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EVALUATION OF PHYSICAL EXERTION BY STATISTICAL ANALYSIS OF WORKER'S HEART RATE AT LOG SKIDDING

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Results of investigation into the physical exertion of the log skidding workers: tractor driver, winch operator and choker are presented. The investigation consisted of laboratory and field measurements and included measurements of the heart rate and assessment of the work effect, the work time structure, and the worker's physical exertion and energy consumption. According to the average rate during daily work, the physical exertion of the tractor driver and winch operator was classified as low exertion (75–95 min^{-1}), whereas that of the choker was established as medium exertion (96–115 min^{-1}). Energy consumption was calculated for the daily working time of 262 minutes, according to field measurements and for normal eight-hour work. According to field measurement values the tractor driver's and winch operator's work was categorized as light work (1.23–2.51 MJ) and that of the choker as heavy work (2.52–6.30 MJ). According to the values for eight-hour work, the tractor driver's and the winch operator's jobs were classified as heavy work (2.52–6.30 MJ/8h) and the choker's job as the heaviest (6.31–10.47 MJ/8h).

Key terms:
energy consumption, ergonomics, field measurements, forestry, heavy work operators, work study

When investigating workers' physical exertion, it is important to determine how high exertion at a particular job that involves a particular work technology is. Understanding total physical exertion during daily work and exertion at a particular work activity is useful for the improvement of the existing technologies and for the development of new technologies, methods and work techniques.

Arh hig rada toksikol, Vol 46 (1995) No 1, pp. 23–32

This knowledge is a reliable guideline to the services dealing with the health, social and technical protection of forest workers.

So far research into workers' physical exertion has been carried out in about ten types of forest work (1–6). The results refer to the evaluation of work heaviness based on the heart rate, measured at several workers' activities during many days of field measurement (Table 1).

Table 1 *The results of physical exertion in some forest operations*

Work operation	Average heart rate min^{-1}	Energy consumption MJ/d	Level of exposure
Manual work in habitat preparation	99	5.05	heavy
Hole drilling for planting by motor drill	107	6.51	very heavy
Manual work in young trees care	107	6.51	very heavy
Sprout cutting by portable brush saw	100	5.22	heavy
Wood cutting and processing by chain saw	108-116	3.8-8	very heavy
Choking of logs in skidding	86-98	3.6-5.61	heavy
Manual loading of 1m-long fire wood on truck	103	6.18	heavy
Manual loading of 1m-long fire wood into waggon	132	13.27	maximum
Drilling of holes in trail construction	92	4.16-5.99	heavy

Skidding from stumps to lorry road is the most complex and expensive work phase in logging because machines run outside the roads in continually changeable field and stand conditions, and because expensive machines with many hazardous activities are used. Along with cutting and processing, skidding is the operation in which workers get injured more than in any other forest activity (7, 8).

When evaluating physical exertion of forest workers, we rely on the methods based on heart rate measurement. Owing to their practicability, these methods are very suitable for forestry research. Team work and correctly organized tests will eliminate most of the disadvantages that these methods may have (9–11). To date results show that the physiological indices as determined by heart rate measurement are a useful and practical help in establishing the physiological requirements of heavy work operators, as are the majority of forestry workers.

METHODS

The methods used in this investigation were developed at the Department of Production Organization in Forestry, Faculty of Forestry Zagreb, and were applied in collaboration with the Heart Clinic for Prevention of Cardiovascular Diseases and Rehabilitation in Zagreb. The research methodology, its foundations and possibilities, advantages and disadvantages are described in detail by *Tomanić and co-workers* (1) (Figure 1).

The subjects in the investigation were four workers in regular employment: two tractor drivers and two chokers, with the work experience from 13 to 23

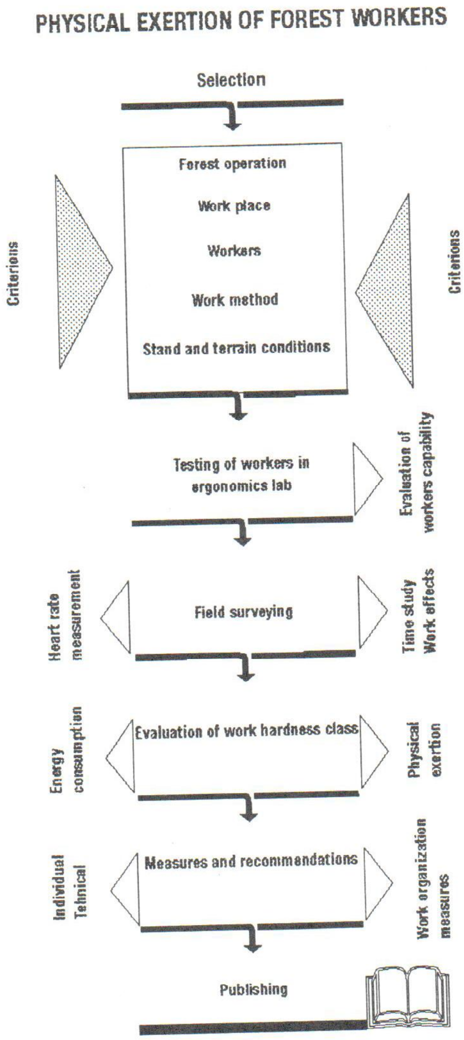

Figure 1 *Research scheme*

Arh hig rada toksikol, Vol 46 (1995) No 1, pp. 23–32

years, without signs of occupational or other diseases. None of the chosen workers had attended a school for forest workers.

Field research was preceded by testing the selected workers at the heart clinic. The test involved a clinical check-up, selected laboratory tests, ECG, spirometry, ergometry, and reography.

Each worker was tested for programmed exertion using the Bruce protocol. The values of the heart rate (min^{-1}), oxygen consumption (L/min), work (W/min) and blood pressure (kPa) were compared with the expected values according to each worker's anthropometric characteristics and age. The exertions were between 96 and 116% of the expected maximum work. Thus was obtained the equivalent of the physical activity similar to the exertion to which the workers were subjected during forestry work. A collective specialist medical report said that the tested workers were capable of physical exertion during work.

A field investigation was carried out in May 1994 in the hills of Zagrebačka gora. The survey encompassed altogether 14 worker/days: six tractor drivers, six chokers and two winch operators. It entailed: minute by minute recording of the work process including the type of activity; minute by minute heart rate reading from a Respironics electronic heart rate meter; measurement of the work effect; measurement and description of other work factors: air temperature, air pressure and humidity, atmospheric condition (cloudiness, wind, precipitation), the ground condition (type of coverage, moisture and muddiness).

The investigation of the skidding operation took place in the Sljeme–Medvedgradske šume management unit, Section 33b. The section covers 10.25 ha, has a well developed relief, distinctly steep slopes, some of which are impossible to conquer by walking. It is covered by a high beech forest aged 135 years, wood stock 110 m^3 net timber or 65 m^3/ha. Felled trees yielded 53% of roundwood and 47% of fuelwood.

The length of the skidding track was 200 m, 10–30 m of which was forest road. The length of cord tug winching ranged from 10 to 40 m. The skidding was only uphill. The average slope in tractor skidding was 20–30%.

During the work the choker rode on the tractor with the tractor driver to the off-road storage where he unfastened the load. Winching was done by the winch operator and choker.

For skidding two adapted tractors were used: Zetor 7245 45 kW and Zetor Crystal 8045 60 kW, and a self-standing winch Nesler Bludenz Maschinenbau 37 kW.

RESULTS

Work effects and work time structure

In the course of the survey the outcome was 65.1 m^3, or 16.3 m^3/d or 4.1 m^3 per worker/day, which is significantly less than the planned normal effect (7.2 m^3) for these working conditions, owing to the shortened duration of daily work averaging 262 min. Assuming the same work time structure and similarly intensive work in the eight-hour working time, a daily effect of 7.5 m^3 per worker is possible.

The total surveyed working time was classified according to the known work study principles for skidding (12) as effective or pure time (EV) and additional or general time (breaks and delays – DV). The additional time factor (f_{DV}) was computed using the formula

$$f_{DV} = 1(DV/EV)$$

with *DV* as additional time, min; *EV* – effective time, min (Table 2).

Table 2 *Work time structure*

Post	Effective time %	Additional time %	Additional time factor
Tractor driver	62.1	37.9	1.61
Choker	59.6	40.4	1.68
Winch operator	58.9	41.1	1.70

The high ratio of additional time is firstly the consequence of heaviness and complexity of the working conditions, and secondly, of insufficient preparation, negligence in work organization and poor understanding of work laws primarily acting in the distribution of work energy, dynamics and break frequency. The established ratio of additional times is considerably higher than known in literature.

Physical exertion indices

The average heart rate during daily work (HR_a) was established for every worker as an arithmetic mean of all measured heart rates, average heart rate for every work activity, and the standard deviation (HR_{std}). The analysis unified all data for the same job.

The average heart rate during daily work of the tractor driver was 88 min^{-1}; in effective time 91 min^{-1}, in additional time 84 min^{-1}. The average heart rate of the choker was 108 min^{-1}; in effective time 121 min^{-1}, in additional time 89 min^{-1}. Winch operator's average heart rate was 89 min^{-1}, in effective time 90 min^{-1}, in additional time 87 min^{-1} (Figures 2–4).

Workers' physical exertion was evaluted on the basis of the heart rate by Ronay classification (13), while the energy consumption values were obtained by Kaminski classification (14).

According to the report on the average heart rate during daily work, physical exertion of the tractor driver and winch operator was classified as low exertion (75–95 min^{-1}), whereas the exertion of the choker was established as medium exertion (96–115 min^{-1}).

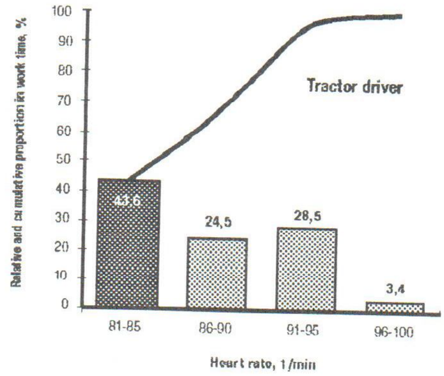

Figure 2 *Daily physical exertion scheme of tractor driver*

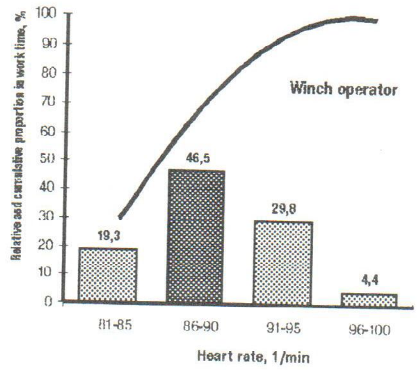

Figure 3 *Daily physical exertion scheme of choker*

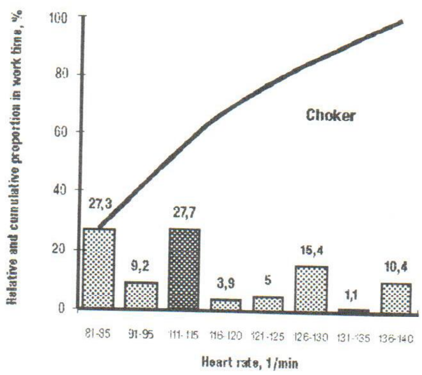

Figure 4 *Daily physical exertion scheme of winch operator*

Energy consumption (EC) was calculated according to the daily heart rate after Vondra's regression model (2), obtained by balancing the 35 pairs of heart rate data and the corresponding EC values taken from the studies of Hubač and Ronay.

$$EC = 14.42 - 0.4268\ HR_a + 0.003914\ HR_a^2$$

with EC as energy consumption, kJ/min; HR_a as heart rate, min^{-1}.

Daily energy consumption was calculated for the work time in field measurements (EC^1) and for normal eight-hour work time (EC^2). The calculated EC was compared to the highest possible energy consumption during daily work for healthy males up to age 40 amounting to 8.33 MJ or approximately 2000 kcal as determined by Kaminsky.

According to EC^1, tractor drivers' and winch operators' work has been evaluated as light work (1.23–2.51 MJ). The calculated energy consumption is 21–22% of the average possible highest energy consumption at work. In terms of EC1, a choker's work has been classified as heavy work (2.52–6.30 MJ), the average consumption being 43% of the average possible highest energy consumption at work.

According to the EC^2 values the work of tractor drivers and winch operators has been evaluated as heavy work (2.52–6.30 MJ/8h). The calculated energy consumption is 41–43% of the average possible highest energy consumption at work. Likewise, the choker's work was classified as heaviest work (6.31–10.47 MJ/8h), while the calculated consumption was 80% of the average possible highest energy consumption at work (Table 3).

Table 3 *Average heart rate, energy consumption and evaluation of exertion*

Post	HR_a	HR_{std}	Evaluation of exertion by HR_a	EC^1	EC^2	Evaluation of exertion by EC^2
	min^{-1}			MJ		
Tractor driver	88	9	small	1.88	3.44	heavy
Choker	108	16	medium	3.68	6.71	very heavy
Winch operator	89	8	small	1.78	3.57	heavy

Workers' exertion at skidding has been determined by the degree of mechanisation and terrain configuration. Steepness of the terrain is highly hazardous because of the risk of fall or lack of proper interaction between the tractor driver and the choker.

Physical exertion of the tractor driver and the winch operator should be analysed together with the psycho-physical exertion. Their work is accompanied by heavy mental stress because of 1. shared responsibility towards the choker's security, 2. handling expensive equipment, and 3. risk of injury. Tractor drivers are exposed to the highest physical exertion during winching (95 min^{-1}) because

Arh hig rada toksikol, Vol 46 (1995) No 1, pp. 23–32

of the physiologically unnatural position of the body when working with switch levers. It may be possible to reduce the exertion by improving the operator's seat construction (revolving seat!), or by a better choice of work means (Figure 5).

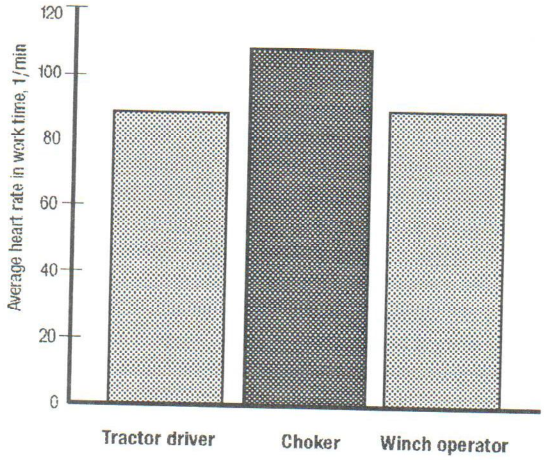

Figure 5 *Average heart rate in work time at log skidding*

With this way of skidding, a choker's exertion mainly depends on the terrain ruggedness where logs are fastened, on the longitudinal and transversal inclination a choker has to master when moving towards the logs in the winching zone, and on the position and accessibility of the log parts to which a cord has to be fastened.

CONCLUSIONS

According to the criteria of energy consumption, the investigated jobs belong to the forestry work types with acceptable exertion. However, the proved damage caused by noise and vibration, which at this kind of work results in damaged hearing and degenerative spinal diseases of machine operators, classifies these jobs among those with high hazards in terms of developing occupational illnesses or invalidity. This calls for urgent ergonomic adaptations of the existing work means, for work organization where workers' exertion is in harmony with the allowable exertion, and for discipline in enforcement of personal and other measures for workers' safety and health.

In order to reduce total exertion and work hazard, skidding should be entirely mechanized by application of new technologies.

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Sažetak

OCJENA FIZIČKOG OPTEREĆENJA STATISTIČKOM ANALIZOM PULSA RADNIKA NA PRIVLAČENJU DRVA

U članku se izvješćuje o istraživanjima fizičkoga opterećenja radnika na privlačenju drva: traktorista, rukovatelja vitlom i kopčaša. Istraživanja su provedena tijekom laboratorijskih i terenskih mjerenja. Višednevno snimanje rada na terenu obuhvatilo je studij rada i mjerenje pulsa svake minute s pomoću elektronskog pulsomjera tipa Respironics. Laboratorijsko testiranje izabranih radnika obuhvatilo je klinički pregled, izabrane laboratorijske pretrage, EKG, spirometriju, ergometriju i reografiju. Rezultati istraživanja odnose se na postignuti radni učinak, strukturu radnoga vremena te ocjenu fizičkoga opterećenja radnika na osnovi prosječnoga pulsa tijekom dnevnog rada i pripadajuće, posredno izračunane energijske potrošnje. Prema nalazu prosječnoga pulsa tijekom dnevnoga rada fizičko opterećenje traktorista i rukovatelja vitlom svrstano je u klasu malog opterećenja (75–95 min^{-1}), dok je opterećenje kopčaša u klasi srednjeg opterećenja (96–115 min^{-1}). Dnevni utrošak energije izračunan je za dnevno radno vrijeme

Arh hig rada toksikol, Vol 46 (1995) No 1, pp. 23–32

ostvareno pri terenskim mjerenjima i normalno osmosatno radno vrijeme. Prema kriteriju energijske potrošnje istražena radna mjesta spadaju među ona u šumarstvu s prihvatljivim opterećenjem. Rad traktorista i rukovatelja vitlom ocijenjen je kao laki rad (od 1,23 do 2,51 MJ). Izračunani utrošak energije čini 21–22% prosječno mogućega najvećeg utroška energije za rad. Rad kopčaša svrstan je u razred teškog rada (2,52–6,30 MJ), a izračunani utrošak čini 43% od prosječno mogućega najvećeg utroška energije za rad. Rad traktorista i rukovatelja vitlom ocijenjen je kao teški rad (2,56–6,30 MJ/8h). Izračunani utrošak energije čini 41–43% prosječno mogućega najvećeg utroška energije za rad. Rad kopčaša svrstan je, prema energijskoj potrošnji u razred najtežeg rada (6,31–10,47 MJ/8h), a izračunani utrošak čini 80% od prosječno mogućega najvećeg utroška energije za rad.

Ključne riječi:
energijska potrošnja, ergonomija, studij rada, šumarstvo, terenska mjerenja, teški fizički rad

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