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ANALYSIS OF MUSCULOSKELETAL DISCOMFORT IN SELF-PROPELLED FOREST MACHINE OPERATORS

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Resumo

Análise de desconfortos musculo-esqueléticos em operadores de máquinas florestais autopropelidas. As recentes inovações na colheita de madeira, com vistas a aprimorar as técnicas das operações florestais, permitiram aos operadores o pioneirismo no uso de novas tecnologias. Em contrapartida, observa-se o surgimento de uma nova classe de doenças ocupacionais relacionadas com os distúrbios musculo-esqueléticos que pode estar associado a esse avanço. Desta forma, foi avaliado se os operadores de máquinas florestais autopropelidas do sistema *full tree* estão suscetíveis aos desconfortos musculo-esqueléticos em níveis de intensidade prejudiciais à saúde ocupacional. Foi aplicado o Questionário Nórdico Musculo-esquelético para identificação das partes corporais com maiores relatos de desconforto e o grau de intensidade desses desconfortos indicado por operadores de *feller buncher*, *grapple skidder* e *grapple saw* em florestas plantadas de *Eucalyptus*. As regiões corporais com relatos de desconfortos foram as regiões da lombar e dos ombros, com grau de intensidade moderado. O *grapple skidder* é a máquina florestal autopropelida com maior número de operadores com desconfortos durante a função laboral.
Palavras-chave: operações florestais, colheita de madeira, saúde ocupacional.

Abstract

Recent innovations in wood harvesting, with a view to improving forest operations techniques, have allowed operators to be pioneers in the use of new technologies. On the other hand, there is the emergence of a new class of occupational diseases related to musculoskeletal disorders that may be associated with this advance. In this way, it was evaluated whether operators of self-propelled forest machines of the full tree system are susceptible to musculoskeletal discomfort at levels of intensity that are harmful to occupational health. The Nordic Musculoskeletal Questionnaire was applied to identify the body parts with the highest reports of discomfort and the degree of intensity of these discomforts indicated by feller buncher, grapple skidder and grapple saw operators in Eucalyptus planted forests. The body regions with reports of discomfort were the lower back and shoulder regions, with a moderate degree of intensity. The grapple skidder is the self-propelled forestry machine with the highest number of operators experiencing discomfort during work.
Keywords: forestry operations, wood harvesting, occupational health.

INTRODUCTION

The prevalence of musculoskeletal symptoms in operators of self-propelled forestry machines used in wood harvesting may occur predominantly in the lower back region and in the upper limbs, which may be related to the experience time of operators in jobs and harvesting activities performed, such as felling trees, extracting bundles of trees and processing of these bundles.

These activities are part of the full tree harvesting system which, when mechanized, is usually carried out through self-propelled forest machines feller-buncher, grapple skidder, and grapple saw, as described by Bilici *et al*. (2019). This system aimes the felling trees, dragging tree bundles to forest roads or intermediate yards, for subsequent wood processing. The feller-buncher, used for felling trees, is equipped with a head-type implement and may have a cutting disk, which guarantees high speed in cutting trees, cutting them as they approach the ground, accumulating a certain number of trees and depositing them on the ground, forming bundles of trees that are suitable for extraction. The felling of trees can be influenced by factors such as slope, soil type, forest type, volume per tree, wood purpose, area sensitivity, silvicultural prescription, and cutting area (ALEXANDR *et al*., 2021).

When extracting bundles of trees to the place where these bundles are processed, a self-propelled forestry machine called a grapple skidder is adopted, which corresponds to an articulated machine, with pneumatic wheels, which carries out the extraction in the form of a drag, in such a way that, during the removal of wood, the traction machine moves the bundle of trees in partial or total contact with the ground. The dragging is carried out in such a way as not to interrupt the natural drainage of the land, reduce the impacts caused by furrowing, compaction,

and water pooling, in addition to not damaging the sprouts, in the case of companies that use coppicing as a silvicultural method (MIYAJIMA *et al*., 2021). Wood processing, on the other hand, has the purpose of sectioning the logs into pre-established sizes according to the specificity of the forest boundaries, which can be carried out by the self-propelled forestry machine grapple saw, which has a cabin with 360-degree rotation, rigid treadmill and crane-type implement with a cutting bar attached (SPINELLI *et al*., 2020).

These self-propelled forestry machines ensured the evolution of forestry operations, allowing increased productivity and optimization of processes, however, they enabled the emergence of ergonomic adversities related to the interaction between human beings and the work environment (MINETTE *et al*., 2018). Thus, the appearance of musculoskeletal discomforts has been observed in the operators of these machines, probably resulting from the time of the daily working day in a sitting position, with a fixed posture and performing repetitive movements with the hands and arms (ARMAN *et al*., 2019).

Musculoskeletal discomforts can be defined as injuries and disorders that affect movement or the musculoskeletal system of the human body, usually related to work activity, therefore, according to the classification of occupational hazards, it is an agent of ergonomic risk (SUNDSTRUP *et al*., 2020). During wood harvesting, the prevalence of musculoskeletal disorders is associated with several factors, ranging from machine traffic in areas with obstacles to the adoption of inappropriate postures by operators. Identifying the origin of this agent allows identifying ergonomic adversities related to man × machine interaction and correcting them, in order to minimize the harmful impact on the occupational health of the worker (LAGERSTROM *et al*., 2019).

Understanding the causes of occupational health is the key to primary prevention. For this reason, in recent decades, there have been great efforts to explore the causes of musculoskeletal symptoms and to take measures for their prevention. Therefore, there are ergonomic techniques and tools used to quantify the levels of exposure and discomfort of operators, among which the Nordic Musculoskeletal Questionnaire (NMQ) stands out, as it is a systematic method for data acquisition to quantify musculoskeletal pain and the prevention of related activities. According to Corlett (1995), the NMQ was developed for self-completion, based on the presentation of a figure called a body map, which consists of the human body divided into 29 parts adopted to properly identify the location of the musculoskeletal symptom.

It should be noted that occupational non-compliance has negative effects, not only for operators of self-propelled forest machines, but also for companies in the forestry sector, demanding to ensure the health and safety of these operators, representing a challenge for those involved (PAINI *et al*., 2020). According to data from the Ministry of Social Security, Brazil, in 2023 alone, approximately 8,650 individuals were removed from their jobs due to occupational illnesses, with formal reports of workplace accidents (CAT). A significant portion of these cases may be associated with musculoskeletal disorders.

Thus, there is a hypothesis that the operators of forest machines used in mechanized wood harvesting may have musculoskeletal discomfort. Thus, the objective was to evaluate whether the operators who work in the mechanized harvest of Eucalyptus in the full tree system are susceptible to musculoskeletal discomfort at levels of intensity that are harmful to occupational health.

MATERIAL AND METHODS

Ethical approval

The research was submitted and approved by the Research Ethics Committee of the São Paulo State University (Unesp), School of Medicine, Botucatu, according to the Certificate of Presentation of Ethical Appreciation (CPEA) number 25739519.1.0000.5411. Thus, all operators participated voluntarily, receiving written clarifications about the methodology and research objectives by reading and signing the Free and Informed Consent Form (FICF), in compliance with Resolution No. 466/2012 CNS/MS of National Committee for Ethics in Research of the Ministry of Health.

Study area

The data were collected in a forest-based company in the southeastern region of Brazil, , which the wood produced is intended for the manufacture of sheets of the Medium Density Fiberboard (MDF) and Medium Density Particleboard (MDP) types. The climate in the region is classified, according to Köppen-Geiger, as Cfa humid subtropical climate. The region has a rainy season in summer and a dry season in winter, with an average temperature of the hottest month above 22ºC (ALVARES *et al*., 2013).

The *Eucalyptus* spp. had spacing of 3 m × 2 m, aged 19.87 years, mean diameter at breast height (DBH) of 16.90 cm, mean height of 26.2 m, individual average volume (IAV) of 0.38 m³, conducted under a high-forest regime, and with a stump height of 15 cm. The study area had a predominance of gently undulating relief, which corresponds to slopes ranging from 3.0% to 8.0%.

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Wood harvesting system

The wood harvesting system employed was the full tree, through which self-propelled forestry machines of the feller buncher type were used for felling and accumulation of trees, the grapple skidder used for dragging the extraction of tree bundles and the grapple saw was adopted for wood processing. In view of this, the feller buncher used was from the manufacturer John Deere, model 903M, with a rigid track system. The grapple skidder was made by John Deere, model 848 H, with a tire wheel system and 4×4 traction. The grapple saw was made by Caterpillar, model 336D2L, with a rigid track system, and forest implement by J. de Souza, model GL 580 r (Figure 1).

Ten operators of self-propelled forest machines that work in the mechanized harvesting of wood in the full tree system were considered, three of which were feller buncher operators, four worked in the operation of the grapple skidder and three performed the operation of the grapple saw.

Figura 1. (A) *Feller buncher*, fabricante *John Deere*, modelo 903M; (B) *Grapple skidder*, fabricante *John Deere*, modelo 848H; (C) *Grapple saw*, fabricante *Caterpillar*, modelo 336D2L.

Figure 1. (A) Feller buncher, produced by John Deere, model 903M; (B) Grapple skidder, produced by John Deere, model 848H; (C) Grapple saw, produced by Caterpillar, model 336D2L.

Analysis of musculoskeletal discomforts

The analysis of musculoskeletal discomfort was measured using the Nordic Musculoskeletal Questionnaire (NMQ), developed by Corlett (1995), which presents a diagram of the body map segmented into 29 parts (Figure 2). In this way, the operator indicated, through an individual interview, the places on the body that feel the greatest discomfort during the execution of the work activity, and for each body part a level of intensity was assigned, which could be absent, small, moderate, severe or unbearable.

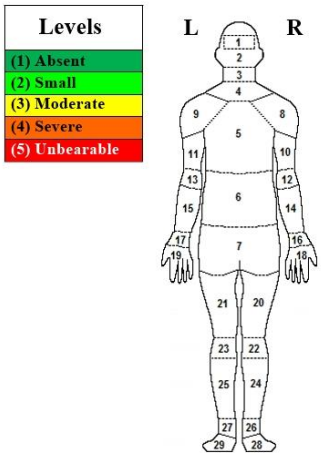

Figure 2. Body map segmented into 29 parts of the Nordic Musculoskeletal Questionnaire (NMQ).

Figura 2. Mapa corporal segmentado em 29 regiões do Questionário Nórdico Musculo-esquelético (QNM).

Statistical analysis of the Nordic Musculoskeletal Questionnaire

Descriptive statistics analysis of the data was performed using mean, standard deviation, coefficient of variation and percentage of the degree of pain intensity of the regions identified in the NMQ, as proposed by Memon (2022). Pearson's correlation coefficient was determined to compare the interaction between the variables of age, height, body mass and time of experience of the operators with the degree of pain intensity of the regions identified in the NMQ.

Following the recommendations of Saraswat (2021), in the analysis of inferential statistics, it was tested whether the type of machine, age, height, body mass and time of experience of the operators interfere with the

degree of pain intensity and the regions identified in the NMQ. Thus, a randomized block design was used, since the control of the blocks was the type of self-propelled forestry machine, and the treatments correspond to the variables of age, height, weight and time of experience of the operators.

Furthermore, the Kruskal Wallis test was adopted to verify the existence of statistical difference between the blocks and treatments in the degree of pain intensity and regions identified in the NMQ. Dunn's test was used to identify which blocks and treatments differed from each other. The tests were performed with a significance level of 5.00% with the R Studio software, version 4.2.1 through the "dunn.test" package.

RESULTS

The analyzed operators were male, aged between 26 and 47 years, body height ranging from 1.61 to 1.76 m, body mass between 58 and 95 kg and average time of experience in the function from 1.25 to 10 years (Table 1).

Table 1. Characteristics of operators of self-propelled forestry machines used in the mechanized harvesting of Eucalyptus in the full tree system.
Tabela 1. Características dos operadores das máquinas florestais autopropelidas empregadas na colheita mecanizada de *Eucalyptus* no sistema *full tree*.

Operators	Machines	Age (years)	Height (m)	Weight (kg)	BMI	Experience time (years)
1	Feller buncher	31	1.76	58	18.72	9
2	Feller buncher	30	1.7	75	25.95	8
3	Feller buncher	31	1.71	85	29.07	7
4	Grapple saw	26	1.75	95	31.02	8
5	Grapple saw	46	1.72	72	24.34	8
6	Grapple saw	32	1.69	77	26.96	9
7	Grapple skidder	47	1.61	90	34.72	9
8	Grapple skidder	31	1.73	68	22.72	1.25
9	Grapple skidder	30	1.75	85	27.76	10
10	Grapple skidder	35	1.72	78	26.37	7.25

Caption: BMI is the body mass index.

Regarding the level of pain intensity in the regions identified in the NMQ, among the evaluated operators, there was no result of severe or unbearable discomfort intensity level (Table 2). In most regions identified in the NMQ, the intensity level was classified as absent. The lower back region and the right and left shoulders were the ones that indicated the highest levels of pain intensity on the part of the operators of the self-propelled forest machines used in the mechanized harvesting of wood.

Table 2. Classification of the degree of pain intensity of the regions identified in the Nordic Musculoskeletal Questionnaire of operators in the mechanized harvest of Eucalyptus in the full tree system.
Tabela 2. Classificação do grau de intensidade de dor das regiões identificadas no Questionário Nórdico Musculo-esquelético dos operadores na colheita mecanizada de *Eucalyptus* no sistema *full tree*.

Region of discomfort	**Percentage of operators who indicated a level of discomfort (%)**				
	Absent	**Small**	**Moderate**	**Severe**	**Unbearable**
Low back	50	30	20	-	-
Hip	90	10	-	-	-
Right shoulder	60	10	30	-	-
Left shoulder	60	10	30	-	-
Right knee	90	-	10	-	-
Left knee	90	-	10	-	-

Pearson's coefficient identified a positive correlation between the operators' age and the degree of discomfort in the lower back and hips (Figure 3). The height of the operators showed a negative correlation with the level of discomfort in the lumbar region and a positive correlation with the level of discomfort in the shoulders. The experience time of the operators showed a negative correlation with the knees.

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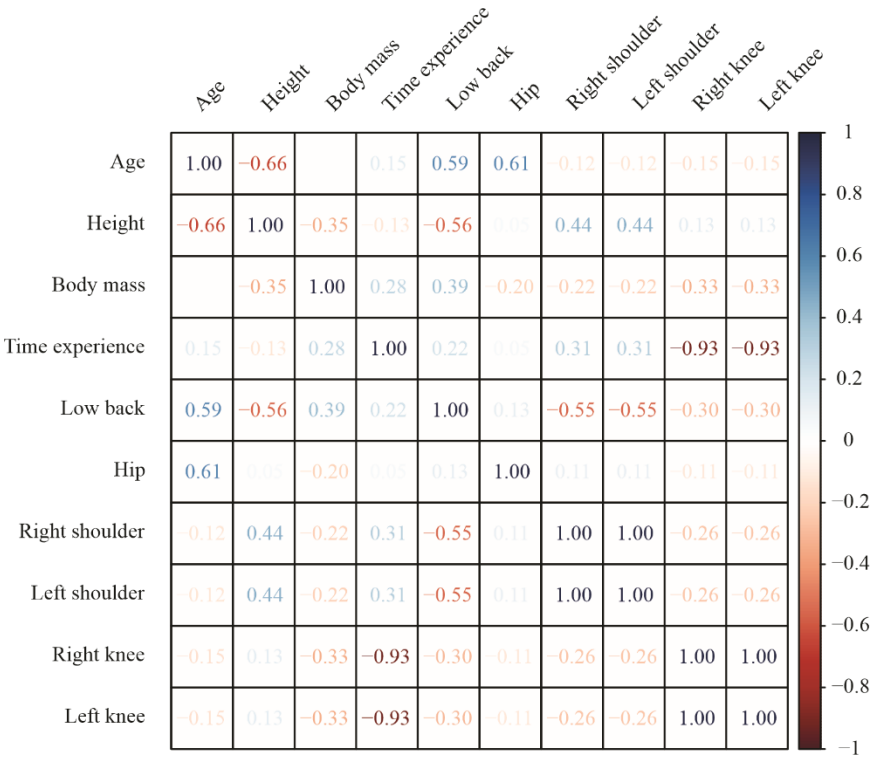

Figure 3. Pearson's correlation matrix of the treatments in relation to the regions identified in the Nordic Musculoskeletal Questionnaire (NMQ) of the operators in the mechanized harvest of Eucalyptus in the full tree system. All correlations were significant.

Figura 3. Matriz de correlação de *Pearson* dos tratamentos em relação às regiões identificadas no Questionário Nórdico Musculo-esquelético dos operadores na colheita mecanizada de *Eucalyptus* no sistema *full tree*. Todas as correlações foram significativas.

The treatments age, height, body mass and time of experience of the operators did not show statistically significant difference in relation to the level of pain intensity of the regions identified in the NMQ. The type of self-propelled forest machine used in mechanized wood harvesting indicated a statistically significant difference in relation to the level of pain intensity in the regions identified in the NMQ. The grapple saw was the one that demonstrated the lowest level of pain intensity in the regions identified by the operators. The grapple skidder operators were the ones who registered the most pain intensity levels in the regions identified in the NMQ (Table 3).

Table 3. Inferential analysis of the classification of the degree of pain intensity of the regions identified in the Nordic Musculoskeletal Questionnaire in relation to the type of self-propelled forest machine used in mechanized harvesting of Eucalyptus in the full tree system.

Tabela 3. Análise inferencial da classificação do grau de intensidade de dor das regiões identificadas no Questionário Nórdico Musculo-esquelético em relação ao tipo de máquina florestal autopropelida empregadas na colheita mecanizada de *Eucalyptus* no sistema *full tree*.

Region of discomfort	**Chi-squared**	**p-value**	**Mean**		
			Feller buncher	***Grapple skidder***	***Grapple saw***
Low back	15.46	0.0004*	1.00 b	2.00 ab	2.00 a
Hip	10.11	0.0063*	1.00 b	1.00 ab	1.33 a
Right shoulder	7.41	0.0245*	2.33 b	1.50 ab	1.33 a
Left shoulder	7.41	0.0245*	2.33 b	1.50 ab	1.33 a
Right knee	6.50	0.0387*	1.00 a	1.50 b	1.00 a
Left knee	6.50	0.0387*	1.00 a	1.50 b	1.00 a

Caption: Means followed by the same letter, within the same line, do not differ statistically at the 5.0% probability level using the Kruskal Wallis test; * Significant at 5.0% probability.

DISCUSSION

When analyzing the profile of self-propelled forest machine operators used in the mechanized harvesting of Eucalyptus in the full tree system, the average age of the operators corresponded to 34 years with an average experience time of 8 years. According to Lagerstrom *et al*. (2019), as the age range of workers increases, there is a proportional predisposition to the emergence of musculoskeletal discomforts that, associated with the time of experience in the work function, are cumulative over time.

The posture adopted by self-propelled forest machine operators was another factor that influenced musculoskeletal discomfort. Due to the effort, especially in the lower back, shoulders and knees, they caused increased pressure on the joints and, therefore, increased tension in the muscles and tendons around the joint. Schettino *et al*. (2022) consider the human × machine interaction resulting from the association between the layout of the machine cabin and the anthropometric profile of the operators, as the main cause for ergonomic problems.

The body regions with the highest reports of musculoskeletal discomfort during the performance of the work activity were the lower back and shoulder regions, respectively. The intensity level classified as absent was found for all body parts, with the exception of the lower back region, shoulders, hips and knees. Thus, the small intensity was predominant in discomforts in the lower back, hips and shoulders, while the moderate intensity could be observed in the lowerer back, shoulders and knees. It is noteworthy that there were no reports of discomfort in body parts with a severe and unbearable level of intensity, so that Wang *et al*. (2022) state that the lack of reports of pain at maximum intensities may characterize satisfactory ergonomic conditions in the work environment.

As a result of performing the work activity in a sitting position and the repetitiveness required to perform the function, the occupational health of the operators can be negatively affected, causing pain mainly in the lower back and shoulder region (PAINI *et al.*, 2019). Thus, prolonged exposure of self-propelled forest machine operators to musculoskeletal discomfort related to the lower back, with intensities ranging from moderate to unbearable, can progress to occupational diseases, such as low back pain, kyphosis, sciatica, herniated disc, etc. (ULMAR *et al*., 2019).

In addition, the shoulder region, when affected by occupational activity, can result in adversities, which can progress to arthrosis, SLAP injury, impingement syndrome, and others. Thus, there is a need to intensify prevention strategies for occupational health problems, considering the practice of labor gymnastics as an effective therapy in reducing stress and reducing the intensity of discomfort caused by pain (PAINI *et al*., 2020; SORANSO *et al*., 2022).

The influence of the variables age, height, body mass and time of experience of the operators in the level of pain intensity of the regions identified in the NMQ can be confirmed through the significant correlation between the variables, as evidenced by the studies by Magnifica *et al*. (2021) e Okur *et al*. (2021). As the self-propelled forest machine cabins were designed based on average anthropometric values of the population, operators with body measurements above or below the average may have difficulty adapting, manifesting discomfort when performing work activities. Empirical knowledge arising from the experience and observation of more experienced operators may be associated with greater postural caution in the performance of work functions, justifying the negative correlation between the operators' experience time and the degree of pain intensity.

The grapple skidder, among the evaluated self-propelled forestry machines, was the one that showed the greatest indications of musculoskeletal discomfort on the part of the operators. In full tree mechanized wood harvesting systems, it is usual to use the grapple skidder to carry out the activity of extracting bundles of trees. Thus, the extraction takes place in the form of dragging, in which, during the removal of the wood, the traction machine moves the logs in partial or total contact with the ground, demanding excessive torque from the engine to perform the activity (MIYAJIMA *et al*., 2021;.SPINELLI *et al*., 2021).

The high torque of the grapple skidder motor, associated with traffic inside the forest stand over obstacles such as slopes, residues and stumps, can cause vibrations and jolts inside the cabin of the self-propelled forest machine. Thus, operators are susceptible to occupational hazards that can aggravate the effects of musculoskeletal discomfort and result in occupational diseases (SCHETTINO *et al*., 2021).

Research on musculoskeletal discomfort in timber harvesting is of critical importance, particularly in regions of Brazil where the availability of skilled labor is limited. This scarcity poses challenges for ensuring worker health and operational efficiency, making the investigation of ergonomic factors and workplace conditions

essential. Despite its significance, studies addressing this topic remain scarce, highlighting a critical gap in the understanding of how working environments can be optimized to minimize the risk of injuries and enhance worker well-being.

The results of this research corroborate those reported by Paini *et al.* (2020), who point out that forestry machine operators often face prolonged static postures, exposure to vibrations and repetitive efforts, factors that contribute to the development of musculoskeletal disorders. These problems impact not only the health of workers, but also the productivity of companies due to absenteeism, staff turnover and costs with treatments and compensation.

CONCLUSIONS

- The analyzes carried out allow us to conclude that the operators of self-propelled forest machines used in the mechanized harvest of Eucalyptus in the full tree system present discomfort with a moderate level of intensity for the low back region, shoulders and knees. The grapple skidder is the one that presents the greatest indications of musculoskeletal discomfort on the part of the operators.
- Based on this information, forestry companies can leverage it as a valuable decision-making tool to mitigate musculoskeletal discomfort among machine operators. One effective strategy is ensuring the proper adjustment of the seat relative to the distance from the pedals, which can significantly reduce strain and discomfort in the operators' knees. Additionally, the inclusion of armrests on machine seats plays a crucial role in minimizing physical exertion during operations, thereby alleviating strain and discomfort in the shoulders.
- Therefore, a greater investment is required in the development and implementation of advanced technologies for manufacturing machine cabins used in wood harvesting. These advancements should prioritize the safety and ergonomic well-being of operators, ensuring that work environments are both secure and comfortable. Moreover, promoting awareness about the proper adjustment of equipment, maintaining correct posture, and incorporating workplace exercise routines can serve as practical measures to prevent musculoskeletal discomfort. Such initiatives not only safeguard the health of operators but also enhance their performance and long-term productivity, ultimately benefiting both workers and forestry companies.

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