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PHYSIOLOGICAL WORKLOAD OF WORKERS EMPLOYED DURING MOTOR-MANUAL TIMBER HARVESTING IN YOUNG ALDER STANDS IN DIFFERENT SEASONS

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Abstract
Objectives: This study examined the physiological strain experienced by workers employed in motor-manual timber harvesting performed in winter and summer, and the applicability of heart rate indices for estimating energy expenditure. **Material and Methods:** The heart rates (HR) of 2 teams consisting of 2 persons working simultaneously during felling and forwarding, in both winter and summer, were measured. Heart rate at work (HR_{work}), resting heart rate (HR_{rest}), relative heart rate (%HRR), ratio of working heart rate to resting heart rate, and 50% level were used to estimate the physiological workload in particular jobs. The HR_{index} (HR_{work}/HR_{rest}) equation was used to estimate the energy expenditure (EE). **Results:** For all jobs, significantly higher physiological workload and energy expenditure were recorded during winter. **Conclusions:** The season significantly affects the physiological workload during logging operations. If there is no possibility of harvesting wood in summer, in order to limit the workload of workers during winter activity, attention should be paid to the proper organization of work and selection of workers. Int J Occup Med Environ Health. 2022;35(4)

Key words:
forestry, heart rate, energy expenditure, logging, winter, summer

INTRODUCTION

Forestry is an important branch of the economy in many countries. Global timber production is growing from year to year, and in 2018 close to 4 billion m^3 of roundwood was harvested worldwide [1]. Despite progress in full mechanization, motor-manual logging technologies still dominate in many countries, including in Europe. Motor-manual timber harvesting is considered to be one of the most onerous and dangerous working operations [2–4].

The physical demands of work are still one of the crucial workload factors in most jobs in the forestry sector, especially those connected with logging. Such work is responsible for engaging the musculoskeletal system in the work and movements of muscles, as well as the cardiovascular and respiratory systems, responsible for the transport of oxygen and energetic components to working muscles. The dynamic work of muscles can be evaluated on the basis of the energetic process (metabolism) in the body. Its value corresponds to the pace of energetic

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processes in muscles, which is proportional to the intensity of physical effort.

The ISO standard [5] presents 4 levels of methods to estimate metabolic rate:

1. Two simple methods to quickly characterize the mean workload for a given occupation or for a given activity.
2. A procedure involving recognition of different activities of a given worker during a representative period of time, estimation of the average metabolic rate for each of them, recording of the sequence of activities in time, and computation of the time-weighted average metabolic rate.
3. Estimation of metabolic rate from recordings of heart rate.
4. Measurement of oxygen consumption (VO_2), a doubly labelled water method, and direct calorimetry.

In the first 2 levels, the possibility of errors is high, especially in case of the methods of the first level, which can be used only for rough estimation. The methods of the fourth level are very reliable, but require very specific measurements, and in field settings are often impractical or even impossible to use [6,7].

A compromise between high reliability and ease of use is provided by the measurement of heart rate (HR). This is regarded as a relatively easy, reliable, unobtrusive and cost-effective method of monitoring which can be applied in an actual work environment [8–11]. The HR parameter can be converted to equivalent VO_2 values and a subsequent estimate of EE with the use of a well-established linear relationship with VO_2, especially at high exercise intensities [5,7,12]. For this reason, HR is widely used for indirect estimations of VO_2 and the level of intensity of work [3,13,14]. This linear HR–EE relationship has also been used in the assessment of workload in forestry [10,15,16].

The practical applicability of the HR–EE relationship is reduced by the need to establish an individual HR/VO_2 relationship by a preliminary incremental test in the laboratory, which increases the overall financial cost and reduces the time-efficiency of the approach [9,11], especially in field studies. This impediment has been reduced by developing a simple HR index (HR_{index}) method to estimate VO_2 without the need for a laboratory test to determine the individual HR/VO_2 relationship. The method is based on the observation that a valid linear relationship exists between HR_{index} (calculated as actual HR/resting HR) and VO_2 expressed as a multiple of the resting metabolic rate (VO_2METs) [17]. This method has been validated in healthy non-athletes, athletes and clinical populations, as well as professional athletes [11,17–19].

Evaluation of physical workload during timber harvesting activities based on HR measurements has been the subject of much research. Most studies have concerned the work of a chainsaw operator. The average HR of loggers ranged 107–138 bpm [4,16,20–24]. Grzywiński and Łukaszuk [25] recorded similar HR levels during tree felling and processing for a logger (119 bpm) and an assistant logger (118 bpm) during timber harvesting in late thinning of pine stands. The highest values of HR were observed during the piling up of wood (124 bpm and 137 bpm, respectively).

It seems clear that the season will have an influence on the metabolic rate and physiological workload of outdoor workers in regions where the climate differs significantly between seasons, e.g., in the temperate zone. Besides the difference in ambient temperatures, snow cover in winter is a very important factor which impedes movement and increases physiological workload in general. Surprisingly, there is little research comparing the metabolic costs of the same work performed in different seasons, either in forestry or in general. Chmielewski and Porter [26] studied the effectiveness parameters of timber harvesting using 2 methods – cut-to-length (CTL) and length-to-cut (LTC) – in the thinning of pine stands in winter and summer. The authors ob-

Table 1. Characteristics of studied workers participating in early thinning of alder stands during winter and summer in the Płaska Forest District (NE Poland)

Variable	Participants (N = 4)			
	logger 1/loader 1 (N = 1)	logger 2/loader 2 (N = 1)	logger assistant 1/loader 3 (N = 1)	logger assistant 2/loader 4 (N = 1)
Age [years]	43	36	20	42
Height [cm]	175	174	170	174
Body mass [kg]	85	80	70	75
Body mass index (BMI) [kg/m^2]	27.7	26.4	24.2	24.8
Basic metabolic rate (BMR) [kJ/min]	5.30	5.21	5.03	4.92
HR_{max} (220 – age) [bpm]	177	184	200	178
Job seniority [years]	25	18	2	24
Job experience with chainsaw [years]	25	16	–	14

served higher energy expenditure in winter, especially with the LTC method. Similarly, Rónay [27] recorded higher EE during timber harvesting in winter in deciduous stands. However, Kukkonen-Harjula and Rauramaa [20] did not observe significant difference in HR in loggers during timber harvesting carried out in autumn and winter.

Comparative studies of the physical workload of workers in a brickyard and a textile manufacturing company in Tunisia during Ramadan in summer and periods of non-fasting in summer and winter showed no significant differences [28]. The variability of HR in winter and summer was investigated in a study of scientific workers and safety inspectors [29]. Another study of heart rate strain during winter and summer work was conducted by Vitalis et al. [30] among Greek steelworkers.

The objective of the present study is to investigate the possibility that, besides many other well-known factors, the season may have an impact on physiological workload. This concerns mainly jobs performed outdoors, including all forest operations, especially timber harvesting, which is performed all year round irrespective of the ambient conditions. This paper is part of a comprehensive study on timber harvesting in young alder stands, the results of which on stand damage and productivity have been published [31,32].

MATERIAL AND METHODS

Participants

Two teams of 2 persons worked simultaneously in the survey areas during both felling and forwarding. The same group of workers was employed in summer and in winter. Felling and processing were conducted by 2 qualified and experienced loggers with their assistants. All workers carried out forwarding of the timber. All subjects were healthy, without chronic disease or current prescription medication. Detailed anthropometric and demographic information for the studied workers is given in Table 1. The subjects were informed about the purpose of the research and how the results would be used. Written informed consent was obtained from each subject.

Study area and work characteristics

The research was conducted in the Płaska Forest District (NE Poland). The survey area was located in 2 adjacent forest compartments (101 h and 132 c) in pure alder stands growing on a typical marshy alder forest site. The selected stands were aged 38 (101 h) and 40 (132 c) years, originating from planting. The average tree heights were 18 m (101 h) and 17 m (132 c). The average diameter at breast height in both stands was 15 cm [33].

The study concerned early thinning operations consisted of tree felling, delimbing and cutting of logs, as well as extraction of timber to a storage yard. The process was the first commercial thinning in these stands. Timber harvesting consisted of tree felling with chainsaws of type Makita DCS520-45 (5.4 kg) and Makita EA5000P38D (5.1 kg), delimbing, and bucking into logs with lengths of 1.2 m and 2.5 m. Forwarding was carried out with a Zetor 7045 (65 HP) farming tractor and a trailer with manual timber loading and unloading.

Twelve studied plots 0.25 ha in area were used in winter (January) and a further 12 in summer (August). In winter, the timber harvesting operations were performed on frozen ground and a snow layer with an average thickness of approx. 32 cm in sunny and windless weather. The air temperature during felling ranged from −11.8°C in the morning to −5.6°C during the warmest time of the day, during skidding from −17.6°C to −9.8°C, respectively. Summertime work was performed in August when the groundwater level was low enough for harvesting. The average air temperature during the summer was 23°C; it was sunny, there was a light wind. The whole process of timber harvesting in both seasons was carried out over 3–4 consecutive days.

Study procedure

Heart rate

Heart rate (HR) was measured using an RS800 wireless heart rate monitor (Polar Electro Oy, Finland) with beat-to-beat frequency acquisition. Working heart rate (HR_{work}) was measured for the entire working day (approx. 8 h) across all tasks, including rest periods. Resting heart rate (HR_{rest}) was identified as the lowest HR from 10 min of morning monitoring before work during rest in a seated position [19].

Relative heart rate at work (%HRR) was determined by applying the following formula [34]:

$$\%HRR = \frac{HR_{work} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100 \quad (1)$$

where:

HR_{work} – the average working heart rate,

HR_{rest} – the resting heart rate,

HR_{max} – the maximum heart rate estimated using the standard formula $HR_{max} = 220 - \text{age}$.

The ratio of working heart rate to resting heart rate was obtained as HR_{work}/HR_{rest} [35]. The 50% level of heart rate reserve (50%Level) was determined using the following formula [36]:

$$50\%Level = HR_{rest} + \frac{HRmax - HR_{rest}}{2} \quad (2)$$

Energy expenditure

The heart rate index was used to determine VO_2 using Wicks' equation [17]:

$$HR_{index} = HR_{work}/HR_{rest} \quad (3)$$

$$VO_2\ (ml \times kg^{-1} \times min^{-1}) = [(HR_{index} \times 6) - 5.0] \times [3.5\ \text{body weight (kg)}] \quad (4)$$

Next, energy expenditure (EE) relative to time ($kcal \times min^{-1}$) was calculated based on an energy equivalent for VO_2 equal to 5.0 $kcal \times l^{-1}$[37]. Finally, net energy expenditure (NEE) ($kJ \times min^{-1}$) was calculated by subtracting the basal metabolism rate (P) from EE [38]:

$$P(kcal \times day^{-1}) = \left(\frac{13.397m}{1\ kg} + \frac{4.799h}{1\ cm} - \frac{5.677a}{1\ year} + 88.362\right) \quad (5)$$

where:

m – body mass (kg),

h – height (cm),

a – age (years).

Statistical analyses

Statistical analyses were performed using the Statistica v. 11 software package (StatSoft Inc., Tulsa, OK, USA). Unpaired Student's t-test was applied to establish differences in HR between winter and summer in subjects performing particular jobs. Statistical analyses were carried out with the significance level $p < 0.05$.

RESULTS

Heart rate

Heart rate during work for loggers was 128.6 bpm and 137.9 bpm in winter and 113.9 bpm and 109.0 bpm in summer. For loggers' assistants it was 123.1 bpm and 149.4 bpm in winter and 113.9 bpm and 96.9 bpm in summer. For loaders, HR_{work} ranged 124.7–154.9 bpm in winter and 108.8–121.6 bpm in summer (Table 2). Significantly higher HR_{work} values were found during winter working than in summer for all workers (loggers: $t = 335.61$, $df = 1$, $p < 0.001$, loggers' assistants: $t = 383.32$, $df = 1$, $p < 0.001$, and loaders: $t = 277.30$, $df = 3$, $p < 0.001$). Analyzing the heart rate values for individual jobs without taking into account the season of the year, a similar level of load was recorded. The highest average HR was found in loaders (124.1 bpm), followed by loggers (122.3 bpm) and loggers' assistants (120.8 bpm).

Pre-work resting heart rates ranged 65–70 bpm in winter and 63–67 bpm in summer (Table 2). The average percentage heart rate (%HRR) during tree felling and processing (loggers and loggers' assistants) was 47.6, while in forwarding operations (loaders) it was 49.1. The respective ratios of working heart rate to resting heart rate were 1.84 and 1.89. The average 50%Level value was 125 bpm in both operations, and the ratio of working heart rate to 50%Level was 0.97 during tree felling and processing and 0.99 during forwarding.

The average percentage heart rates (%HRR) during wintertime timber harvesting in both operations were very similar (58.4 in tree felling and processing, 57.7 in wood loading) and significantly higher than the summer values (36.8 and 40.5, respectively). The ratio of working heart rate to resting heart rate during both operations performed in winter was twice as high as in summer. In summer, the ratio was 1.68 for tree felling and processing (loggers and their assistants) and 1.75 for the timber loading operation (loaders). In turn, the ratio of working heart rate to 50%Level was 1.07 in both operations in winter, while during summer working the ratio was 0.87 for tree felling and 0.91 for timber loading.

Energy expenditure

Net energy expenditure (NEE) values for all jobs ranged from 26.5 to 41.9 $kJ \times min^{-1}$ in winter, and from 17.8 to 29.6 $kJ \times min^{-1}$ in summer. With the exception of loader 4, NEE was higher in winter than summer (Table 2). For loggers, NEE in winter was similar in the 2 workers and was about 38 $kJ \times min^{-1}$. In summer, however, the difference in NEE between loggers was 5 $kJ \times min^{-1}$. For loggers' assistants, a greater difference in NEE was found in winter than in summer. Without considering the season, the highest NEE was found for loggers (32.8 $kJ \times min^{-1}$), followed by loaders (30.5 $kJ \times min^{-1}$) and loggers' assistants (26.2 $kJ \times min^{-1}$).

According to the current Polish classification [39], the work done in the particular jobs was classified as moderate or heavy physical work. With the exception of logger's assistant 1 and loader 4, NEE in winter exceeded 30 $kJ \times min^{-1}$, causing the work to be classified as very heavy.

DISCUSSION

Analysis of the mean working heart rates in all jobs indicated that motor-manual timber harvesting is a physically demanding activity. The obtained HR values correspond to the results of other studies. A study of Finnish loggers during winter work [20] recorded a workload of 123 bpm. Kirk and Parker [40] obtained an HR of 127 bpm

Table 2. Heart rate indices, oxygen consumption (VO_2) and energy expenditure (EE) for particular jobs during early thinning of alder stands in winter and summer in the Płaska Forest District (NE Poland)

Variable	Heart rate indice						VO_2 [ml/kg/min]	EE [kcal/kg/min]	Net EE [kJ/min]
	HR_{work} [bpm] (M±SD)	HR_{rest} [bpm] (M)	%HHR (M)	ratio (M)	50%Level (M)	HR_{work}/50%Level (M)			
Logger									
1									
winter	128.6±18.2	65	56.8	1.98	121	1.06	24.05	0.12	37.44
summer	113.9±21.5	63	44.6	1.81	120	0.95	20.47	0.10	30.31
2									
winter	137.9±17.7	67	60.6	2.06	125	1.10	25.72	0.13	38.37
summer	109.0±21.0	64	38.4	1.70	124	0.88	18.26	0.09	24.96
Logger assistant									
1									
winter	123.1±16.3	66	42.6	1.86	133	0.92	21.67	0.11	27.23
summer	113.9±20.6	67	35.3	1.70	132	0.86	18.20	0.09	21.37
2									
winter	149.4±23.3	70	73.5	2.13	124	1.20	27.32	0.14	39.07
summer	96.9±26.6	64	28.9	1.51	121	0.80	14.29	0.07	17.08
Loader									
1									
winter	136.5±15.8	65	63.8	2.10	121	1.13	26.60	0.13	41.00
summer	111.2±22.9	63	42.3	1.76	120	0.93	19.57	0.10	30.31
2									
winter	125.4±18.0	67	50.0	1.87	125	1.00	21.80	0.11	31.66
summer	109.5±22.5	64	37.9	1.71	124	0.88	18.43	0.09	24.96
3									
winter	154.9±21.4	66	66.3	2.35	133	1.16	31.79	0.16	41.90
summer	108.8±22.2	67	31.4	1.62	132	0.82	16.60	0.08	18.43
4									
winter	124.7±21.5	70	50.6	1.78	124	1.00	19.91	0.10	26.50
summer	121.6±20.5	64	50.5	1.90	121	1.00	22.40	0.11	29.65

for a chainsaw operator. Research by Grzywiński and Łukaszuk [25] during logging in a pre-felling pine stand indicated a load of 119 bpm on average for a woodcutter and 118 bpm for his assistant (without shortwood piling). In turn, Çalişkan and Çağlar [22] found that during felling and delimbing of spruce the HR ranged 110–132 bpm, averaging 122.8 bpm. Other studies report lower values, averaging 107 bpm [23], 108 bpm [16] and 115 bpm [41]. Apud and Valdes [4] found the average HR of a lumberjack during logging to be 114.2 bpm. In turn, Arman et al. [24] recorded HR during elements of tree processing work at 117.7 bpm (back cut 115.6 bpm, undercut 114.8 bpm). A similar average HR_{work} value of 117 bpm was reported by Seixas [42].

The results obtained confirmed the significant influence of the season on the heart rate and physiological cost during motor-manual timber harvesting. In winter the mean working heart rate values for individual jobs ranged 123.1–154.9 bpm, which corresponds to hard and very hard physical work [3]. During summer the mean HR_{work} for the analyzed jobs was significantly lower and ranged 96.9–121.6 bpm. These values allow summertime logging to be classified as moderate to hard physical work. The wide range of HR values represented in the results (96.9–154.9 bpm) may explain to some extent the variation in the HR results found in the literature. Since information regarding the time of year is rarely included in study descriptions, it can be assumed that the available results come from different periods of the year.

The observed differences in HR between seasons are in contradiction with the results of Kukkonen-Harjula and Rauramaa [20], who found no significant differences in HR during timber harvesting in autumn (10°C, snowless conditions) and in winter (–5°C, deep snow). This fact is puzzling, because snow cover strongly influences the physiological response of the body [43–45]. In addition, work in cold conditions requires the use of warmer clothing, which leads to an increase in the body weight of the employee and causes a reduction in motor skills. In such a situation, maintaining the mechanical efficiency of the body requires an adequate physiological response and greater expenditure of energy.

The mean physiological workload was 47.6% of the relative heart rate (HRR) during tree felling and processing (loggers and loggers' assistants), while in the loading operation (loaders) it reached a value of 49.1%. These values indicate that for all subjects the physiological cost is high, acceptable only for persons with a healthy cardiovascular system [3].

In general, this finding corresponds with the results of other studies. Eroglu et al. [16] and Melemez and Tunay [41] found the physiological workload during timber harvesting using chainsaws to be 40.9% and 42%, respectively. However, in another study conducted in Turkey [22], the %HRR of chainsaw workers was calculated at 44.79. Seixas [42] found an average HRR of 41% in chainsaw operators, whereas Kirk and Parker [40] reported a %HRR of 52. On the other hand, Cheta et al. [23] in a study conducted during timber harvesting in poplar stand in Romania found a %HRR of 34.38.

The mean ratio of working heart rate to resting heart rate in felling and processing activities was 1.84 and 1.89 during manual timber loading and unloading. A very similar value (1.84) was found for a choker setter in New Zealand [46]. The values of the HR_{work}/HR_{rest} ratio are higher than those reported in the literature for physically demanding activities such as work in the steel industry (1.28) [30].

The values of 50%Level and HR_{work}/50%Level support the findings based on %HRR. According to Lammert [34], if HR_{work}/50%Level is equal to 1, then the work being undertaken can be classified as hard continuous work. On this basis, the tasks of all workers in winter, having a mean value of 1.07, may be classified as hard continuous work. HR_{work}/50%Level during summerwork was 0.87 for tree felling and processing and 0.91 for timber loading, and thus falls short of the criterion for such a classification.

On the basis of HR_{index}, net energy expenditure values per minute were determined for all jobs. The NEE values were in general significantly higher in winter than in summer, ranging 26.5–41.9 $kJ \times min^{-1}$ and 17.8–29.6 $kJ \times min^{-1}$, respectively.

There is little reported information regarding differences in energy expenditure for timber harvesting operations in different seasons. Rónay [27] found a much higher energy cost in winter than in summer during harvesting in hardwood stands using the shortwood method, among others. Unfortunately, the author presented only the EE for a working shift, which makes comparisons difficult. Higher values of EE during shortwood system harvesting conducted in winter and in summer were also obtained by Chmielewski and Porter [26]. The authors presented the value of EE in relation to the volume of harvested wood (kcal/m^3). Logging was conducted in pine stands of age class III, where the average tree volume was higher than in the age class II stands analyzed in this study, which means that a direct comparison of the results may not be meaningful.

The usability of heart rate indices to determine the physiological strain of subjects in field situations is well-known and has been proven and validated in many studies. The use of HR to estimate EE is subject to certain limitations, due to:

– inability of HR to account for the anaerobic component of exercise, potentially causing underestimation of energy expenditure of high intensity;
– a disproportionately high response of HR at very low exercise intensities;
– the effect of environmental factors and within-subject variation on the HR/VO_2 relationship during activity [9].

Within the limitations of HR-based methods, HR_{index} is a low-cost and easy-to-use field method to estimate EE. The HR_{index} equation was developed retrospectively from aggregate data from 60 published studies. Its validation provided a reasonable estimate of metabolic demand [11,12]. This new method of EE estimation is useful when an energy expenditure value is required to classify the workload. This applies, for example, to the Polish classification of the heaviness of work and the determination of employees' entitlement to regeneration meals. The regulations on these matters are based on net energy expenditure values.

CONCLUSIONS

Based on physiological indicators, it can be concluded that the season significantly affects the physiological workload during logging operations. In all jobs, higher heart rate indices and energy expenditure values were recorded during logging performed in winter than in summer. Due to the high groundwater level and low bearing capacity of the ground typically found in alder swamp forest sites, they are often not accessible for machine logging. In this case, felling trees with a chainsaw will often be the only acceptable method of harvesting. If there is no possibility of harvesting wood in summer at low groundwater levels, in order to limit the workload of workers during winter activity, attention should be paid to the proper organization of work (length and distribution of breaks during the working day, time of work shifts) and selection of workers. Due to the level of physiological strain during motor-manual logging in winter, this work should be performed by younger workers (<40 years of age). The performance of such heavy work by older employees may lead to serious health consequences.

This study also shows that heart rate indices can be used as an effective means of determining the physiological strain of subjects in field applications. The use of the heart rate index (HR_{index}) equation gives the ability to estimate EE without personal discomfort or disruption to subjects' normal work routine. Additionally, in comparison with indirect calorimetry methods, heart rate measurement makes it possible to collect real time data from an entire working day easily and at low cost.

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