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DETERMINING PHYSICAL WORKLOAD OF CHAINSAW OPERATORS WORKING IN FOREST HARVESTING

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Abstract

Forestry in Turkey appears to be one of the most hazardous occupations with frequent and severe accidents and many diseases. Physically heavy work, inadequate working methods, tools and equipment cause occupational accidents, diseases and unnecessary fatigue. The improvement of safety, health, well-being and efficiency is a basic requirement for prosperity, and ergonomics is a very important tool for this. Chainsaw work is both physically arduous and potentially dangerous. A contributing factor to the high injury rate of loggers could be the high physiological and biomechanical load of chainsaw work. This study investigated the comparative cardiovascular load imposed on 46 chainsaw operators and 92 assistant employees during felling and delimbing under normal conditions. A practical application of ergonomic principles was utilized, considering heart rate as the indicator to evaluate the heaviness of chainsaw work. Also anthropometric dimensions and factors affecting work capacity to carry out physical effort with chainsaw were determined.

Keywords: Chainsaw, Heart rate, Logging, Cardiovascular load, Anthropometry

1. Introduction

The fact that human body is not appropriate for excessive work and human power falls short to do such kind of work requires technological developments. Forest operations differ greatly from industrial works in terms of ergonomics. Mechanization of forest operations has increased productivity since it has accelerated some phases of operations. Although there has been no physical development in human body, there have been lots of technological developments especially in this century.

Forest operations vary (felling, delimbing, logging etc.) and they are performed in different natural conditions (terrain, climate etc.) and with various instruments (chainsaw, axe etc.). Logging activities require considerable amount of physical energy, particularly with motor-manual operations. Harvesting is far more hazardous than any other forest operation [1]. Many logging systems in Turkey use a crew with one chainsaw operator and two assistant employees to fell and delimb trees.

Forest-labor productivity is perceived to be lower in developing countries than in industrialized nations because of socio-economic and cultural, factors that influence working and living conditions [2]. Physical work is performed as a result of muscle action. Andersen et al. have reported a close relationship between heart rate and oxygen consumption, with the rate increasing in proportion to work intensity [3]. Therefore, the physical workload can be estimated by comparing heart rates measured at rest and while working [4]. Thus, the higher the rate, the greater the physiological workload [5]. To efficiency supply oxygen to the body, the average heart rate during work should not exceed 40% of the range between the individual worker's resting rate and its maximum recorded under stress [6]. It is the circulatory system that carries the food which is the energy source of the body to muscles. An increase in the consumption of energy is met by an increase in heart rate. So, there is a strong relation between heart rate and energy consumption. Efforts to measure heart rate (i.e. taking the pulse) have proven to be one of the most useful ways to assess cardiovascular load because it can be done very easily [4, 7, 8].

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Machines that can fell and delimb trees are commonly used in developed countries, however they are expensive and complex. Motor-manual systems continue to be used in felling and delimbing activities in Turkey. It is therefore desirable to investigate opportunities to reduce the physiological workload of loggers working with chainsaws.

The two most common methods of measuring physiological workload are by oxygen consumption or direct heart rate monitoring [9, 10]. The measurement of oxygen consumption in the field presents problems of both practically and validity. To measure oxygen consumption the logger must wear a mask which may be uncomfortable and impede their performance, and therefore, true readings may not be obtained. Direct measurement of heart rate on the other hand can be reliably undertaken with little or no interference to the operator or their work cycle. Additionally, heart rate has the ability to measure total strain, unlike oxygen consumption which only measures energy expenditure [10]. Accordingly, heart rate data collection techniques [11] were used to estimate the physiological workload of the subjects during the particular study.

The purpose of this investigation was to compare the cardiovascular workload imposed by felling and delimbing with chainsaws in the steep terrain. During the operations with chainsaw in the forest, heart rate values of chainsaw operators and assistant employees which are the indicators of workload were measured. Then, factors which have effects on the physical workload in forest operations were shown using statistical analyses.

2. Material and Method

This study was carried out during the phase of felling trees in stand and transporting them near the forest road in the Zonguldak-Devrek Forest Enterprise in the Western Black Sea Region. During the operations of chainsaw operators and assistant employees (1+2), measurements and examinations were carried out.

In wood production operations, in order to find out the factors that affect workload; working area, social situation, anthropometric etc. characteristics of 46 operators and 92 assistant employees working in different regions were determined. Altitude (Al), temperature (Te), relative humidity (Rh), wind velocity (Wv), pressure (Pr), slope (Sl), ground hindrance (Gh=1: high hindrance, 2: hindered, 3: low), light (Li), noise (Ns), daily working time (Dw), duration of lunch break (Lb), duration of total breaks (Db), total years worked (Tw), age of the worker (Ag), educational status (Es=1: literate, 2: primary school, 3: secondary school, 4: high school, 5: university), number of persons in the family (Fp), working time within the year (Wm), smoking status (Sm=1: smoking, 2: not smoking), alcohol consumption (Ac=1: drinking, 2: not drinking), stature (St), eye height (Eh), shoulder height (Sh), waist height (Wh), knee height (Kh), shoulder breadth (Sb), shoulder-elbow length (Se), elbow-fingertip length (Ef), upper limb length (Ul), chest depth (Cd), body weight (Bw), heart rate while working (Hr) and heart rate while resting (beats/min) were all measured. With the help of the data obtained, workload of chainsaw operators and assistant employees were shown comparatively.

One hundred thirty eight apparently healthy males from the logging industry participated in the study. All were experienced chainsaw operators who had worked under normal logging conditions in Turkey. Before testing, all chainsaw operators were informed about the purpose of the study and told of their right to withdraw from the study at any time. Heart rates which indicate the physical workload of workers were measured both at rest and while working. Heart rates were measured at one-minute intervals for workers both at rest and while working continuously in normal operations. We used a Polar S610i heart rate monitoring system.

The chainsaw operator rested for 10 minutes to obtain a pre-work heart rate. Working heart rate was determined as the chainsaw started felling and delimbing. Heart rate was recorded throughout the study period. These heart rate responses have been expressed as a proportion of heart rate range (%ΔHRratio-Cardiovascular load) [12, 13]:

$$\%\Delta HR_{ratio} = \frac{HR_{work} - HR_{pre\text{-}work}}{HR_{maximum} - HR_{pre-work}} \times 100$$

HRwork : Heart rate while working
HRpre-work : Heart rate before working, while resting
HRmaximum : 220 - age (year), maximum heart rate adjusted for age

Table 1. Severity of Work in terms of VO2, Heart rate, and Energy expenditure*

Work severity	VO2 (L/min)	Heart rate (Beats/min)	Energy expenditure (kcal/min)
Light work	< 0.5	< 90	< 2.5
Moderate work	0.5-1.0	90-110	2.5-5.0
Heavy work	1.0-1.5	110-130	5.0-7.5
Very heavy work	1.5-2.0	130-150	7.5-10.0
Extremely heavy work	> 2.0	150-170	> 10.0

* Adapted from Astrand et al. (2003)

After the workload was determined, correlation analysis was performed to find the mutual relation among the data obtained. Factor analysis was used to combine the factors affecting workload under specific factors. Finally, work severity was divided into three categories taking the workload-heart rate relation into consideration and a discriminant analysis was performed. In statistical analysis, SPSS 11.0 statistics software was used.

3. Results and Discussion

3.1. Physiological workload

The table 2 was prepared to show the workload of chainsaw operators and assistant employees. In the table, heart rates while working, change limits, %ΔHRratio, average age of workers and heart rates at rest are all displayed.

Table 2. Average and Range of Heart Rates for Forest Workers

	Chainsaw operator	Assistant employee
Heart rate + SD	115±7	91±8
Range	103-130	75-106
%ΔHRratio	42	17
Age	46	38
Resting Heart rate	73	72

Heart rates at rest were found to be 72-73 per minute. In general, heart rates at rest ranges from 60 to 75 [13]. As can be understood from the table, the work of chainsaw operators is involved in the heavy workload (heart rate: 115) group. Also, the work of assistant employees is involved in moderate workload (heart rate: 91) group. %ΔHRratio of chainsaw operators was found to be over 40%, which is the limit for chainsaw operations [10, 15].

Shemwetta et al. (2002) found the average heart rate 118 beats/min during chainsaw operations, Kirk and Parker (1994) found a heart rate of 127 and %ΔHRratio 52 for the chainsaw operators aged about 35, Seixas (1995) found the average heart rate 117 and %ΔHRratio 41 while working with an operator and an assistant employee for chainsaw operations [4, 10, 16]. Working with System (1+1) in an eucalyptus plantation, Malinovski (1988) found an average heart rate of 105.5 beats/min for the chainsaw operator and 113.8 beats/min for the assistant employee [17]. The findings obtained in this study are similar to those of other studies in the world.

In table 3, the correlations among 31 variables which affect the operator and the assistant employee in terms of ergonomics in chainsaw operations are shown. The values which correlate to each other in 95% confidence level are shown as bold in the table. The highest positive correlations are between stature and eye height (r=0.969), stature and shoulder height (r=0.894), shoulder height and eye height (r=0.890), heart rate and noise (r=0.841) and between age and total years worked (r=0.840). On the other hand, the highest negative correlations are between daily working time and lunch break (r=-0.786), age and educational status (r=-0.759). It is seen in the table that the highest positive correlations are between anthropometric dimensions. This is a natural case. These anthropometric values concerning length have a close relation with each other. That heart rate correlates high to noise results from chainsaw operations. Heart rates are high because operators are exposed to much noise, they are affected by vibration and the weight of the chainsaw and they don’t wear protective equipment. The high correlation between age and total years worked is an expected result. Workers of old age have worked more than the younger ones.

When the highest negative correlations are considered; it is clear that daily working time and lunch break have a negative correlation. Having a longer lunch break requires that logging activities performed in the day must be done in a shorter period. It is understood from the table that the workers of old age is usually educated poorly. This is again quite common in developing countries.

Table 3. Correlation Analysis

	Al	Te	Rh	Wv	Pr	Sl	Gh	Li	Ns	Dw	Lb	Db	Tw	Ag	Es	Fp	Wm	Sm	Ac	St	Eh	Sh	Wh	Kh	Sb	Se	Ef	Ul	Cd	Bw	Hr
Al	1																														
Te	**-,608**	1																													
Rh	**-,193**	**-,385**	1																												
Wv	-,108	**-,299**	-,045	1																											
Pr	**-,423**	**,349**	,108	-,061	1																										
Sl	**-,602**	**,795**	**-,188**	**-,296**	**,385**	1																									
Gh	**,255**	**,585**	**-,659**	**-,449**	,143	**,399**	1																								
Li	**-,506**	**-,173**	**,291**	**,559**	,126	-,025	**-,677**	1																							
Ns	,015	**,316**	**-,325**	-,128	,106	**,236**	**,441**	**-,269**	1																						
Dw	**,477**	,002	-,164	**-,369**	**-,261**	,070	**,464**	**-,732**	,046	1																					
Lb	**-,568**	-,063	**,204**	**,493**	,120	-,046	**-,599**	**,771**	-,150	**-,786**	1																				
Db	**,532**	**-,479**	**,501**	**-,263**	-,061	**-,344**	-,094	**-,342**	**-,179**	**,408**	**-,564**	1																			
Tw	**,228**	**-,236**	-,063	-,002	**-,223**	**-,199**	-,101	-,133	**,306**	,105	-,083	**,204**	1																		
Ag	,126	,047	**-,248**	-,157	-,174	-,012	,137	**-,201**	**,334**	,052	-,092	-,004	**,840**	1																	
Es	-,020	-,131	,166	,008	,032	-,076	-,167	,150	**-,314**	-,076	,092	-,034	**-,720**	**-,759**	1																
Fp	**,212**	**-,174**	,139	-,097	**-,239**	**-,297**	-,105	-,177	-,161	,154	**-,184**	**,380**	**,510**	**,576**	**-,417**	1															
Wm	**-,497**	**,652**	-,097	**-,274**	**,360**	**,516**	**,316**	-,136	,097	-,061	,029	**-,309**	**-,364**	-,091	,016	-,167	1														
Sm	,107	**-,239**	**,251**	**-,218**	,047	**-,195**	-,153	-,070	-,088	-,081	,008	,134	-,057	**-,262**	**,375**	-,039	,042	1													
Ac	**,402**	**-,170**	-,149	**-,207**	**-,224**	-,142	,154	**-,258**	-,015	,074	**-,281**	**,185**	-,008	-,076	**,199**	-,025	-,051	**,530**	1												
St	**-,281**	,098	**,203**	-,031	,142	,126	-,166	,100	,019	-,067	,153	-,118	**-,413**	**-,341**	**,545**	**-,171**	**,254**	,001	**-,315**	1											
Eh	**-,231**	,033	**,175**	,036	,103	,059	**-,188**	,112	-,048	-,067	**,185**	-,133	**-,428**	**-,370**	**,560**	**-,178**	**,171**	-,027	**-,350**	**,969**	1										
Sh	-,120	,122	-,022	-,013	,064	,159	,027	-,042	,211	,023	,011	-,166	**-,277**	**-,202**	**,441**	-,147	,136	,049	**-,170**	**,894**	**,890**	1									
Wh	**-,455**	**,654**	-,144	**-,279**	,111	**,435**	,251	-,147	,197	-,009	-,044	**-,278**	-,104	**,180**	-,057	,137	**,509**	**-,270**	**-,252**	**,486**	**,456**	**,506**	1								
Kh	**-,219**	**,357**	-,114	-,165	-,010	**,337**	,144	-,112	,215	,070	-,094	**-,176**	**-,237**	-,112	**,281**	**-,184**	**,261**	**-,221**	,022	**,590**	**,558**	**,608**	**,697**	1							
Sb	**,329**	**-,284**	,144	-,025	-,075	**-,307**	-,006	**-,270**	**,243**	**,247**	**-,222**	**,321**	**,365**	**,344**	**-,310**	**,345**	-,133	-,163	**-,443**	**,189**	,153	,150	-,014	-,074	1						
Se	-,004	**,337**	**-,207**	**-,446**	**,297**	**,271**	**,475**	**-,396**	**,356**	**,287**	**-,282**	-,078	**,237**	**,381**	**-,372**	**,208**	**,307**	,142	-,090	,080	,031	**,208**	**,393**	,023	**,326**	1					
Ef	-,117	**,194**	-,040	,101	**,168**	,158	,149	-,162	,277	,061	-,026	-,091	,016	**,198**	-,146	,152	**,459**	**-,216**	**-,377**	**,428**	**,406**	**,472**	**,462**	**,237**	**,469**	**,402**	1				
Ul	**-,173**	,156	-,013	-,131	,067	**,237**	,010	-,013	,212	,056	-,021	-,135	,160	**,356**	**-,253**	**,295**	**,212**	**-,186**	**-,275**	**,492**	**,429**	**,569**	**,489**	**,303**	**,370**	**,515**	**,469**	1			
Cd	**,286**	-,132	-,079	,089	-,010	-,140	,164	**-,313**	,212	**,300**	**-,178**	**,180**	**,443**	**,440**	**-,481**	**,423**	,099	-,005	**-,268**	-,103	-,134	-,038	-,119	**-,351**	**,670**	**,430**	**,572**	**,285**	1		
Bw	**,268**	-,042	-,035	-,120	,123	-,138	**,296**	**-,379**	,313	**,351**	**-,246**	,163	**,425**	**,379**	**-,417**	**,282**	-,003	,142	**-,292**	-,088	-,103	,016	,014	**-,295**	**,588**	**,682**	**,373**	**,186**	**,765**	1	
Hr	,119	,068	-,137	-,019	,087	,013	**,244**	-,117	**,841**	-,063	-,061	-,039	**,289**	**,254**	**-,262**	-,139	-,147	-,071	,011	-,084	-,126	,098	,085	,135	**,220**	**,201**	,141	,108	,094	**,268**	1

3.2. Factor analysis

In forest harvesting operations, determining the workload in relation to each of 31 variables is quite difficult. Because in forestry, workload is the result of many factors which have complex relations among each other. Moreover, there can be more than one variable that have similar effects on workload. For this reason, it is important to measure workload using the most important variable instead of lots of variables. A factor analysis was made by applying Principal Component Analysis Method. Determining the most important variables and interpretation of factors were realized according to Varimax rotated factor matrix which was obtained as a result of a rotation and have a higher practical value.
Following the analysis of 31 variables which can be measured, 8 factor groups were found (Table 4, 5). Cumulatively with 8 factors, 84.56% of the total variance can be explained. In other words, nearly 85% of workload can be determined with these 8 factors. Then, 15% of workload depends on other factors which can't be measured or regarded to be stable.

Table 4. Rotation Sums of Squared Loadings

Component	Total	% of Variance	Cumulative %
1	4,560	14,710	14,710
2	4,268	13,769	28,479
3	4,246	13,696	42,175
4	3,504	11,302	53,476
5	3,427	11,054	64,530
6	2,291	7,390	71,920
7	2,059	6,643	78,563
8	1,859	5,997	84,560

While interpreting the factors, factor loads which are higher than 0.50 were taken into consideration as the absolute value. In order to represent the common characteristics of the variables, the variable having the highest factor load was chosen. Thus, each of the chosen variables represented a different aspect of workload.

Factors were classified as factor 1: stature, factor 2: terrain conditions, factor 3: daily working time, factor 4: body weight, factor 5: age, factor 6: noise, factor 7: humidity, and factor 8: harmful habits.

Table 5. Rotated Component Matrix

	1	2	3	4	5	6	7	8
Sh	,929							
St	,920							
Eh	,905							
Kh	,722							
Wh	,630	,563						
Ul	,623							
Te		,883						
Sl		,826						
Tw		,758						
Al		-,708	,579					
Pr		,587						
Lb			-,936					
Li			-,872					
Dw			,850					
Gh			,666					
Wv			-,612					

Cd		,874				
Bw		,827				
Sb		,664				
Ef		,614				
Se		,545				
Ag			,883			
Tw			,785			
Fp			,741			
Es			-,709			
Hr				,940		
Ns				,878		
Rh					,894	
Db	,526				,667	
Sm						,917
Ac						,681

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

The most important variable groups obtained as a result of factor analysis can be compared to those developed by Bridger (1995) [18]. He classified factors affecting physical work capacity like as personal (age, body weight, gender, alcohol consumption, tobacco smoking, training, nutritional status and motivation) and environmental (air pollution, climate, noise, altitude, protective clothing and equipment). In factor analysis, it was aimed at finding the factors that affect workload the most by analyzing dependent and independent variables. Physical and mental workload depends on factors such as age, sex, body size, health, nutritional status and training.

4. Conclusions

Felling trees is a high intensity physical work and a dangerous activity that requires training, personal protective equipment, and continual attention. Many factors can influence a worker's capacity to carry out physical work. Some of the more common personal factors are stature, body weight, age, alcohol consumption, tobacco smoking and training.

In this study, it was determined that the operations of chainsaw operators were classified as heavy work, and the operations of assistant employees as moderate work in terms of physiological workload. The most important factors that have influence on physiological workload are stature, terrain conditions, daily working time, body weight, age, noise, humidity and harmful habits. Taking these into consideration, active precautions should be taken concerning the work conditions of especially the chainsaw operators. Physical properties (stature, weight etc.) should be assigned importance while selecting the operators, daily working time should be scheduled keeping the rest breaks in mind, chainsaws should be changed with less harmful (noise, weight etc.) ones and alcohol consumption and smoking of workers should be decreased to minimum level possible. Chainsaws must be produced in quantity and quality protecting the workers and the environments. Ergonomics can make an important contribution to improve work methods, techniques and the organization of work.

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