Work 41 (2012) 4957-4962
DOI 10.3233/WOR-2012-0038-4957
IOS Press

Ergonomic factors and production target evaluation in eucalyptus timber harvesting operations in mountainous terrains

Amaury Paulo de Souza[1], Luciano José Minette, André Luis Petean Sanches, Emília Pio da Silva, D.S, Forest Science; Valéria Antônia Justino Rodrigues, Luciana Aparecida de Oliveira
Ergonomic Laboratory – Forest Engineering Department, Federal University of Viçosa, 36570-000 - Viçosa, Minas Gerais, Brazil

Abstract. There are several forest operations involved in Eucalyptus timber harvesting. This study was carried out during brush-cutting; tree felling, bucking, delimbing, piling and manual extraction operations, with the following objectives: a) analyzing, ergonomically, two systems of brush-cutting: one manual and the other semi-mechanized, using two different machines; b) ergonomically evaluating three different brands of pruner machines used in delimbing felled trees. c) determining the feasible target of productivity as a function of ergonomic factors relevant to establish the time of resting pauses for workers in manual and semi-mechanized timber harvesting systems in mountainous terrain. Brush-cutting, either manual or semi-mechanized, is an activity carried out prior to timber harvesting. It is usually a hard work, with low productivity when compared with mechanized systems. Pruner machines have been used by forest companies, due to the great possibilities to improve productivity, quality and the health of workers. Ergonomics is a discipline that promotes the adequacy of work to the physical and mental characteristics of human beings, seeking to design production systems and products considering relevant aspects, including social, organizational and environmental factors. Companies should consider the ergonomic factor in the determination of daily worker production targets.

Keywords: Productivity, forest workers; work performance

1. Introduction

1.1 Brush cutting problems

Several machines, implements and tools can be used in timber harvesting to help workers in their job. Sickle is a tool used in manual brush-cutting operations in mountainous terrains. Due to relative lower price of motorized brush-cutters and tree pruners, there has been greater use of these machines to increase productivity and well-being of workers in operations for cleaning Eucalyptus stands.

Some brush-cutters and tree pruners available in the market have design deficiencies, including excessive vibration and noise, which can damage the health and safety of workers [6].

1.2. Tree delibing problems

Tree pruner machines have been used by forest companies to delimb felled trees, instead of the manual method, with the use of small axes.

The tree pruner is a machine similar to the chainsaw with respect to its engine. However, its cutting component is different, which is fixed on the tip of a telescopic rod with length ranging from 2 to 5 m.

Some pruners available on the market have design deficiencies, including excessive vibration and noise, which can damage the health and safety of workers.

1.3.Ergonomic problems

[1] Corresponding authors. Emails: maury@ufv.br, minette@ufv.br, florestandre@yahoo.com.br, valeriaufv2001@yahoo.com.br, luolijsc@yahoo.com.br.

According to Saliba [11], vibration is an oscillatory motion of a body due to unbalanced forces in rotating components and alternating movements of a machine or equipment. If a body vibrates, it describes an oscillatory and periodic motion involving displacement over the time. Thus, speed, acceleration and frequency are involved in the displacement.

According to the ISO 5349 [9] standards, exposure to vibration in the hand-arm area mainly affects the vascular, neurological, osteoarticular and muscular systems. Iida [8] also states that forestry workers who used chainsaws presented gradual degeneration of the nervous and vascular tissue, which caused loss in manipulative ability and finger tact, impairing motor control.

Noise can be considered an unwanted sound or even an auditory stimulus that does not contain useful information for the task running [8].

Many studies have demonstrated that noise has serious effects (psychological and physiological) on humans, such as loss of concentration, difficulties to speak, loss of reflexes, reduced speech intelligibility, irritation, permanent hearing loss to permanent deafness, among others [10].

Heavy load lifting is still observed in day-to-day forestry work and may cause physical overload problems [2] in workers. Under such conditions, workers may feel fatigued and may complain about cramps, muscle aches, tremors and sleep disturbances [5].

Biomechanics studies the interactions between work and humans, related to the musculoskeletal movements involved and their consequences. It mainly examines the issue of body postures at work and the application of forces involved. In forestry, there is still the percentage of work performed while workers are in awkward postures, mainly related to manual handling, which greatly increases the risk of injuries and strains on muscles and joints.

1.4.Production target problems

One of the main goals of ergonomics is to preserve the physical and mental capacity of human beings, mainly by presenting and proposing solutions for better working conditions. Ergonomics is a discipline that promotes the adequacy of workplace to the physical and mental characteristics of human beings, seeking the design of production systems and products considering social, organizational and environmental factors [4,7,12,16,17].

Worker productivity has historically been evaluated based on studies on time, operation variables and production [13,14]. However, the setting of targets for sustainable and more productive operations must also consider human factors and those that affect their physical and mental limitations.

The workload is a quantitative or qualitative (mental, sensory-motor, and physiological) measure of operators' requirements to perform a given job. Thus, the adjustment of workload to ergonomic factors and the individual characteristics of workers is the main contribution of ergonomics to promote improvements in working conditions and to assist in the establishment of productivity targets of workers with low damage risk to their health

The objectives of this study were the following: a) analyzing, ergonomically, two systems of brush-cutting: one manual and the other semi-mechanized, using two different machines; b) ergonomically evaluating three different brands of pruner machines used in delimbing felled trees. c) determining the feasible productivity target, considering the relevant ergonomic factors to establish the time for the periods of rest for workers in manual and semi-mechanized timber harvesting systems, in mountainous terrain.

2. Method

The data were collected from machines and operators working in a mountainous area of a pulp and paper company located in the East of Minas Gerais State. The appropriate methods of ergonomics and statistical analyses were used to collect and analyze the data. All data were collected by using the Ergonomics Laboratory measuring instruments required by the methodology.

2.1. Brush cutting and delimbing methods

The ergonomic work analysis methodology was used to collect data from manual and semi-mechanized operations.

The brush cutting working team consisted of two operators and a helper for moving branches. The tool used in the manual operation was a steel sickle with 37 cm in length and a 140-cm long wood handle. The brush cutting machines were of two brands, "A", model KA 85R and "B", model FS 280.

The tree delimbing work team also consisted of two operators and a helper for moving branches away from the trees. The analyses were performed with three different pruners: brand "A", model PT 2500

Start 42; model "B", 325 P5; and brand "C", model KA 85R – HT.

The following methodologies were used to collect ergonomic factor data:

Vibration: the evaluation of the vibration of the machines was carried out according to the technical criteria adopted by ISO 5349-1:2001, ACGIH and European Directive 2002/44/EC.

Heat stress: The heat from the workplace environment was evaluated according to the Brazilian Norm N5-15, Annex 3- Tolerance limits for heat exposure [3].

Noise: assessment of the occupational noise from the machines was based on the criteria established by the Brazilian Norm NR 15, Annex 1[3].

Physical Workload: The assessment of physical workload was carried out according to the methodology proposed by Apud [2].

Biomechanics: The 3D SSPP 6.0.5 software developed by the University of Michigan [15] was used in the analysis.

2.2. Production target methods

Evaluations were carried out for timber extraction with TMO (agricultural tractor equipped with a winch named TMO). In this operation, the heaviest work cycle elements were manual log piling and manual downhill cable pulling, which was done by a crew member called TMO helper. The element was named TMO pulling cable. The following operations were also investigated: felling and bucking with chainsaw; delimbing and topping with a small axe; manual brush cutting with a sickle; and timber extraction by downhill manual log throwing. These operations were selected because they were the hardest work in mountainous terrain timber harvesting. The study areas were representative within the company in terms of vegetation, terrain slope and general topography.

2.2.1. Determining the working pauses

The time consumed with existing working pauses, effective work and low ergonomic risk activity were determined by means of work studies.

The ergonomic analysis was carried out to determine de amount of pauses needed for each factor that affects the mental and physical capacity of workers. The work can be reorganized do meet the ergonomic principles by quantifying the necessary pauses. The effective time for eight hours of work can be used to establish the production target.

2.2.2. Effective working time

The amount of time spent on the planned activity was determined by Eq. (1).

$$\mathbf{TET = DJ - TPE} \qquad \textbf{Eq. (1)}$$

TET = Effective working time (min)
DJ = Turn time (min.)
TPE = TPA + TPB
TPE = Time of the existing pauses (min.);
TPA = Time of the planned pauses (min.);
TPB = Time of low ergonomic risk activity (min)

2.2.3. Recommended pause time due to ergonomic factors

The ergonomic analysis indicated the critical factor to recommend the amount of time for pauses in a working turn (TPR, recommended pause time). The resting pause time could be necessary due to heat stress, workload, repetitiveness, vibration and noise. The pause time needed due to work repetitiveness was determined using the methodology proposed by Couto [5], who takes into account the type of repetitiveness, force, posture, load weight and mental work load.

The time needed to reorganize the existing pauses was determined by Eq. (2).

$$\mathbf{TRP = TPR - TPE} \qquad \textbf{Eq. (2)}$$

TRP= Time needed to reorganize the existing pauses, min
TPR = Recommended pause time, min
TPE = Existing pause time, min

2.2.4. Production target in use

The production target used was provided by the company, according to previous internal studies. The establishment of the new production targets was carried out based on these studies, in which changes were made according to the percentage of time needed to reorganize the existing pauses, for each operation.

3. Results and discussion

3.1. Brush cutting operation

The brush cutting operation results are presented according to the ergonomic factor evaluated.

3.1.1. Vibration

The global levels, A(8) $m.s^{-2}$, vibration transmitted to hands by brush cutter in operations for cleaning eucalyptus stands were: machine KA 85R, right hand was equal to 5.55 $m.s^{-2}$; and left hand was equal to 6.32 $m.s^{-2}$; and machine FS 280, right hand was equal to 7.77 $m.s^{-2}$; and left hand was equal to 8.64 $m.s^{-2}$. These results showed that the operator of the KA 85R and FS 280 brush-cutters could work only 25% and 12% of the 8-hour turn, respectively, according to the ACGIH Norm.

3.1.2. Noise level

The noise level (Leq) measured for KA 85R and de FS 280 were respectively 88,7 and 95,6 dB(a). These values were above the recommended limit of 85 dB(A), established by the Brazilian Norm NR-15 [3]. The brush-cutter operator should use ear protector to work an 8-hour turn.

3.1.3. Physical workload

Table 1 shows the workload classification and percentage of resting time for an 8-hour turn, according to the cardiovascular load for the sickle and brush-cutter operators. The work was classified as moderately heavy and no resting pauses were needed for the sickle operator, while for the brush cutters KA 85R and FS280, the operators needed 7% and 19% of resting time, respectively.

Table 1

Cardiovascular load, percentage of resting and Workload classification for sickle and brush-cutter operators

Equation variables	Tool	Brush cutters	
	Sickle	KA 85R	FS 280
Working heart rate (bpm)	117	116	110
Resting heart rate (bpm)	94	72	69
Cardiovascular load (%)	36	45	58
Heart rate limit (bpm)	132	111	97
Resting time pauses (%)	0	7	19
Workload classification	Moderately heavy	Moderately heavy	Moderately heavy

3.1.4. Biomechanics

According to the 3D Static Strength Prediction Program from the University of Michigan [15], there was low risk for low back compression at the L5-S1 vertebral disk for the sickle and brush cutters operators. Other body articulations presented strength percentage of capacity below 99%, indicating that there are some damage risks for the operators.

3.2. Delimbing operation

The results of the delimbing operation with tree pruners are presented according to the ergonomic factor evaluated.

3.2.1 Vibration

The global levels, A(8) $m.s^{-2}$ of vibration transmitted to hand by brush cutter in operations for cleaning eucalyptus stands were: machine A, right hand was equal to 9.04 $m.s^{-2}$ and left hand was equal to 7.43 $m.s^{-2}$; machine B, right hand was equal to 6.35 $m.s^{-2}$ and left hand was equal to 7.35 $m.s^{-2}$; and machine C, right hand was equal to 7.39 $m.s^{-2}$ and left hand was equal to 6.98 $m.s^{-2}$. These results showed that the operator of the “A” tree pruner could work only 12% and pruners “B” and “C”, up to 25% of the 8-hour turn, according to the ACGIH [1].

3.2.2. Noise level

The measured noise level (Leq) for tree pruners “A”, “B” and “C” were respectively 88,4; 87,8 and 91,1 dB(A). These values were above the recommended limit of 85 dB(A), established by the Brazilian Norm NR-15 [3]. Tree pruner operators should use ear protector to work an 8-hour turn.

3.2.3. Physical workload

Table 2 shows the workload classification and percentage of resting time for an 8-hour turn, according to the cardiovascular load for the operators of pruners “A”, “B” and “C”. The work was classified as heavy and the percentage values of resting pauses for the operators, for an 8-hour turn, were 23%, 28% and 26%, respectively.

Table 2

Cardiovascular load, percentage of resting pauses and Workload classification for the “A”, “B” and “C” pruners’ operators.

Equation variables	Tree pruners		
	A	B	C
Working heart rate (bpm)	148	135	139
Resting heart rate (bpm)	66	72	69
Cardiovascular load (%)	66	77	69
Heart rate limit (bpm)	116	105	109
Resting time pauses (%)	23	28	26
Workload classification	Heavy	Heavy	Heavy

3.2.4. Biomechanics

According to the 3D Static Strength Prediction Program from the University of Michigan, there was no risk for low back compression at the L5-S1 vertebral disk for the sickle and brush cutters operators. The body joints: elbow, torso and hip presented strength percentage capacity below 99%, indicating that there are some damage risks for the operators of delimbers.

3.3. Production target

The results showed that, in all activities, the main factor determining the resting pauses was heat. The average WBGT for the study period was 28.5 ºC and the workload was classified as heavy. These values were compared with the NR-15 limits [3] and the percentage of resting pauses was found to be equal to 75%. None of the other ergonomic factors evaluated showed the need for resting pauses equal to or higher than heat stress.

The second important ergonomic factor was repetitiveness, which revealed the need for resting pauses for downhill manual log throwing equal to 43%, followed by manual log piling, 31%; felling and bucking, 27%; and TMO cable pulling, delimbing and brush cutting, 25%.

The time and motion study indicated that most activities were performed by the "production system payment", in which workers can finish the day's work when the production target is accomplished. This encouraged employees to work continuously to finish sooner the work day, without realizing the damage to their health caused by their effort, which is greater than their work capacity.

The biomechanical analysis demonstrated that the timber extraction by downhill manual log throwing could cause injury to the L5-S1 disc and manual log piling operation can do the same. Besides, in all positions and loads handled, there was at least one joint at risk of being injured. These two operations should be mechanized because the resting pauses will not prevent de risk damage found in the biomechanics studies.

All the company production targets were reduced to meet the needs demonstrated by the results of this study (Table 3).

Table 3

Actual and recommended production and percentage of reduction in production targets established by the company for each operation studied.

Operation	Actual production	Recommend Production	Percentage of production reduction
Manual downhill cable pulling	90 m³/turn	39 m³/turn	57
Felling and bucking	32 m³/turn	17 m³/turn	47
Delimbing and topping	32 m³/turn	16 m³/turn	51
Manual brush cutting	800 trees/turn	477 trees/turn	40

4. Conclusions

The results showed that in brushing cutting semi-mechanized system, all machines presented vibration and noise levels above the recommended limits established by national and international standards. The brush-cutter “X”, model FS 280 was more harmful to workers. The cardiovascular load was above 40% for all machine operators investigated, indicating an activity with high physical demands. The biomechanical analysis revealed that the activity in all systems exposed the workers to the risk of injury to the elbow, back and hip articulations. All machines, tools and systems required ergonomic improvements to meet the requirements for being used by humans. According to the ISO 5349, all pruner machines presented vibration levels above the recommended limits. The machine "A”, model PT 2500 Start 42, presented the highest vibrations levels. The noise levels were above the recommended limits established by the

Brazilian norm (NR 15-Anexo 1). The machine "C", model KA 85 R HT, presented the highest noise level. The operators' physical work load estimated by the Cardiovascular Load Method was above the limit of 40%, in all the tests, indicating heavy work operations, thus requiring resting pauses. The biomechanical analysis revealed that all machines exposed the workers to the risk of injuries to the elbow, back and hip articulations of the human body. All machines and operations required ergonomic improvements to meet the requirements for human beings. All operations analyzed showed the need for increased time for pauses and improvement in work organization. The heat proved to be the most relevant factor for determining the need for pauses, followed by repetitiveness, force, working posture, weight moved and mental workload. All productivity targets were reduced to meet the time of ergonomic resting pauses necessary for workers, in different activities.

Acknowledgements

The authors acknowledge the FAPEMIG – Fundação de Amparo à Pesquisa do Estado de Minas Gerais and The CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico for financial assistance in this work.

References

[1] ACGIH - American Conference of Governmental Industrial Hygienists. Hand–arm (segmental) vibration. In: Documentation of the Threshold Limit Values for Physical Agents hand–arm (segmental) vibration, 7th Ed. Cincinnati, 2011.

[2] Apud, E. Guidelines on ergonomics study in forestry. Genebra: ILO, 1989.

[3] BRASIL. Ministério do Trabalho e Emprego - MTE. Norma Regulamentadora NR-15 – Atividades e Operações Insalubres. Portaria GM n.º 3.214, de 08 de junho de 1978.

[4] Chapanis, A. The chapanis chronicles: 50 years of human factors research, education, and designer. Santa Barbara: Aegean, 1999.

[5] Couto, H. A. Índice TOR-TOM: Indicador ergonômico de eficácia de pausas e outros mecanismos de regulação. Editora Ergo. Belo Horizonte, MG. 2006.

[6] Fiedler, N. C. et. al. Avaliação dos riscos de acidentes em atividade de poda de árvores na arborização urbana do Distrito Federal. Revista Árvore, Viçosa, v. 30, n. 2, p. 223-233, 2006.

[7] Grandjean, E. Fitting the task to the man. London: Taylor & Francis, 1986.

[8] Iida, I. Ergonomia: projeto e produção. São Paulo: Editora Edgar Blücher Ltda, 2003.

[9] ISO - International Organization for Standardization. Mechanical vibration – measurement and evaluation of human exposure to hand transmitted vibration, ISO 5349-1:2001 (E). Geneva, 2001. 24p.

[10] Noronha, E.H.; Travaglia Filho, U.J.E.S.L. Quantificação dos níveis de ruídos num estande de tiros da PM do Distrito Federal [periódico on-line]. Centro de Ciências de Educação e Humanidades – CCEH. Universidade Católica de Brasília, jun 2005; vol. I; nº 3.

[11] SALIBA, T. M. Manual prático de avaliação e controle de vibração: PPRA. São Paulo: Editora LTr, 2009.

[12] Salvendy, G. Handbook of human factors and ergonomics. 2 ed. New York: Wiley, 1997.

[13] Sanders, M. M.; McCormick, E. J. Human factors in engineering and design. 7 ed. New York: Mcgraw-Hill,1993.

[14] Stanton, N. et al. Handbook of human factors and ergonomics methods. Boca Raton: CRC Press, 2004.

[15] University of Michigan, 3D static strength prediction program, version 2.0 – user's manual. Michigan: Universidade de Michigan, Centro de Ergonomia, 1993. 76 p.

[16] Vicente, K. J. The human factors. New York: Routledge, 2004.

[17] Wilson, J. R.; Corlett, E. N. Evaluation of human work: a practical ergonomics methodology. 2 ed. London: Taylor & Francis, 1995.