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Forestry work in the Italians alps: metabolic demand assessed by heart rate measurements.

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Abstract

Objective: This research aims to: a) assess the energy expenditure during typical forestry activities; b) assess the actual workload of forestry work; c) define the eventual relationship between oxygen uptake ($\dot{V}O_2$) and heart rate during the studied working phases.

Methods: Eleven healthy skilled forestry workers were studied. Using a portable device, oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), pulmonary ventilation ($\dot{V}E$) and heart rate (HR) were measured. The forestry work was divided into four phases: walking uphill, felling, limbing & chain-sawing and complementary activities. A work time report was kept and in each phase a weighted average (WA) of all parameters was obtained.

Results: Walking uphill, felling, limbing & chain-sawing activities did not show significant statistical differences between each other and were classified as heavy activities (mean $\dot{V}O_2$ 2.17 l min^{-1}, mean HR 157 beat min^{-1}). The complementary activity was found to be less demanding and statistically differed in respect to the others ($\dot{V}O_2$ 0.55 l min^{-1}, HR 98 beat min^{-1}). By the WA, the actual workload of forestry work resulted in a moderate to heavy-optimal job ($\dot{V}O_2$ and HR being 1.51 l min^{-1} and 133.5 beat min^{-1} respectively in a typical working day). Furthermore it was possible to set up a relationship between $\dot{V}O_2$ and HR for the forestry work.

Conclusions: Forestry activity can be classified as moderate to heavy-optimal. Finally, a good and linear correlation between $\dot{V}O_2$ and HR proved to be an easy tool to evaluate the metabolic demand.

Key words: oxygen uptake, work classification, heart rate, weighted average, working timetable

Introduction

The geomorphology and the climatic characteristics of Italian alpine forests seldom call for the use of automated processes in forestry work. Cutting trees is performed manually using only a chainsaw. The present study aimed to evaluate forestry workers' metabolic and cardiac activity when performing their typical daily activities; assessing the actual workload of forestry work and setting up a relationship to assess metabolic stress using heart rate.

In the literature there are just a few and outdated studies about metabolic and cardiac evaluation on forestry workers. With respect to metabolic demand, Kukkonen-Harjula [1] measured 1.9 l min^{-1} oxygen uptake ($\dot{V}O_2$) as mean value of the various phases of logging in Finnish workers. Hagen et al. [2] reported about 1.7 l min^{1} of $\dot{V}O_2$ as energetic cost for forestry tree felling in Norway. In the Italian alps, Cristofolini et al. [3] measured about 1.4 l min^{-1} $\dot{V}O_2$, 35 l min^{-1} ventilated air volumes ($\dot{V}E$). Moreover these last authors measured a mean heart rate (HR) of 140 beats/min^{-1} as the cardiac response. All authors indicated that felling trees was the main activity of forestry work. This activity, from an ergonomic point of view, can be classified as heavy work since it engages about 420 watts of metabolic power [3]. But, the above mentioned authors referred to different values of time spent performing this highly demanding task during a workday: Kukkonen-Harjula [1] assumed that these activities were performed for 5 hours/day, while Hagen et al. [2] made an assumption of 6 hour/day. Noteworthy, Hagen et al. [2] as well as Cristofolini et al. [3] defined percentages of time spent among work phases but all the aforementioned authors did not justify their assumptions according to a working day timetable on the basis of objective time data measurements. Furthermore, the cited studies assessed metabolic data using the Oxylog metabolimeter. This metabolimeter is not free from criticism. As Harrison et al. assert [4], the Oxylog is neither easy nor comfortable to carry, data are not automatically registered, response time is too long and carbon dioxide output ($\dot{V}CO_2$) is not measured.

The rationale to perform further investigations on the metabolic and cardiac demand of forestry workers is based on the convenience of assessing the workload, taking into account the time spent in several forestry activities. In this way the entire energy expense for the whole working day can be considered as the sum of the ponderate contribution of each activity. Furthermore, a more efficient portable metabolimeter was chosen. This one in addition to $\dot{V}O_2$, $\dot{V}E$ and HR also produced $\dot{V}CO_2$ data. Thus it was possible to calculate the respiratory exchange ratio (RER), i.e. the ratio between $\dot{V}CO_2$ and $\dot{V}O_2$. Finally, to suggest HR as an indirect, rapid and easy method for $\dot{V}O_2$ evaluation.

Measurements were carried out in a typical forestry environment with skilled professional workers, while the ergonomic classification of forestry work was carried out by comparing data collected with the standards in well-defined industrial jobs.

Material and methods

Methods

After local ethical approval, eleven subjects, belonging to the forestry division of Rovereto (Trento, Italy), were examined. The forestry division of Rovereto consisted of 28 worker. As a consequence, the number of enrolled workers is a representative sample. All subjects underwent periodical health inspections as requested by the Italian Ministry of Public Health Guidelines. No pulmonary, cardiovascular or muscular pathology were evident in their medical records. Workers were males between 29 and 51 years of age, with almost 10 years of extensive professional experience in the forestry industry. Subjects, after being informed on the techniques and the purpose of the research, gave their consent.

To define the subjects' physiological profile, before the evaluation of forestry activities and in the same environmental condition, the maximum aerobic power ($\dot{V}O_2$ max) was assessed in all subjects using the following indirect method: after recording 3 minutes of basal activity, the subject performed a step test with a 40 cm grade at a regular rate (20 steps min^{-1}). During the step test $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E$ and HR were measured with the metabolimeter. When both metabolic and cardiac parameters showed a steady state, and after at least 5 minutes from the beginning, the test ended. Thus, data collected were used to determine the $\dot{V}O_2$ max using the Åstrand's nomogram [5]. Data for $\dot{V}O_2$ max prediction were corrected for age as indicated in Åstrand, I. [6]. The $\dot{V}O_2$ max and the anthropometric characteristics of subjects, reported as average ± sd were: 3.3 ± 0.6 l*min^{-1}; age 39 ± 6 years; body mass 82.3 ± 10.3 kg; stature 1.77 ± 0.07 m; body mass index 26.5 ± 3.16 kg*m^{-2}.

All the measurements were carried out at an altitude ranging between 800 and 1100 meter in May and June. Temperature, air humidity and atmospheric pressure were among 18 and 26 centigrade degrees, 38 e 70% and 631 e 666 mmHg respectively.

In the forest yards data were collected during a typical workday. All measurements were performed during each of the four working phases reported below.

a) Walking Uphill. The subject, while carrying the chain saw (about 7 kg), a fuel tank (about 5 kg), and the tools they normally use (about 3 kg), walked uphill for about 500 meters to reach the tree-felling site;
b) Felling. Once upon arrival at the working site, the worker started to fell the selected trees;
c) Limbing & Chain-Sawing. After felling, the worker began to cut the branches and the bark; then each trunk was immediately cut into pieces about 5 m in length;
d) Complementary. During the intervals between felling and limbing & chain-Sawing phases, the worker supplied the chain saw with fuel, planned the next activity, and moved the trunk using mechanical tools, etc.

Each subject was requested to spend at least 30 minutes in each phase with the metabolimeter switched on. All gas volumes were corrected to standard temperature and dry pressure. All data were calculated during the last 15 min of each phase to exclude transient phenomenon of the metabolic and cardiac responses. As is conventional in exercise physiology, $\dot{V}O_2$ and $\dot{V}CO_2$ data were considered in ml kg^{-1} of BM; $\dot{V}O_2$ was also scaled as a percentage of the $\dot{V}O_2$ max of the subjects. Furthermore, energy expenditure was reported as equivalent metabolic (MET) deriving by $\dot{V}O_2$ data.

In addition, with regards to cardiac data, HR was normalized to the maximum (HRmax). The indirect measure of HRmax was estimated as 220 minus subject's age [7].

The percentage of the total working time dedicated to each of the aforementioned phases during a working day was computed from the daily activity record filled by the workers during a typical workday and from the reports of the working schedule of previous days.

Materials

The metabolimeter K4 (Cosmed, Italy) consisted of a facial mask incorporating a turbine the aim of which was to measure the $\dot{V}E$. A small percentage of the expired air was sent to a measure chamber (dimension 170*48*90 mm; unit and batteries weighting about 800 g) placed on the subject's back. In this chamber, the percentages of O_2 and CO_2 contained in the air sample were measured. Samples, collected every 30 seconds, were telemetrically transmitted to a receiver positioned about 30 m away from the subject. The receiver immediately printed the data, allowing an online evaluation, while simultaneously storing the same data in a magnetic memory. Subsequently data were transmitted on a PC for offline examination. Furthermore, the device also continually monitored and stored the HR values. The K4 is an ergonomic and comfortable tool that does not limit the subject during their work. Every day, the metabolimeter was calibrated with a 3 l syringe for the air volume and standard gas mixture (5% CO_2, 16% O_2 and rest N_2) for O_2 and CO_2 analyzers. The accuracy and reliability of the metabolimeters used were ascertained by Meyer and colleagues [8].

Weighted Average

Metabolic and cardiac parameters were computed as a weighted average (WA) taking into account the percentages of the working time spent in each activity. To do this, time spent in each forestry activity was computed as the percentage of the total working time. Hence, the values measured in each activity were scaled to the relative percentage and the WA was defined by the summing of these results.

Statistical analysis

In order to calculate the statistical power of sample size, complementary activities were compared with each others. The power was calculated to one side with $\alpha=0.01$ for n=11 and were 0.84 for $\dot{V}O_2$ and 0.98 for HR. It was hypothesized a (mean ± SD) 0.5 ± 0.3 and 100± 15 for complementary activity and of 1 ± 0.4 and 130 ± 20 for all others; $\dot{V}O_2$ and HR respectively.

Apart from the data presented as WA, all parameters are expressed as mean and standard deviation. The ANOVA method was adopted to evaluate the statistical significance of the results. The level of statistical significance was set at $p<0.01$.

Results

The report on daily work activity showed that the percentages of the total working time (7 hours per day) spent in the four working phases were approximately: 15% in Walking Uphill, 15% in Felling, 30% in Limbing & Chain-sawing and 40% in Complementary. These percentages were adopted to compute the WA.

The overall mean values of metabolic and cardiac data in each activity are shown in table 1.

It is noteworthy that all data were calculated on 30 epochs (15 min), a choice which gives them a statistical consistence. No significant differences were observed between Walking Uphill, Felling, Limbing & Chain-sawing phases in $\dot{V}O_2$, $\dot{V}E$, $\dot{V}CO_2$ and RER. On the contrary, during complementary activity, $\dot{V}O_2$, $\dot{V}E$ and $\dot{V}CO_2$ were 4-5 times less expensive than the others and these differences were shown to be statistically significant ($p<0.001$) for all of the variables. Also RER was shown to be statistically lower. Cardiac data did not vary between Walking Uphill, Felling, Limbing & Chain-sawing phases either, while the Complementary activity HR and the ratio between HR and HRmax were about 60% lower, with a significant difference ($p<0.001$).

In table 2 the WA of metabolic and cardiac data obtained in the present study are reported.

Table 1. Metabolic and cardiac data in each work phase. All values are reported as mean and standard deviation.

Work phases	$\dot{V}E$	$\dot{V}O_2$	$\dot{V}O_2$/BM	$\dot{V}O_2/\dot{V}O_{2max}$	RER	Emergy expenditure	MET	HR	HR/HRmax
	[l min^{-1}]	[l min^{-1}]	[ml kg^{-1} min^{-}]	[%]		[Kcal min^{-1}]		[beats*min^{-1}]	[%]
Walking Uphill	65.71	2.35	28.24	73.3	0.99	11	8	160	89.1
	± 15.5	± 0.49	± 5.1	± 10.8	± 0.08	±2.3	± 1.4	± 7	± 5.9
Felling	61.60	2.05	25.13	63.2	1	9.6	7.17	151	83.6
	± 16.7	± 0.3	± 4.2	± 14.0	± 0.08	± 1.4	± 1.2	± 21	± 12.1
Limbing &	62	2.12	26.01	65.3	0.97	9.9	7.43	159	88.4
Chain-sawing	± 15	± 0.29	± 4	± 13.7	± 0.05	± 1.4	± 1.14	± 17	± 10.4
Complementary*	19.86	0.55	6.57	14.71	0.85	2.5	1.88	98	55
	± 7.8	± 0.24	± 2.4	± 4.35	± 0.09	± 1.1	± 0.69	± 10	± 5.4

*All complementary phase data resulted significantly different with respect to the others ($p<0.001$)

Table 2. Metabolic and cardiac data: weighted averages (WA) of a typical workday.

For example WA of MET is equal to 5.25 and this value was obtained as follows: (MET Walking uphill (8) * 15% total working time + MET Felling (7.17) * 15% total working time + MET Limbing & chain sawing (7.43) *30% total working time + MET Complementary (1.88) * 40% total working time) * (total working time)$^{-1}$.

$\dot{V}O_2$ [l min^{-1}]	$\dot{V}O_2$/BM [ml kg^{-1} min^{-1}]	MET	Energy expenditure [Kcal min^{-1}]	$\dot{V}O_2$/$\dot{V}O_{2max}$ [%]	RER	$\dot{V}E$ [l min^{-1}]	HR [beats*min^{-1}]	HR/HRmax [%]
1.51	18.43	5.25	7	45.94	0.92	45.64	133.5	68.9

Table 3a. Work classifications: * Scherrer 1967, **Fox et al., 1989; * McArdle et al 1996.**

Work Classification	$\dot{V}O_2$ [l min^{-1}]	$\dot{V}O_2$/BM [ml kg^{-1} min^{-1}]	$\dot{V}E$ [l min^{-1}]	MET	RER
Moderate*	1.5		35	6	0.85
Heavy:		//			
Optimal	2	50	8	0.90	
Fatiguing	2.5		60	10	0.95
Moderate **	1.5	21	<35	<6	0.85
Heavy:					
Optimal	≤2	≤28	≤50	≤8	=0.9
Strenuous	≤2.5	<35	<60	<10	0.95
Moderate ***	1 ÷ 1.49	15.3 ÷ 22.9		4 ÷ 5.9	
Heavy	1.5 ÷ 2	23 ÷ 31		6 ÷ 7.9	

Table 3b. Work classification: Wells et al., 1957.

Classification	Energy expenditure [Kcal min^{-1}]	HR beats*min^{-1}
Light:		
Slight	<4	<100
Moderate	4-7.5	101-120
Heavy:		
Optimal	8-10	121-140
Strenous	10.5-12.5	141-160
Severe:		
Maximal	13-15	161-180
Exhaustive	>15	>180

Table 3c. Work classification: Soula et al., 1961.

Classification	VO_2/VO_{2max} [%]
Light	<25
Intense	25 - 50
Submaximal	50 - 75
Maximal	75 - 100
Exhaustive	>100

The comparison between WA (table 2) and table 3a have shown that forestry work can be classified as moderate to heavy-optimal

Comparing the WA data with table 3b and 3c, forestry work can be classified as light moderate with respect to the energy expenditure, heavy optimal with respect to the HR and intense with respect the $\dot{V}O_2$ % of $\dot{V}O_2$ max.

Finally, our data also confirmed that the classic relationship between $\dot{V}O_2$ and HR in the forestry work exists [5]. Considering the need to take also into account the subject's age, the $\dot{V}O_{2}$*BM^{-1} was correlated with HR*HR$_{max}^{-1}$. The correlation between $\dot{V}O_{2}$* BM^{-1} and HR*HR$_{max}^{-1}$, is reported in figure 1. In the same figure, the fitting value and the confidence intervals are shown.

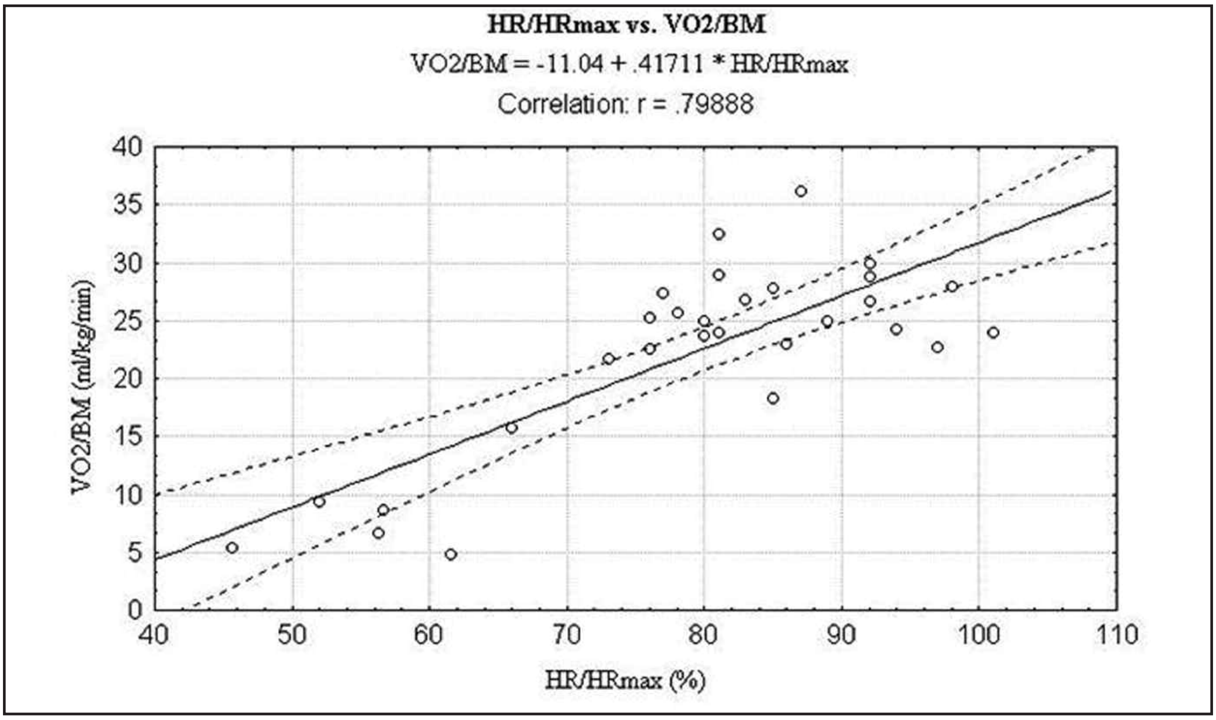
Discussion

In literature several papers investigates the energy demand requested during forestry activities. Moreover these studies assessed the cardio-pulmonary response for this activity. Some of the limitations of these studies were that the instrumentation used did not allow for the measurement of Carbon Dioxide output. As a consequence there are no indications on the metabolic process involved. Moreover, poor information was reported on working day timetable on the basis of objective time data measurements.The aims of the present study were:

1) to assess the time spent in each forestry activity and to weight the energy demand in each activity with relation to the time spent, in order to offer a more accurate total energy expenditure, and the working classification;
2) to identify the metabolic processes involved based on the Ratio Exchange Respiratory.

All subjects were healthy and $\dot{V}O_{2max}$ values scaled by body mass (in average 40 ± 3.8 ml kg^{-1} min^{-1}) indicate that these workers had a medium level of

Figure 1. Relationship between metabolic expenditure and the heart rate with respect to the maximum one. It is noteworthy that HR_{max} was estimated by using the standard formula of HR_{max} = 220-age. Dashed lines corresponding to the 95% confidence interval. The representative equation is: $VO_2*BM^{-1} = -11.04 + 0.4171 * (HR*HR_{max}^{-1})$.



physical fitness. Rodhal K. [7] refers analogous $\dot{V}O_2$ values in heavy job workers, including forestry workers. It must be taken into account that our $\dot{V}O_{2\,max}$ data were obtained by an indirect method; this procedure implies an underestimated result of about 15% [5]. Even if all subjects underwent a periodical health inspection and were fit for forestry work, it is necessary to take into consideration that the mean value for body mass index (BMI), was 26.3, which falls into the overweight- pre obese category (BMI between 25 and 29.9; [9].

Forestry activities are carried out in a particular geological environment, and the worker often performs his activity on a steep bank. This is considered as an energetically demanding condition because the worker is asked to maintain an unnatural and uncomfortable posture [10]. Thus, the muscle-skeletal apparatus is stressed by either the workload or by the environmental conditions. Moreover, the geomorphology of the Italian Alps often forces workers to walk for long distances on steep routes to reach the forestry yard. This fact explains the high energy demand for the uphill phase.

Considering the aims of this study, a detailed analysis of the results can be found below:

A) Ergonomic classification of forest work.

$\dot{V}O_2$ data, when computed as the mean of all phases (1.76 l min $^{-1}$) are consistent with those of Hagen et al. [2] (mean: 1.7 l min $^{-1}$), while Cristofolini et al. [3] presented data showing a lower result (mean: 1.4 l min $^{-1}$). Cristofolini et al. [3] suggested that the contributions of energy deriving from the anaerobic processes were not negligible. Using metabolimeter K4 it was possible to calculate the respiratory exchange ratio (RER), which did not exceed 1 among all phases (tab 2). Consequently, anaerobic metabolism can not be considered as an important contribution.

Moreover, considering the energy expenditure of forestry activities as MET, Ainsworth et al. [11] reported 8 MET for cutting trees and 9 MET for limbing trees. In the present research, except during the complementary phases, MET ranged from 7 to 8.

According to the work classifications reported in table 3a, Walking Uphill, Felling and Limbing & Chain-Sawing phases were shown to be heavy activities [12], as heavy-optimal-to-strenuous activities [13] or as heavy to very heavy activities [14]. Moreover, based on Wells et al. [15] and Soula et al. [16] classifications (tabs 4b, 4c), Walking Uphill, Felling and Limbing & Chain-Sawing phases were identified as heavy-optimal-to-strenuous and sub-maximal work respectively. In the light of the aforementioned classifications, it could be stated that these activities are on the border between heavy-optimal and strenuous effort.

On the other hand, considering the metabolic cost of a working day, as documented by WA data (table 2), a less severe assignment of the forestry work resulted. In fact $\dot{V}O_2$ BM $^{-1}$ and MET corresponded to a moderate activity, while $\dot{V}O_2$ and $\dot{V}E$ were on the border between moderate and heavy-optimal job (compare table 2 with table 3a); energy expenditure of forestry work resulted as moderate activity according to table 3b; metabolic expenditure, expressed as percentage of the maximum one, corresponded to intense activity, according to table 3c.

B) Cardiac Engagement.

Actual HR data were near to the maximum, higher than the figures expected on the basis of $\dot{V}O_2$ data. Perhaps this could be explained by the isometric (or near to isometric) activity of the arm, which often occurs during this type of work. The effect of isometric effort, as well as the work performed with the arms, on increasing HR is well known [5].

According to Wells et al. [15] the HR mean value corresponded to a heavy-strenous effort (tab 4b). Nevertheless, if the cardiac work is considered during the whole working day, i.e scaled on WA, it was less demanding than mean values. Hence, on the basis of WA, forestry work was shown to be a heavy-optimal job [15].

HR measurement is a non-invasive procedure and is easily and continuously performed with a cardiofrequency meter. The high correlation between $HR*HR_{max}^{-1}$ $\dot{V}O_2$ and BM^{-1} as well known in exercise literature [13], was confirmed also for forestry workers. This fact allowed us to set up the relationship shown in figure 1, through which it is possible to detect forestry $\dot{V}O_2$ consumption by means of only HR data collection. Using the equation reported in figure 1 the value can be easily detected. Particular work conditions and the characteristics of forestry $\dot{V}O_2$ work activities indicate the need for an easily detectable method to monitor these workers especially when care must be exerted on a large number of workers.

Conclusions

Based on the weighted average results, the Italian forestry workday activity resulted in a moderate to heavy-optimal job. Nevertheless, $\dot{V}O_2 * \dot{V}O_{2max}^{-1}$ and $HR*HR_{max}^{-1}$ weighted average suggest an involvement only of aerobic metabolism. This conclusion is confirmed by the RER values that never exceeded 1 in each work phase. These considerations suggest that forestry work can be safely performed for the cardiac and metabolic health even in alpine conditions.

Finally the relationship between oxygen uptake and heart rate can be a useful and easy tool to determine the physiological (metabolic) strain of subjects in applied field situation. The possibility to collect, in real time, HR data from a working subject with minimal personal discomfort or disruption from his normal work routine ensures the collection of accurate and relevant data. Data interpretation can be used to support decision making or job planning, to better engage workers in specific tasks and to prevent or mitigate any adverse effect on the worker's health and safety.

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