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

IVAN MARTINIĆ

Faculty of Forestry, University of Zagreb, Zagreb, Croatia

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 (75–85 min⁻¹); whereas that of the choker was established as medium exertion (90–115 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 (2.52–0.30 MJ). According to the values for eight-hour work, the tractor driver’s and the winch operator’s jobs were classified as heavy work (2.52–0.30 MJ/h) and the choker’s job as the heaviest (0.31–10.47 MJ/h).

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.
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 (1-5). 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>
<thead>
<tr>
<th>Work operation</th>
<th>Average heart rate min⁻¹</th>
<th>Energy consumption MJ/d</th>
<th>Level of exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual work in habitant preparation</td>
<td>0.0</td>
<td>5.05</td>
<td>heavy</td>
</tr>
<tr>
<td>Heli drilling for planting by motor drill</td>
<td>107</td>
<td>6.51</td>
<td>very heavy</td>
</tr>
<tr>
<td>Manual work in young trees care</td>
<td>107</td>
<td>6.51</td>
<td>very heavy</td>
</tr>
<tr>
<td>Sprout cutting by portable brush saw</td>
<td>100</td>
<td>6.22</td>
<td>heavy</td>
</tr>
<tr>
<td>Wood cutting and processing by chain saw</td>
<td>108-116</td>
<td>3.8-8</td>
<td>very heavy</td>
</tr>
<tr>
<td>Choking of logs in skidding</td>
<td>86-98</td>
<td>3.6-5.81</td>
<td>heavy</td>
</tr>
<tr>
<td>Manual loading of 1m-long firewood on truck</td>
<td>103</td>
<td>6.18</td>
<td>heavy</td>
</tr>
<tr>
<td>Manual loading of 1m-long firewood into wagon</td>
<td>132</td>
<td>13.27</td>
<td>maximum</td>
</tr>
<tr>
<td>Drilling of holes in trail construction</td>
<td>92</td>
<td>4.19-5.99</td>
<td>heavy</td>
</tr>
</tbody>
</table>

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 Tomanic 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
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 Respirotronics 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 Sileme–Medvedgradske sume 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 m³ net timber or 65 m³/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 0042 60 kW, and a self-standing winch Nesler Luzern Maschinenbau 37 kW.

RESULTS

Work effects and work time structure

In the course of the survey the outcome was 65.1 m³, or 16.3 m³/d or 4.1 m³ per worker/day, which is significantly less than the planned normal effect (7.2 m³) 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 m³ 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

\[
f_{DV} = \frac{1}{EV/DV}
\]

with \( DV \) as additional time, min; \( EV \) - effective time, min (Table 2).

<table>
<thead>
<tr>
<th>Role</th>
<th>Effective time</th>
<th>Additional time</th>
<th>Additional time factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor driver</td>
<td>62.1%</td>
<td>37.9%</td>
<td>1.61</td>
</tr>
<tr>
<td>Choker</td>
<td>59.6%</td>
<td>40.4%</td>
<td>1.68</td>
</tr>
<tr>
<td>Winch operator</td>
<td>58.9%</td>
<td>41.1%</td>
<td>1.70</td>
</tr>
</tbody>
</table>

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 \( (HR_d) \) 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 evaluated on the basis of the heart rate by Ronay classification (13), while the energy consumption values were obtained by Kaniński 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.

$$EC = 14.42 - 0.4260 \; HR_a + 0.003914 \; HR_a^2$$

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 (EC¹) and for normal eight-hour work time (EC²). 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 Kanninsky.

According to EC¹, 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 EC² 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>
<thead>
<tr>
<th>Post</th>
<th>HR_a</th>
<th>HR_w</th>
<th>Evaluation of exertion by HR_a</th>
<th>EC¹</th>
<th>EC²</th>
<th>Evaluation of exertion by EC²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor driver</td>
<td>88</td>
<td>9</td>
<td>small</td>
<td>1.00</td>
<td>3.44</td>
<td>heavy</td>
</tr>
<tr>
<td>Choker</td>
<td>108</td>
<td>15</td>
<td>medium</td>
<td>3.68</td>
<td>6.71</td>
<td>very heavy</td>
</tr>
<tr>
<td>Winch operator</td>
<td>89</td>
<td>6</td>
<td>small</td>
<td>1.78</td>
<td>3.57</td>
<td>heavy</td>
</tr>
</tbody>
</table>

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
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 (resembling seat!), or by a better choice of work means (Figure 5).

![Figure 5 Average heart rate in work time at log skidding](image)

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.

REFERENCES


Sažetak

OCJENA FIZIČKOG OPTEREĆENJA STATISTIČKOM ANALIZOM PULSA RADNIKA NA PRIVLAČENJU DRVA

U članku se izvješćuje o istraživanjima fizičkog opterećenja radnika na privlačenju drva: traktorista, rukovatelja višika i kopčača. Istraživanja su provedena tijekom laboratorijskih i terenskih mjerenja. Višesekundno snimanje rada na terenu obuhvatilo je studij rada i mjerenje pulsa svake minute s pomoću elektronskog pulsomjera tipa Respronics. Laboratorijsko testiranje izabranih radnika obuhvatilo je klinički pregled. Izabrane laboratorijske prilagodbe, EKG, sprijemne, ergonomiju i fotografiju. Rezultati istraživanja objavljene su na postignut radni učink, strukturu radnog vremena u vezi fizičkog opterećenja radnika na sjeni procijenjenog pulsa tijekom dnevnog rada i propadnju, posredno izraženom energijske potrošnje. Prema nalazu procijenjenog pulsa tijekom dnevnog rada fizičko opterećenje traktorista i rukovatelja višika svrstanju je u klasu malog opterećenja (75-95 min-1), dok je opterećenje kopčača u klasu srednjeg opterećenja (95-115 min-1). Dnevni utrošak energije izrađivan je za dnevno radno vrijeme.
ostavljeno pri terenskim mjerenjima i normalno osnosno radno vrijeme. Prema kriteriju energetske potrošnje istražena radna mjesta spadaju među ona u šumarstvu s prihvatljivim opterećenjem. Rad traktorista i rukovatelja vitom odijenjen je kao teški rad (od 1,23 do 2,51 MJ). Izračunani utrošak energije čini 21-22% prosječno mogućeg najvećeg utroška energije za rad. Rad kopčala svrstan je u razred teškog rada (2,52-6,30 MJ), a izračunani utrošak čini 43% od prosječno mogućeg najvećeg utroška energije za rad. Rad traktorista i rukovatelja vitom odijenjen je kao teški rad (2,56-6,30 MJ/8h). Izračunani utrošak energije čini 41-43% prosječno mogućeg najvećeg utroška energije za rad. Rad kopčala svrstan je, prema energetskoj potrošnji u razred teškog rada (6,31-10,47 MJ/8h), a izračunani utrošak čini 85% od prosječno mogućeg najvećeg utroška energije za rad.

Ključne riječi:
energetska potrošnja, ergonomija, studij rada, šumarstvo, terenska mjerenja, teški lični rad

Requests for reprints:

Ivan Martinić, M. Sc.
Faculty of Forestry
University of Zagreb
Grevčevska 29
10000 Zagreb, Croatia