Workload analysis in logging technology employing a processor aggregated with a farm tractor

Krzysztof Leszczyński* and Arkadiusz Stańczykiewicz

University of Agriculture in Krakow, Department of Forest and Wood Utilization, Al. 29 Listopada 46, 31-425 Kraków, Poland

Abstract

Aim of study: The aim of this research was to analyze the workload of the operators while logging at the motor-manual level in coniferous stands undergoing two tending treatments (early and late thinning). The technologies under the investigation employed a power chainsaw, tractor equipped with a cable winch as well as delimbing and cross-cutting Hypro 450 processor.

Area of study, materials and methods: The research areas were located in lowlands and in a mountain range of the Western Carpathians. In the analysis it was assumed that the heart rate at work, expressed in beats per minute, would be an indicator of the workload affecting the human organism. Based on the heart rate, three indicators were calculated: relative heart rate at work (%HRR), 50% level of heart rate reserve, ratio of working heart rate to resting heart rate.

Main results: The lowest average workload (typical for light work, %HRR<20) was recorded for the processor operator in late thinning (%HRR=16), whereas, the highest one (indicating heavy work, %HRR=48.69>40%) was for the chainsaw operator in early thinning, working with a processor. Cumulative distribution function of the workload at the work station of the skidder operator was characterized by bimodality – an occurrence of two extreme, high and low, workload values.

Research highlights: The workload in early thinning was higher by about 7% than in late thinning at the work station of both, the processor operator as well as the chainsaw operator working with a processor.

Keywords: logging; tractor processor; heart rate; workload; cardiovascular strain.

Citation: Leszczyński K., Stańczykiewicz, A. (2015). Workload analysis in logging technology employing a processor aggregated with a farm tractor. Forest Systems, Volume 24, Issue 2, e024, 8 pages. http://dx.doi.org/10.5424/fs/2015242-06607.

Received: 29 Jul 14. Accepted: 08 Apr 2015

Copyright © 2015 INIA. This is an open access article distributed under the Creative Commons Attribution License (CC by 3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Funding: This work was supported by the University of Agriculture in Krakow, Faculty of Forestry under Grant DS-3412/KULiD.

Competing interests: The authors have declared that no competing interests exist.

Correspondence should be addressed to Krzysztof Leszczyński: rlleszcz@cyf-kr.edu.pl

Introduction

Despite the rapid development of the multi-operational forestry machinery market, using such machines on a large scale in Polish forestry is mainly dependent on the investment capacities of forestry companies (Sowa et al., 2007; Spinelli & Magagnotti, 2012). Market fluctuations and the considerable impact of the wood industry have caused a significant increase in the investment risk. Statistics for 2013 indicate (Anonymous, 2014) that the annual overall volume of wood harvested in Poland accounts for about 37 mil. m³. In public forests (including properties of the State Treasury, communal units and National Parks) nearly 35 mil. m³ of large wood (debarked stems of minimum diameter of 5 cm) is harvested. Solutions designed to decrease the weight of tools used for logging are limited and they usually involve skidding (Magagnotti & Spinelli, 2011; Ottaviani et al., 2011). During the tending treatments performed in maturing stands (over the age of 20) – thinning – 16,990 thousand m³ of large wood, including 10,592 thousand m³ of large softwood, was harvested in Poland in 2013. It seems that a possible solution is mechanization appropriate for so-called small scale forestry (Spinelli & Magagnotti, 2012), including processors aggregated with farm tractors. It is estimated that the unit cost of such a solution would not exceed 6 EUR/m³ (Sowa et al., 2007). Delimbing and cross-cutting aggregates are mainly produced in Scandinavia, where their major manufacturers are located (Hypro AB, Melfare AB Lutea, Niab AS Fors MW, PATU).

Delimbing and cross-cutting processors are mounted on the three-point suspension system of a tractor. They are additionally equipped with a cable winch with a 2-ton pulling force (with a winch rope
length of up to 50 m) and a hydraulic crane with a maximum radius of 6 m. These technical parameters allow the processing of stems up to 40 cm in diameter. Hypro and Melfare processors are furnished with movable rollers (similar to harvesters) providing the continuity of the delimbing process in contrast to cyclical delimbing systems applied in Niab and PATU processors. The possibility of controlling aggregates in two ways, from the tractor cab as well as at the processor panel in the standing position, eliminates the necessity to assume dangerous body positions while delimbing or cross-cutting and, so reduce the number of injuries and accidents at work (Grzywiński et al., 2010; 2013).

However, before any new production solution is employed, an analysis that would indicate an improvement in work conditions should be carried out (Shannon et al., 1998). It can be assumed that determining the cardiovascular load through monitoring heart activity is a universal indicator in this respect (Keytel et al., 2005; Kim et al., 2009). It is applied to examinations based on short-term observations (20 – 30 minutes) as well as lengthier ones lasting the whole day, or even an entire month, in the so-called diary method. A practical problem reported in many papers is a sure inconvenience resulting from the necessity to determine the power work capacity (Leonard, 2003). From the practical point of view, this activity is usually omitted when commencing analyses in the real environment with restricted access to workers is assumed (Kirk & Sullman, 2001; Magagnotti & Spinelli, 2011; Ottaviani et al., 2011). The superior goal is to demonstrate the level of significant changes in ergonomic factors within the solution under the analysis. The variability in indicators is not only due to the technology and outer environmental factors (including the number of obstacles), it also results from motivation, engagement and temporary availability of the workers. Field research (Leszczyński, 2011) displayed that indicators of work heaviness explained a much smaller part of variations in the analyzed variables in comparison with the physicochemical parameters of the working environment or technology.

The aim of this research was to analyze the workload of the operators (expressed by relative heart rate at work) while logging at the motor-manual level in coniferous stands undergoing two tending treatments (early thinning and late thinning). The technologies under the investigation employed a power chainsaw, tractor equipped with a cable winch as well as delimbing and cross-cutting Hypro 450 processor. The research areas were located in lowlands and in a mountain range of the Western Carpathians.

**Materials and methods**

In the experiment the workload experienced by the fellers working with two technological variants of wood harvesting at the motor-manual level were compared. A) Long Wood System method (LWS): the chainsaw operator (CSO) performed cutting and delimbing with a power chainsaw, whereas, the farm tractor operator (TO) carried out semi-suspended skidding by means of a Fransgard 6000 cable winch mounted on the lift of a Zetor 6741 (74 kW) tractor. B) Cut-To-Length method (CTL) employing a Hypro 450 processor mounted on the lift of an MTZ 820 BELARUS (61 kW) tractor: the chainsaw operator (CSO&PO) only performed the cutting of trees, whereas, the processor operator (PO) carried out other processing operations, including hauling stems to the skidding roads by means of a cable winch mounted on the processor as well as delimbing and cross-cutting.

In the analysis it was assumed that the heart rate at work, expressed in beats per minute (BPM), would be an indicator of the workload affecting the human organism. Based on this value, three indicators characterizing the physical workload were calculated, as defined by Kirk & Sullman (2001):

1. **Relative heart rate at work using the formula of Vitalis, 1987:**

   \[
   \%HRR = (HR_{work} - HR_{rest}) / (HR_{max} - HR_{rest}) \times 100,
   \]

   where \( HR_{work} \) – average working heart rate, \( HR_{rest} \) – resting heart rate, \( HR_{max} \) – maximum heart rate (\( HR_{max} = 220 – \text{age of the study subject} \));

2. **50% level of heart rate reserve using the formula of Lammert, 1972:**

   \[
   50\%\text{Level} = HR_{rest} + 0.5 \times (HR_{max} - HR_{rest})
   \]

3. **Ratio of working heart rate to resting heart rate using the formula of Diament, 1968:**

   \[
   \text{Ratio} = HR_{work} / HR_{rest}.
   \]

The experiment was conducted in coniferous stands (pine, spruce and fir) during two cutting sequences of tending treatments (early thinning and late thinning). For every trial, three rectangular plots of 50x100 m² were established. The longer side was situated along an existing skidding road, which contributed to limiting the passage. In total, observations were carried out in 36 trial plots of an overall area of 18 hectares. As a result of the experiment 380 m³ of wood was harvested, including 167 m³ of wood extracted during early thinning treatments. The average breast height diameter (the stem diameter at the height of 1.3 m) was 18 cm in respect of early thinning (ET) and 30 cm in the case...
of late thinning (LT); the trees heights were respectively 17 and 22 m.

For recording the working times and workload timing software was used. It was developed by a team from the Department of Forest and Wood Utilization, University of Agriculture in Krakow, and designed to be run on a minicomputer PSION-Workabout and Polar RS800 CX sports watch for monitoring heart rate. The Polar RS 800 CX sports watch consists of a chest belt with an in-built transmitter and two electrodes as well as a shoulder-worn device for storing data. The data was sent via radio waves from the transmitter to the receiver; the latter one resembled a shoulder-worn watch. The device performance is based on the principles of ECG measurement (Crawley, 2008) and the measurement error does not exceed 1% (www.polar.fi).

The resting heart rate (HRrest) was estimated in 10-minute observation periods while the workers were sitting in the seat of the vehicles in which they had driven to the work station. In the research the principle of non-interference with the work process carried out by the people in the experimental area was assumed. Therefore, the observations were carried out in an unobtrusive manner. The values were read out only after the data had been transmitted to the computer, which eliminated the mental pressure exerted on the workers that might have occurred due to the urge to compete or improve the obtained results. Based on self-established procedure, the data collected by both of the devices was compared, without taking into account the preparatory and completing times. The observation time for a single trial plot was different and it oscillated between 4 and 6.5 working hours. Files with incidental breaks and stoppages were removed from the sets of data gathered. The research was conducted in the period of the greatest predisposition for physical exercise, i.e. between 8 am. and 2 pm.

In order to balance the experiment, a three-stage process of methodical sampling without replication was performed (Fisz, 1967). The sampling of 1,000 elements was carried out at the level of; a) a single experiment; b) three replications jointly; and c) three types of stands (pine, spruce and fir ). As a result, the sets characterizing the workload in coniferous stands during two cultivation treatments (ET, LT) were obtained.

The experimental plots were located within an area of the Regional Directorates of the State Forests in Katowice and Kraków. The observations were conducted over a period of three years (2008-2010) by repeating experiments in early spring and early autumn by temperature from -3ºC to 12ºC. The logging operations were performed by a constant group of workers aged between 22 and 29 (Table 1). In fact, the workers engaged in the research were used to the piece wage system. To avoid problems resulting from maximization of the workload, as reported by i.a. Bünger et al., (1997), Toupin et al., (2007); Ottaviani et al., (2011), for the time of the experiment the hourly wages system was adapted. The resting heart value was estimated in the so-called “sitting test”.

The statistical analyses included descriptive characteristics of the sets as well as testing for homogeneity hypotheses using Pearson’s chi-square test, equality of variances by means of Fischer-Snedecor F-test and equality of average values with the use of one- and two-sided t-test for data of unequal variances (heteroscedastic t-test). All operations on data and calculations were conducted using the VBA environment and procedures provided by Ms Office Excel 2007.

**Results**

Continuous time-motion analysis was performed, which allowed us to conduct analyses of the time structure and the technological operations duration. The acquired results indicated a high share of the operational time (sum of T1 and T2, Table 2) which varied from 71.3% for the processor operator in late thinning (PO_LT) up to 87.6% for the chainsaw operator in late thinning (CSO_LT, variant A). For comparing the time structures within the certain groups of technological operations, Pearson’s test of homogeneity was applied. The results obtained (Table 3) when comparing pairs indicated statistically significant differences (p-value<0.01), even in respect of the very same operator.

| Variable | Age | Height, cm | Weight, kg | Body mass index (BMI), kg·m⁻² | Heart rate rest (HRrest), bpm | Maximal heart rate (HRmax), bpm | 50% Level |
|----------|-----|------------|-----------|-------------------------------|-----------------------------|-------------------------------|-----------|
| CSO      | 29  | 170        | 76        | 22.2                          | 69                          | 191                           | 130       |
| PO       | 22  | 182        | 76        | 26.2                          | 72                          | 198                           | 135       |
| TO       | 28  | 185        | 85        | 26.3                          | 64                          | 192                           | 128       |

CSO - chainsaw operator; PO - processor operator ; TO - tractor operator
The highest load at the level of 56.98 %HRR (HR work=136 bpm) was observed for the chainsaw operator working in technology B (early thinning treatment). The occurrence of such a high value during maintenance (T7) can be explained by the worker behavior after a momentary peak load and delay in his heart response to the exercise.

The average values (Table 5) indicate that the lowest load was a characteristic trait for the work station of the processor operator in late thinning (PO_LT, %HRR=16, HRwork=85 bpm), whereas, the highest one was recorded for the chainsaw operator in early thinning, working in variant B (CSO&PO_ET, %HRR=48.69; HR work=126 bpm).

In further statistical analyses the hypothesis of equality of variances for the samples obtained was tested. The Fisher-Snedecor test conducted (Table 6), contradicted this hypothesis at the level p-value<0.001, displaying diversity in the workload experienced by the fellers at the investigated work stations. In order to confirm the differences in aver-

Table 2. Frequency of working times within the operational groups (n=1000) (in percent)

| Variable       | T1  | T2  | T4  | T5  | T7  |
|----------------|-----|-----|-----|-----|-----|
| PO_ET          | 61.6| 25  | 1.8 | 6.60| 5   |
| PO_LT          | 44.6| 26.7| 4.3 | 20.30| 4.1|
| CSO&PO_ET      | 28.9| 53  | 5.6 | 11.10| 1.4|
| CSO&PO_LT      | 41.5| 44.5| 2.2 | 9.60 | 2.2|
| CSO_LT         | 48.6| 39  | 3.4 | 6.80 | 2.2|
| TO_LT          | 51.8| 34.6| 0   | 6.20 | 7.4|

PO_ET - processor operator, early thinning; PO_LT- processor operator, late thinning; CSO&PO_ET - chainsaw operator by using processor technology, early thinning; CSO&PO_LT - chainsaw operator by using processor technology, late thinning; CSO_LT - chainsaw operator by means of skidding tractor technology, late thinning; TO_LT - skidding tractor operator, late thinning;

T1 - effective work time; T2 - auxiliary time; T4 - fault cleaning time; T5 - resting time; T7 - daily time for maintenance of supporting machinery.

Table 3. Pearson’s chi-square test of the working time homogeneity

| Variable       | Chi²-stat |
|----------------|-----------|
| PO_ET          | 108.6810**|
| CSO&PO_ET      | 47.6466**|
| CSO&PO_LT      | 16.5696**|
| TO_LT          | 143.0509**|
| TO_LT          | 46.7024**|

** - statistical significance at the level p-value < 0.01.
Abbreviations as in Table 2.

When taking into account the workload during particular operations, the lowest value (excluding the tractor operator, in which case the time of fault removal was not identified, T4) was recorded at the work station of the processor operator in late thinning. The value of relative heart rate at work during a break (T5) accounted for %HRR=9.12, whereas, the respective overall heart rate was HRwork=76 bpm (Table 4). The highest load at the level of 56.98 %HRR (HR work=136 bpm) was observed for the chainsaw operator working in technology B (early thinning treatment). The occurrence of such a high value during maintenance (T7) can be explained by the worker behavior after a momentary peak load and delay in his heart response to the exercise.

The average values (Table 5) indicate that the lowest load was a characteristic trait for the work station of the processor operator in late thinning (PO_LT, %HRR=16, HRwork=85 bpm), whereas, the highest one was recorded for the chainsaw operator in early thinning, working in variant B (CSO&PO_ET, %HRR=48.69; HR work=126 bpm).

In further statistical analyses the hypothesis of equality of variances for the samples obtained was tested. The Fisher-Snedecor test conducted (Table 6), contradicted this hypothesis at the level p-value<0.001, displaying diversity in the workload experienced by the fellers at the investigated work stations. In order to confirm the differences in aver-

Table 4. Characteristics of the workload per specified working times

| Variable       | PO_ET | PO_LT | CSO&PO_ET | CSO&PO_LT | CSO_LT | TO_LT |
|----------------|-------|-------|-----------|-----------|--------|-------|
| T1 HR. bpm     | 90    | 85    | 125       | 119       | 114    | 98    |
| %HRR           | 19.05 | 15.91 | 48.14     | 43.20     | 39.05  | 25.05 |
| T2 HR. bpm     | 107   | 92    | 133       | 120       | 116    | 94    |
| %HRR           | 31.93 | 20.75 | 54.39     | 44.42     | 41.09  | 22.01 |
| T4 HR. bpm     | 106   | 89    | 102       | 91        | 92     | 0     |
| %HRR           | 31.63 | 19.02 | 29.77     | 20.90     | 22.40  | 0.00  |
| T5 HR. bpm     | 89    | 76    | 104       | 101       | 100    | 82    |
| %HRR           | 18.57 | 9.12  | 31.35     | 29.27     | 28.20  | 12.51 |
| T7 HR. bpm     | 100   | 87    | 136       | 101       | 106    | 88    |
| %HRR           | 26.70 | 16.86 | 56.98     | 29.35     | 33.39  | 17.19 |

Abbreviations as in Table 2.
Workload in logging technology employing a tractor processor

Table 5. Descriptive statistics of the workload (n=1000)

| Variable   | Mean HR, bpm | SD HR, bpm | Mean %HRR | SD %HRR |
|------------|--------------|------------|-----------|---------|
| PO_ET      | 95           | 17.8       | 22.85     | 13.29   |
| PO_LT      | 85           | 13.7       | 16.00     | 10.20   |
| CSO&PO_ET  | 126          | 19.7       | 48.69     | 15.53   |
| CSO&PO_LT  | 117          | 17.2       | 41.61     | 13.57   |
| CSO_LT     | 113          | 14.7       | 38.42     | 11.56   |
| TO_LT      | 95           | 19.4       | 22.64     | 15.36   |

Abbreviations as in Table 2.

Table 6. Results of hypothesis tests for the relative heart rate at work, %HRR

| Variable 1 | Variable 2 | F-statistics | HA<sup>1)</sup> | t-statistics | Delta<sup>2)</sup> |
|------------|------------|--------------|-----------------|--------------|-------------------|
| PO_ET      | PO_LT      | 1.6991***    | H1>H2           | 12.9234***   | 6.85              |
| CSO&PO_ET  | CSO&PO_LT  | 1.3099***    | H1>H2           | 10.8530***   | 7.08              |
| CSO&PO_LT  | CSO_LT     | 1.3788***    | H1>H2           | 5.6624***    | 3.19              |
| TO_LT      | PO_LT      | 2.2690***    | H1>H2           | 11.3922***   | 6.64              |
| PO_ET      | TO_LT      | 0.7488***    | H1=H2           | 0.3184*      | 0.20              |

*** - statistical significance at the level p-value<0.001; ns - no significance (p-value=0.7502); 1) HA - alternative hypothesis; 2) delta - %HRR average differences between variable 1 and variable 2. Abbreviations as in Table 2.

From the practical point of view, we often estimate the limit values of the workload, which, according to Strasser (Stampfer et al., 2009), are in fact individual values. Nevertheless, we frequently assume, according to Bullinger (Ottaviani et al., 2011), the limit value %HRR=40 of the so-called maximum heart rate reserve as well. A value exceeding beyond the limit value while working in the trial areas may be presented by means of a cumulative probability. The analysis of the curves displayed in figures 3 and 4 indicated that the lowest probability of working above the specified threshold, i.e. constant capacity of the human organism, was recorded while operating a processor in late thinning (0.013, Figure 4), whereas, the highest one was observed in the case of the chainsaw operator working in the variant with a processor in early thinning (0.697, Figure 3).
The physical workload may be characterized by many parameters described in this paper. It may be expressed in units of energy, number of heart beats at work (net cardio cost), percentage of utilized heart rate reserves (%HRR), 50% Lammert indicator, ratio between the heart rate at work and the resting heart rate (Kirk & Sullman, 2001). Due to the strong relation between the heart rate at work and the oxygen absorbed (V\textsubscript{O2}), the indicator of heart rate reserves utilization (%HRR) is preferable.

The volume of oxygen absorbed against the maximum value (V\textsubscript{O2max}) is the basic criterion in classification of the workload. Exceeding the threshold of 50% in individual values shows an extremely heavy workload involving an anaerobic energy release (Fibiger, 1978), which consequently leads to so-called oxygen debt. By analogy, the threshold %HRR=40 is considered as the limit value of the so-called constant capacity of the human organism (Stampfer et al., 2009). Schlick et al., (2010) pointed out that the limit value should account for NCC=40 bpm at work if the resting value (HR\textsubscript{rest}) was estimated for the lying down position. Otherwise, it was suggested to decrease this value to 35 bpm. Having inserted the last-mentioned value into formula 1, the permissible %HRR threshold was obtained, which oscillated between 27 for the skidder operator and 29 for the chainsaw operator, thus, it was much lower than the one used in the results analysis.

Having employed the data displayed in tables 5 and 1, the net cardiovascular cost (NCC) could have been estimated directly, the value of which regarding the chainsaw operator oscillated between 44 and 57 bpm. Assuming the lower threshold value (a stricter criterion), it may be stated that in all the analyzed variants of the chainsaw operator work, the threshold of so-called constant capacity was exceeded.

The ratio of the heart rate at work to the value of 50% Lammert level (HR\textsubscript{work}/50%Level) is another indicator of the workload. The results displayed in table 5 are below value 1. This indicates that the workers avoided exceeding a certain threshold of physical load. The result obtained indirectly confirms the “Constant Strain Behavior” analyzed in detail by Toupin et al., (2007). However, it should be noted that in the case of short-term observations the workers may tend to exploit the full load of their organisms (Ottaviani et al., 2011), which may significantly affect, if not prevent us from, conducting any analysis of the obtained results.

Based on the published data quoted in the paper (Kirk & Sullman, 2001), the values of the ratio of working heart rate to resting heart rate exceeding 1.45 allow us to rank the work of the chainsaw operator and skidder operator as heavier than nursing and car as-
work. The workload of the processor operator is comparable with that of steel workers, in which case the value of HR_work/HR_rest=1.28 is assumed. On the other hand, the workload of the chainsaw operator in early thinning (variant B) may be compared with that of a cable hauler choker setter working in mountainous terrain – (HR_work/HR_rest=1.84).

The workload analysis is an individualized research tool and it often depends on the temporary predispositions of workers. Taking into consideration the existence of the circadian cycle, the research presented herein was conducted in the periods of the highest predisposition for physical exercise. It seems that the assumed time for conducting the research results in extremely high coefficients of the operational time usage (Table 2). However, many publications report that the number of breaks (overt and covert ones) during heavy physical work may account for as much as 40% (Sowa et al., 2006; Leszczyński & Jalowska, 2011).

Summary and conclusion

In the experiment the workload experienced by an operator of a skidder equipped with a cable winch, an operator of Hypro 450 processor aggregated with a farm tractor and a chainsaw operator working in two variants (A – individual work, B – cooperation with the processor operator) were compared. For the analysis a few indicators that characterize the workload were employed. Due to the strong relation between the heart rate at work and volume of absorbed oxygen (V\textsubscript{O2}), it was assumed that the heart rate reserve utilization %HRR would be the most significant indicator.

Pearson’s test for homogeneity of comparison in pairs was used to demonstrated the statistically significant differences in the working day structure, even in respect of the very same worker. The lowest average workload (typical for light work, %HRR<20) was recorded at the work station of the processor operator in late thinning (PO\textsubscript{LT}, %HRR=16, HR\textsubscript{work}=85 bpm). The highest workload, indicating heavy work, (%HRR>40) was observed for the chainsaw operator in early thinning, working in variant B (CSOSPO\textsubscript{ET}, %HRR=48.69, HR\textsubscript{work}=126 bpm).

It was established that the workload in early thinning was higher by about 7% at both the work stations of the processor operator and the chainsaw operator working in variant B. A statistically significant increase in the workload of 3.19 %HRR was also noted for the chainsaw operator working in technology B (with a processor) in comparison with the individual work (technology A). The differences observed in the workload at lower work efficiency seem to be useful in the context of introducing changes in remuneration systems in forestry work proposed by Toupin et al., (2007). At the work station of the skidder operator bimodal distribution of the workload values was recorded (an occurrence of extreme, high and low).

References

Anonymous, 2014. Forestry 2013. A. S. D. CSO, Ed. Warsaw: Central Statistical Office. Poland. 344 pp. www.stat.gov.pl.

Bünger J, Bombosch F, Mesecke U, Hallier E, 1997. Monitoring and analysis of occupational exposure to chain saw exhausts. Am Ind Hyg Assoc J, 58(10): 747–751. http://dx.doi.org/10.1085/15428119791012405

Crawley MB, 2008. Validation of the sensewear hr armband for measuring heart rate and energy expenditure. Master thesis. Cleveland State University. USA.

Fibiger W, 1978. Workload on workstations and physical capacity. In Polish, Warszawa, Poland, Instytut Wydawniczy CRZZ. 100 pp.

Fisz M, 1967. Probability theory and mathematical statistics. 3rd ed. New York London Sydney: John Wiley & Sons, Inc. 678 pp.

Grzywiński W, Sawa L, Nowik A, Nowicki G, 2013. Occurrence of musculoskeletal disorders in woodcutters. Proc. FORMEC 2010 Forest Engineering: Meeting theNeeds of the Society and the Environment, Padova (Italy), July 11 – 14. pp: 1–10.

Grzywiński W, Wandyucz A, Tomczak A, Jelonek T, Szaban J, 2010. Occurrence of musculoskeletal disorders in woodcutters. Ergon 32(4): 389–398. http://dx.doi.org/10.1016/S0003-6780(01)00003-5

Kirk PM, Sullman MJ, 2001. Heart rate strain in cable hauler choker setters in New Zealand logging operations. Appl Ergon 32(4): 389–398. http://dx.doi.org/10.1016/S0003-6780(01)00003-5

Kirk PM, Sullman MJ, 2001. Heart rate strain in cable hauler choker setters in New Zealand logging operations. Appl Ergon 32(4): 389–398. http://dx.doi.org/10.1016/S0003-6780(01)00003-5

Leonard WR, 2003. Measuring human energy expenditure: what have we learned from the flex-heart rate method? Am J Hum Biol 15(4): 479–89. http://dx.doi.org/10.1002/ajhb.10187

Leszczyński K, 2011. Factor analysis in ergonomic profiling of workplaces in forestry. In: Technology and Ergonomics in the Service of Modern Forestry, Publishing House of Agriculture in Krakow, Poland. pp: 113–129.

Leszczyński K, Jalowska M, 2011. Similarity of the workstations involved in sanitation felling. Sylwan, 155(7): 437–445.

Magagnotti N, Spinelli R, 2011. Replacing steel cable with synthetic rope to reduce operator workload during long
winching operations. Small-Scale For 11(2): 223–236. http://dx.doi.org/10.1007/s11842-011-9180-0
Ottaviani G, Talbot B, Nitteberg M, Stampfer K, 2011. Workload benefits of using a synthetic rope strawline in cable yarder rigging in Norway. Croat J For Eng 32(2): 561–569.
Schlick C, Bruder R, Luczak H, 2010. Arbeitswissenschaft. 3rd ed., Heidelberg Dordrecht London New York: Springer. 1208 pp. http://dx.doi.org/10.1007/978-3-540-78333-6
Shannon H, Robson L, Guastello S, 1998. Methodological criteria for evaluating occupational safety intervention research. Saf Sci 31: 161–179. http://dx.doi.org/10.1016/S0925-7535 (98)00063-0
Sowa J, Kulak D, Szewczyk G, 2007. Costs and efficiency of timber harvesting by NIAB 5-15 processor mounted on a farm tractor. Croat J For Eng 28(2): 177–184.
Sowa J, Leszczyński K, Szewczyk G, 2006. Human energy expenditure in late thinning performed in mountain spruce stands. Acta Scientarium Polonorum Seria Silvarum Colendarum Ratio et Industria Lignaria 5(1): 73–80.
Spinelli R, Magagnotti N, 2012. Wood extraction with farm tractor and sulky: estimating productivity, cost and energy consumption. Small-Scale For 11(1): 73–85. http://dx.doi.org/10.1007/s11842-011-9169-8
Stampfer K, Leitner T, Visser R, 2009. Efficiency and ergonomic benefits of using radio controlled chokers in cable yarding. Croat J For Eng 31(1): 1–9.
Toupin D, LeBel L, DuBeau D, Imbeau D, Boutillier L, 2007. Measuring the productivity and physical workload of brushcutters within the context of a production-based pay system. Forest Policy Econ 9(8): 1046–1055. http://dx.doi.org/10.1016/j.forpol.2006.10.001