause high demand on the wrist joints, as well as asymmetrical postures for long periods of time and a fast-paced of work environment (Silva et al., 2014). This situation also can cause pain in the shoulder and neck regions (Murphy and Oliver, 2011), MSDs, and ligament and tendon injuries, leading to possible workplace absence (Silva et al.,

2013). The objective of this study was to evaluate the body posture and repetitive motions adopted by feller buncher and harvester operators in the mechanized wood harvesting operations of pine stands, aiming to improve comfort, safety, and health of forest operators.

MATERIAL AND METHODS

This study was carried out in wood harvesting forest stands of a company located in Paraná State, Brazil, between the coordinates 24°01'57" S and 50°27'30" W, with an average altitude of 776 m. The region's climate is classified as Cfa, according to Köppen-Geiger, with annual averages of temperature equal to 19 °C and precipitation of 1,455 mm (Alvares et al., 2013). The forest stands were established by the *Pinus taeda* L. specie at 16 years-old in a spacing of 3 m x 2 m and under clear management regime, with average values of tree volume equal to 0.5 m³, annual volume increase of 27.3 m³.ha⁻¹.year⁻¹, and volume production of 44.84 m³.ha⁻¹. The stands were managed to produce medium density fiber board panel wood (MDF), particle board (PBO), laminate floors, and commercial logs.

The full tree wood harvesting method was used by the forestry company in a system with feller buncher, skidder, and processor harvester. A feller buncher performed the felling and formation of bunches of trees, in which this bunches were skidded to the roadside by a skidder, where a harvester cut the trees into logs of different assortments (on-site processing), as demanded by the consumer market.

Body postures and repetitive motions adopted by the feller buncher and harvester operators was evaluated, due to the high number of short-duration operational cycles performed for felling and on-site processing operations, respectively (Figure 1).

Feller buncher had 1.70 m of free height and 0.9 m of width, 300 hp (224 kW) rated power engine, 35.6 t weight (without head), cutting head of 2.69 t operating weight, maximum cutting diameter of 0.585 m, and tracks with leveling and dimensions of 0.61 m wide by 4.75 m long. Harvester had 1.75 m of free height and 0.93 m of width, 64 hp (122 kW) powered engine, 27.9 t weight (without a head), processing head of 1.8 t, maximum cutting diameter of 0.55 m and four decking knives, track 0.70 m wide by 4.45 m long, and 1.92 m between wheel sets.

The studied population was composed by three male operators for each machine, in which all of them were right handed (Table 1). In this aspect, the study was approved by the Research Ethics Committee (COMEP),



FIGURE 1 Feller buncher (a) and harvester (b) evaluated in a clearcutting operation of pine stand.

TABLE 1 Descriptive statistics of the data groups.

Variables	Feller buncher	Harvester
Age (years)	47.3 ± 10	42.0 ± 8.0
Height (m)	1.75 ± 0.07	1.72 ± 0.08
Body mass (kg)	90.1 ± 9.9	84.0 ± 7.0
Experience time as machine operator (years)	20.3 ± 5.2	8 ± 1.4
Experience time in a current machine (years)	7.3 ± 3.1	3.3 ± 1.2

wherein the operators received an information about the research and use of images and data, in compliance with the Resolution No. 466/2012 CNS/MS of the National Commission of Ethics in Research (CONEP) of the Brazilian Ministry of Health (Brazil, 2012).

We filmed the entire operators' workday to identify the typical postures and repetitive motions adopted by them at their machines' workstations. Two cameras equipped with a recording unit with four channels were installed inside the machine cabin. The first one was fixed facing inside the cabin to capture typical operators' postures, in which the second camera was installed facing outside to film the actual operations, aiming to identify the effective time in each typical posture of the operators.

Simultaneously, a time-motion study was carried out to determine the effective times of work cycle elements: Search and Cut (SC) and Motion and Bunching (MB) for the feller buncher; and Search (SE)

and Processing (PR) for the harvester. By means of the film data, typical postures adopted by the operators were identified at each operational cycle element and analyzed through Rapid Upper-Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) methods.

RULA method (McAtamney et al., 1993) evaluates muscular works of upper limbs in a static way through an identification of angles in different body limbs, including repetitiveness and load handling analyzes. Thus, scores for each body segment of group A (arms, forearms, wrists, and wrist rotation) and group B (neck, trunk, and legs) were obtained using specific tables, in which scores for the use of musculature and manipulated loads were added. For this, a final score was obtained to identify the action levels and verify the required intervention for each typical posture.

REBA method (Hignett and McAtamney, 2000) is a semiquantitative body evaluation that considers the static muscles, movement angulations, load handling, work repetitiveness, and handle quality. Posture scores were obtained with angulation specific tables to body group segments: A (trunk, neck, and legs) and B (arms, forearms, and wrists). The obtained scores increased with load handling, handle quality, and activity conditions (repetitiveness and maintenance of static postures) for composing the final score and action levels to verify the interventions needed for each posture. The possible final scores of REBA and RULA methods and respective results are shown in Table 2.

Repetitive motions performed by operators in each operational cycle element was quantified and converted to minute and work shift, assuming an average operating efficiency equal to 80%. In addition, Latko's scale, Silverstein's criterion, and Strain index (SI) methods were used to analyze RSI/WMSDs risks in upper limbs.

TABLE 2 Possible postural results by REBA and RULA methods.

Score	Action level	Risk	Action (providence)
REBA (Rapid Entire Body Assessment)			
1	0	Insignificant	Acceptable posture; actions are not required
2 or 3	1	Low	Actions may be required
4 to 7	2	Medium	Actions are required
8 to 10	3	High	Actions are quickly required
11 to 15	4	Very high	Actions are immediately required
RULA (Rapid Upper-Limb Assessment)			
1 or 2	1	*	Acceptable posture if not maintained or repeated for long period.
3 or 4	2	*	Investigations and possible work changes are required.
5 or 6	3	*	Investigations are required, as well as possible quickly work changes.
7 or more	4	*	Investigations are required, as well as possible immediately work changes.

Latko's scale (Latko et al., 1997) was applied to evaluate the repetitiveness level of activities based on the manual labor observation. This scale is numbered from 0 to 10 and contemplates movement dynamics and pause times in three hands activity levels: low - between 0 (hands stopped/inert most of time, without regular effort) and 1 (consistent, long visible pauses, very slow movements); medium - between 4 (constant slow motion, frequent small pauses) and 6 (constant movement/effort, non-frequent pauses); and high - between 8 (constant rapid movement or continuous exertion, non-frequent pauses) and 10 (constant rapid movement or continuous exertion, difficulty in maintaining/conserving).

Silverstein's criterion (Silverstein et al., 1987) considered the repeatability occurrence when identical movements were performed two to four times per minute, or when the operating cycle elements were performed in a time lower than thirty seconds. In addition, this criterion considers the activity can be highly repetitive when the same work element is greater than 50% of the operating cycle.




SI (Moore and Garg, 1995) is a semiquantitative method to evaluate the workstation and used to identify the RSI/WMSDs risks in distal upper limbs (hands), in which the SI is determined by multiplying the values obtained by the analyzes of intensity, duration and frequency of effort, hand and wrist posture, and rhythm and duration of work. SI value less than 3 indicates the work is safe, with probable absence of WMSDs risks; between 3 and 5 means an uncertain, with eventually recoverable WMSDs risks; between 5 and 7 shows some risk, in which the activity is associated with WMSDs; and above 7 indicates high WMSDs risk.

RESULTS

In the analysis of operators' body postures at their workstations, 20 operating cycles wererandomly selected for each machine, with average duration equal to 21 and 36 seconds, respectively. Only a typical posture adopted by tree cutting operators with feller buncher and two in wood processing with harvester were obtained, whose results of the postural evaluations by REBA and RULA methods are shown in Table 3.

In the operation with feller buncher, the partial elements of Search and Cut (SC) and Motion and Munching (MB) showed the same typical posture, covering 100% of the effective time of the operation. Although there were none unfavorable angulations in the typical posture, two critical points were observed: repetitiveness and wrist rotation that deviated from

TABLE 3 Postural evaluation by REBA and RULA methods in a clearcutting operation of pine stand.

Typical posture	Percentage of time in the posture	Assessment method	
		REBA	RULA
Cutting with feller buncher			
 SC/MB	100	S = 3 A = 1 R = low D = there may be a need for action	S = 3 A = 2 D = further investigation and possible changes needed.
		Processing with harvester	
 SE1/PR1	79	R = medium D = there is a need for action.	S = 4 A = 2 D = further investigation and possible changes needed.
		 SE2/PR2	21

the neutral position. This situation occurred due to the many repetitive hand movements by the operators for performing the harvesting operations.

Therefore, due to excessive use of musculoskeletal system and the lack of time for recovery for the upper limbs, fatigue and pain may be occur in the future, contributing for arising RSIs/MSDs in the operators. RULA method indicated the need for further investigations in the work, with possible changes in operational procedures, while REBA method showed a low risk to operators' health, but a possibility for adopting ergonomic actions, such as the introduction of pauses/breaks for recovery interspaced throughout the workday.

In the operation with harvester, the worst typical postures were Search 2 (SE2) and Processing 2 (PR2) obtained in the wood processing. Both postures presented problems due to trunk and neck flexions between 20° and 60°, and 10° and 20°, respectively, with further lateral bending for such limbs, besides the maintenance of these improper postures in 21% of the effective working time. In addition, Then, typical postures Search 1 (SE1) and Processing 1 (PR1) presented unfavorable characteristics in relationship of wrists' rotation, with the operator in a same posture for 79% of the effective working time and performing repetitive motions.

By means of the RULA analysis, we verified the need for further investigations in the work execution and the need for changes in the typical postures SE1 and PR1 adopted by the operators in medium and long terms. The typical postures SE2 and PR2 will require further investigations and changes in a short period, demonstrated by the frontal and lateral inclination of trunk and neck by the operators. In the REBA method, all the typical postures were classified in a same level of action, with a medium risk to operators' health and the need for medium and long-term ergonomic actions, such as the introduction of pauses/breaks and stretching sessions to instruct the operators about the adoption of correct postures.

Repetitive motions analysis was performed from 10 operating work cycles for each machine, with average duration equal to 22 and 37 seconds, respectively. These results are shown in Figure 2, considering an average efficiency of 80%.

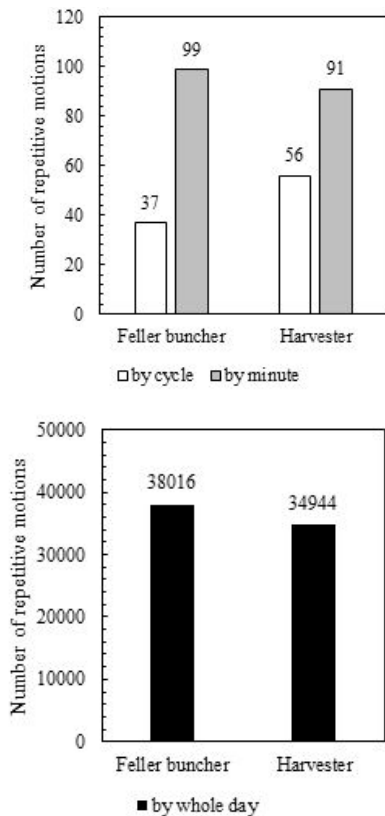


FIGURE 2 Repetitive motions for feller buncher and harvester in a clearcutting operation of pine stand.

The operators were overloaded with repetitive hand movements on the workday, due to the use of joysticks as well as the operation characteristics, which require many short-duration movements to carry out the work. The repeatability assessments performed by the three methods are shown in Table 4.

TABLE 4 Assessment of repetitive motions with feller buncher and harvester in a clearcutting operation of pine stand.

Operation	Latko et al. (1997) scale	Silverstein criterion (1985)	Strain Index method (Moore and Garg, 1995)
Cutting with feller buncher	S = 8 F = constant rapid movement or continuous effort, pauses not frequent A = high repeatability	F = average cycle time less than 30 seconds and same element covering more than 50% of the cycle A = there is repeatability	S = 20.3 F = above 7 points A = high risk of RSIs/MSDs
On-site processing with harvester	S = 8 F = constant rapid movement or continuous effort, pauses not frequent A = high repeatability	F = more than 4 repetitive motions by minute and same element covering more than 50% of the cycle A = there is repeatability	S = 20.3 F = above 7 points A = high risk of RSIs/MSDs

Latko scale indicated the occurrence of repetitiveness, due to the motions performed by the operators' hands in both machines, in which these movements were classified at the Score 8. Thus, there were fast and constant movements or continuous efforts without frequent pauses that attesting the high repetitiveness for performing the work.

Silverstein criterion showed repeatability in the operation with feller buncher, due to average cycle time lower than 30 seconds, while the harvester operators performed more than four repetitive motions per minute. Moreover, in both harvesting operations, a same element of the work cycle (SC/MB for feller buncher and SE1/PR1 for harvester) covered more than 50% of the operating cycle.

SI value equal to 20.3 points were found in both operations, which it is higher than the highest score suggested by the SI method (7 points), suggesting high risk of RSIs/MSDs. Also, the duration and frequency of the effort higher than 80% of the work cycle were the most critical situation, with more than 20 efforts by minute. In addition, the non-neutral posture of hands and wrists and the fast-paced working contributed to the obtained high score.

DISCUSSION

In the tree felling operation with feller buncher, improper posture was related to the time in which the operator stayed in a same condition (100% of the effective time). In the wood processing with harvester, operators' improper posture occurred mainly due to

the obstruction of their vision by the machine's crane. In addition, an incorrect procedure adopted in the harvesting operation was identified, in which the spin of the machine cabin was not completely executed for searching and processing the wood, causing the operators to flex his trunks and tilt sideways for 21% of the effective time for better vision.

Gerasimov and Sokolov (2014) reported the forest machine operators can be affected by injuries on the neck, arms, and cervical spine, due to excessive time in seated and static position, as observed with feller buncher in this study, as well as the adoption of ergonomically inappropriate postures as verified with harvester. Seated and static posture for a long period, according to Fernandes et al. (2011), causes uncomfortable muscular pains and, therefore, alternation of postures is recommended.

Paini et al. (2016), studying operators' body posture in mechanized wood loading, noted the operators stayed in a same posture for a long time, and constant trunk rotations and repetitive hand and wrist movements that made the operation unsuitable and repetitive, requiring ergonomic actions to improve working conditions. In this study, we also verified the need for posture alternation to recover muscles, avoiding fatigue and improving operators' comfort and health.

The high repetitive motions frequency observed in both machines can cause discomfort in the operators' hands and forearms. In this context, Couto et al. (2007) emphasized the tendons are not totally elastic structures, once when movements are executed, they need a time to return for the available condition for a new muscular contraction. Thus, the lack of pauses between repetitive motions can result in excessive use of the musculoskeletal system and significant risk of RSIs/MSDs.

Thereby, feller buncher and harvester operators were exposed to repetitive motions at their workstations. Regis Filho et al. (2006) affirmed the workers that perform highly repetitive and forced activities with a same movement pattern are 29 times more susceptible to develop pathologies in their hands and wrists. Silva et al. (2014), studying RSIs/MSDs in forest harvesting machine operators, concluded that 63% of operators were affected by musculoskeletal symptoms, in which the same condition work can perform different impacts on the workers. Thus, working time can be an indicative of muscle wasting and performed tasks contribute to a considerable risk of RSIs/MSDs.

Therefore, since wood harvesting operations are cyclical, reduction of repetitive motions effects on

the operator is important. As recommended ergonomic practices, we can mention the adoption of recovery pauses with stretching sessions on the workday; the implementation of an instructional program to keep operators informed of the proper posture and movements required by the harvesting operations; and the provision of guidance about RSIs/MSDs through lectures and courses to improve comfort, well-being, safety, and health of forest operators.

CONCLUSIONS

Feller buncher operators adopt only one posture in the workday, which can be harmful to their health due to the lack of body muscles relaxation, while harvester operators flex the trunk and neck to improve the visibility on the wood processing operation, maintaining the same posture for long period and contributing for an improper posture. Repetitive motions performed by feller buncher and harvester operators may contribute to Repetitive Strain Injuries (RSI) or work-related Musculoskeletal Disorders (MSDs), in which ergonomic practices can be implemented to improve operators' comfort and health.

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