African Journal of Biotechnology Vol. 9(35), pp. 5651-5658, 30 August, 2010
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2010 Academic Journals

Full Length Research Paper

An assessment of physiological workload of forest workers in felling operations

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Accepted 16 July, 2010

This study examined the physical strain experienced by chainsaw operator and the applicability of heart rate indices for measuring physical strain in forest felling operations in north eastern region of Turkey. The heart rate of ten chainsaw operators were recorded continuously throughout the working day and applied to heart rate indices. The average working heart rate was 122.8 beats/minute (bt. min^{-1}), while the pre-work resting heart was 70.5 bt. min^{-1}. The average physical workload (%HRR) rate range was 44.79, while the ratio of working heart rate to resting heart rate was 1.74. The average ratio of working heart rate to 50% level was 0.97. The workers had a mean estimated maximum aerobic capacity ($Vo_{2\ max}$) of 43.34 milliliters per kilogram and minute (ml kg^{-1} min^{-1}). All physiological measures placed the task of chainsaw operations in the heavy workload categories. Average hourly production decreased from 8.5 m^3 in the morning to 7 m^3 in the afternoon. The cutting-falling phase accounted for 30% of the hazards, with the remaining 70% occurring during branch cleaning. This study also shows that heart rate indices can be used as an effective means of determining the physiological strain of subjects in applied field situations. The workers will achieve optimum physical and mental performance if they are provided by an adequate fluid and food throughout the day.

Key words: Forest, felling operations, chainsaw operator, physiological workload, heart rate.

INTRODUCTION

Turkey has 21.2 million hectare forests and they constitute 27.2% of the country area. The yearly average growing stock is 11.3 million cubic meters (OGM, 2006). The productivity of Turkey forests is 36 million m^3 and the volume, which must be harvested in the management plans, is 16 million m^3. On the other hand, annual wood production is about 13.5 million m^3 and 60% of this figure is industrial wood (Engür et al., 2007).

Technical phases for timber harvesting are: felling (cutting and falling, branch cleaning, peak taking, bucking and debarking), timber haulage (taking out the log by dragging it near the chopped wood and then carrying it) and transportation (taking it from the roadside to store at wood processing centers) (Karaman, 2001).

Timber harvesting and transportation operations have been carried out by mostly forest villagers and rarely forest contractors. The constitution, forestry laws and regulations dictate that all forest works should be realized by forest villagers or their cooperatives nearest to their workplace. Forest workmanship provides vital economic contributions, especially for forest villagers, which comprise about 7.6 million people (10.6% total national population) living over 20,500 forest villages (Engür et al., 2007).

According to ILO, forest workmanship is accepted as a hard labour because it is characterized with difficult dirty-dangerous working environment, heavy physical effort and high accident risks. Technical, social, psychological and environmental factors, as well, are required for the forest workmanship to be evaluated as hard works (ILO, 1998).

Physical work is performed as a result of muscle action. During aerobic combustion, those muscles use oxygen to transform food into mechanical energy. The more energy is required to carry out a given task, the more oxygen is needed to necessitate the increased blood circulation. Consequently, a higher heart rate has reported a close

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Abbreviations: **BMI,** Body mass index; **HRr,** resting heart rate; **HRw,** working heart rate; **%HRR,** percent heart rate; **$Vo_{2\ max}$,** maximum oxygen consumption capacity.

relationship between heart rate and oxygen consumption, with the rate increasing in proportion to work intensity (Abeli et al., 1994; Galinsky et al., 2000; Vısser et al., 2004; Huysmans et al., 2006). Therefore, the physical workload can be estimated by comparing heart rates measured during resting and working.

The part of human body that revealed the physical condition of the most important physiological criteria in the press is oxygen consumption. Oxygen consumption is directly related to the heart beat. These parameters are used to determine metabolic energy consumption (Roja, 2005; Rehn et al., 2009). Works directly showing oxygen consumption of the heart is an important indicator which shows that the heart works hardly during heart beat and resting. Because of the fact that active muscles and also the heart need more O2 than relaxed muscles, O2 consumption of the heart and the size of work is associated directly with contraction ratio of the heart. This is due to the fact that, the heart and active muscles need more O_2 than relaxed muscles. O_2 consumption of the heart and the size of work done by the heart are associated directly with contraction ratio of the heart (Wilmore and Costill, 1994; Dababneh et al., 2001).

Work capacity, aerobic capacity or cardiovascular endurance level is usually the maximum oxygen consumption capacity ($Vo_{2\ max}$) determined by measurement. Max Vo_2 aerobic energy system and the functional power capacity +are the most current measurement methods. Oxygen consumption (in liters per minute (L/min) or as milliliter per minute (ml/min)) of the body to press each kilogram per minute and the amount of O_2 milliliter (ml/kg/min) are expressed as well (Sönmez, 2003; Scott and Christie, 2004).

It is universally accepted that manual forestry work is considered 'high risk' employment. These risks are predominantly due to the labour-intensive nature of tasks, as well as the natural and material hazards, all of which contribute to an increased threat of injury to the forestry worker (Driscoll et al., 1995; ILO 1998; Bentley et al., 2002; Wästerlund et al., 2004; Okunribido et al., 2008). Kirk and Parker (1994) conducted, in New Zealand, a variety of forestry research activities in which employees were examined in terms of physiology. Employees and work conditions of different land types in the average heart rate values are given as a comparison. Moreover, physiological workload (%HRR) value has been found for afforestation work (60%), chainsaw (52%) and cable crane (37%).

Parker et al. (1999) in New Zealand, assert that 11 operators used chainsaw in cutting down the hedge and tree branches. With relevant researches, polar heart rate measuring devices and measurements taken as a result of physiological workload were found for StihlO36 (29.9%), StihlO44 (31.8%) and StihlO66 (36.7%).

Kirk and Sullman (2001) studied the physiological measurements during wood extraction in New Zealand from the four workers related to the work load. The physiological work load value was found to be 36.4%, when the average heart rate value was 106 beat/min at different job levels, terrain, slope, etc., as a result of their experiment. Shemwetta et al. (2002) in Tanzania, assert that forest industry workers and their productions were studied and the heart rate value was found when they were working with their hands for loading (178 beat/min), cross-cutting (133 beat/min) and cutting and debarking (121 beat/min).

The purpose of this paper is to determine the physiological workload of forest workers (ten chainsaw operators) during the cutting-falling and branch cleaning activities that occur under timber harvesting conditions in north eastern Turkey.

MATERIALS AND METHODS

Study location

The location of the research is 38° 01' 49" - 38° 13' 16" E, 40° 42' 47" - 40° 30' 13" N and 900-1500 m above sea level. The study area was located in spruce (*Picea orientalis*) forest in north eastern Turkey (Figure 1). The region has a per-humid climate with a mean annual temperature of 14.2℃ and a little seasonal variation. The maximum temperature is 37.3℃, while the minimum temperature is -9.8℃ 'dir. The average annual precipitation is about 1297.8 mm. The average rate of relative humidity is 76% and the region in July - August months are the warmest months (SMAGD, 2005).

Measurements and observation were done for the felling (cutting-falling and branch cleaning) of spruce areas at Giresun Forest Enterprise District in summer months, when there was effective production.

The subjects of the study are ten chainsaw operators working in cutting-falling and branch cleaning operations. A working day consists of 8 h from 08:00 to 17:00, with one hour rest break at 12:00 - 13:00.

Physiological measurements

Heart rate

The number of heart beats per minutes (pulse) is determined by the range method for the physiological workload. For this purpose, polar S610i brand pulse time meter and the polar belt was used. This device sends the pulse data taken by polar belt from the heart region, for 5 s, to the polar clock. The polar clock can measure the pulse data, for 5 seconds, and the amount of consumed energy and by its infra-red apparatus, the data can be transferred to a computer.

Measurements and calculations of physiological workload of the heart beat values are classified according to Table 3 (Vitalis, 1987; Parker et al., 1999; Kirk and Sullman, 2001). From the calculations of physiological workload, values were grouped to identify the class operation in terms of cutting-falling and branch cleaning results. Relative heart rate at work (%HRR) was determined by applying the formula (Vitalis, 1987).

$$\%\,HRR = \frac{HRw - HRr}{HR\ \max - HRr} \times 100$$

where, HR_w is the average working heart rate, HR_r is the resting heart rate, HRmax is the maximum heart rate that was estimated by using the standard formula of HR_{max} : 220 (Age). 50% level of heart rate reserve (50% level) was determined using the formula by (Lammert, 1972):

$$HRr + \frac{HR\ \max - HRr}{2}$$

Figure 1. The location of research area in Giresun Forest Enterprise Region.

Ratio of HR_W to HRr was obtained using the formula (Diament et al., 1968):

$$\frac{HRw}{HRr}$$

Estimated $Vo_{2\ max}$

Operators' ages, heights, weights, birth dates and other user information such as status of sport were recorded in the polar clock. To determine the maximal oxygen consumption and the maximal heart beat of the operators, the fitness test module was run, while the operators were resting. Approximately, maximum oxygen consumption (**$Vo_{2\ max}$**) was automatically calculated and recorded in the polar clock for a time period of 4 - 5 min.

Production measurements

Work activity

Continuous time study was undertaken to determine the percent of working day spent on each task. The volume of timber felled per hour in a day by each faller was derived by multiplying the number of trees felled by the average stem volume in cubic meters (m^3).

Workplace, work conditions and work process change irregularly in felling processes and study forms were prepared according to this change. Time periods for every course were calculated as 1/100 min (PM) with a chronometer, while the amount of time done was determined as number and m^3. Other factors affecting the study (the kind of tree, diameter, height, slope, ground flora, ground litter and land roughness) were also recorded. There was no interference with workers starting or finishing time, breaks and dealing with other things. The heart rate and work activity data were merged using a Pentium IV 1.66 GHz personnel computer (PC) and the spreadsheet package ''Microsoft Excel Version 2003''.

Slope and hindrance

Ground slope was measured using a Sunnto inclinometer. Hindrance rating was determined using the subjective rating system as outlined in (Kirk et al, 1996), with 1 = low, 2 = hindered, 3 = high hindered and 4 = extreme hindrance. The temperature was measured using thermometer, pressure using barometer and altitude using altimeter.

Safety

Hazardous cutting-falling and branch cleaning situations and techniques as defined and modified by Parker and Kirk (1993), were used to determine hazard type, ratio and frequency of occurrence

RESULTS AND DISCUSSION

Subject

The physical characteristics of each subject are shown in Table 1.

$BMI = \frac{W}{H \times H}$, (20 = under weight, 20 – 25 = correct weight, 25 – 30 = over weight)

The workers had a mean age of 33.9 years (range: 24 to 51), height of 1.78 m (range: 1.67 to 1.90) and weight of 79.8 kg (range: 70 to 98) (Table 2). Their mean body mass index of (BMI) 25.18 (range: 23.10 to 27.10) revealed that they were the correct weight for their height. The workers had a mean estimated maximum aerobic capacity ($Vo_{2\ max}$) of 43.34 milliliters per kilogram for every

Table 1. Physical characteristics of subject.

Subject	1	2	3	4	5	6	7	8	9	10
Age (years)	42	51	25	28	27	24	30	34	40	38
Weight (kg)	98	78	80	75	77	79	70	76	82	83
Height (m)	1.90	1.76	1.85	1.80	1.72	1.83	1.67	1.73	1.75	1.78
Body mass index (BMI)	27.1	25.2	23.4	23.1	26.0	23.6	25.1	25.3	26.8	26.2
Resting heart rate (bt. min^{-1})	70	69	72	76	71	67	72	70	65	73
Estimated $Vo_{2\ max}$ (ml kg-1 min^{-1})	44.6	38.6	44.7	44.3	41.4	52.0	42.8	40.5	41.0	43.5
Average working heart rate (bt. min^{-1})	124	110	130	125	132	122	127	124	118	116
Percent heart rate range (%HRR)	50.0	41.0	47.2	42.2	49.9	42.6	46.6	46.5	42.4	39.5

Table 2. Mean working heart rate indices.

Subject	Age	Height	BMI	Vo_2	HRw	HRr	%HRR	Ratio	50% level	HRw 50% level
1	42	1.90	27.10	44.60	124	70	50.0	1.77	124	1.00
2	51	1.76	25.20	38.60	110	69	41.0	1.59	119	0.92
3	25	1.85	23.40	44.70	130	72	47.2	1.81	133	0.98
4	28	1.80	23.10	44.30	125	76	42.2	1.64	134	0.93
5	27	1.72	26.00	41.40	132	71	49.9	1.86	132	1.00
6	24	1.83	23.60	52.00	122	67	42.6	1.82	121	1.01
7	30	1.67	25.10	42.80	127	72	46.6	1.76	131	0.96
8	34	1.73	25.30	40.50	124	70	46.5	1.77	128	0.97
9	40	1.75	26.80	41.00	118	65	42.4	1.82	122	0.97
10	38	1.78	26.20	43.50	116	73	39.5	1.59	127	0.91
Mean	33.9	1.78	25.18	43.34	122.8	70.5	44.79	1.74	127.1	0.97

BMI, Body mass index; HRr, resting heart rate; HRw, working heart rate; %HRR, percent heart rate; $Vo_{2\ max}$, maximum oxygen consumption capacity.

minute (ml kg^{-1} min^{-1}) (range: 38.60 to 52.00), indicating that they possessed aerobic capacities above the average range (Table 2).

Physiological workload

Heart rate results are shown in Table 2. The average work heart rates range from 110 - 132 bt. min^{-1} with the overall average being 122.8 bt. min^{-1}. The pre-work resting heart rates ranged from 65 to 73 bt.min^{-1} with an overall average of 70.5 bt. min^{-1}. The average physical workload (%HRR) rate range was 44.79, while the ratio of working heart rate to resting heart rate was 1.74 (Figure 2). The average ratio of working heart rate to 50% level was 0.97. The 50% level and HR_/50% level indices support the %HRR findings. Lammert (1972) suggested that the 50% level can be successfully used as a simple and elective way of measuring strain. Lammert (1972) stated that if the heart rate at work/50% level is equal to 1, then the work being undertaken can be classified as hard continuous work.

Physiological workload average value (HRR, 44.79%) is examined in terms of weight when the chainsaw is heavy and the work is determined to be in its class. Heavy on the features of the business group (7.5 to 10 kcal per minute between energy consumption), the number of heart beat was found to be between 110 and 130 (Table 3). The average heart rate value of forest workers in Tanzania during rest was found to be 68 beat/min (Abeli et al., 1994). Based on an estimated maximal oxygen consumption value of 40 ml kg^{-1} min^{-1}, which was obtained from South African soldiers of a similar ethnic origin (Christie and Scott, 2005), these workers, during the last workload were working at approximately 75% of $Vo_{2\ max}$.

With chainsaw, such as cable crane, to cut, cross-cut and skid, various forestry activities that varied between 60 to 31% of physiological workload were determined (Kirk and Parker 1994, Kirk and Sullman, 2001). Working with Chilean forestry workers, Apud (1983) reported a mean heart rate and oxygen uptake (Vo_2) of 109 bt.min^{-1} and 1.36 L.min^{-1}, respectively over the course of a chainsaw operator's shift. In overall, Chilean chainsaw operators were found to expend 3729 kcal during the working day. Analysis of the mean working heart rates (106 bt. min^{-1}) indicated that choker setting is a moderate workload activity (Rodahl, 1989). This overall average

Table 3. Grades of physical work.

Grade of work	Energy expenditure (kcal/min)	Energy expenditure 8h (kcal/day)	Heart rate (beat per min)	Physiological workload (%)
Resting	1.5	<720	50 - 60	0 - 10
Very light work	1.6 - 2.5	768 - 1200	60 - 70	10 - 20
Light work	2.5 - 5.0	1200 - 2400	70 - 90	20 - 30
Moderate work	5.0 - 7.5	2400 - 3600	90 - 110	30 - 40
Heavy work	7.5 - 10	3600 - 4800	110 - 130	40 - 50
Very heavy work	10.0 - 12.5	4800 - 6000	130 - 150	50 - 60
Unduly heavy work	>12.5	>6000	>150	>60

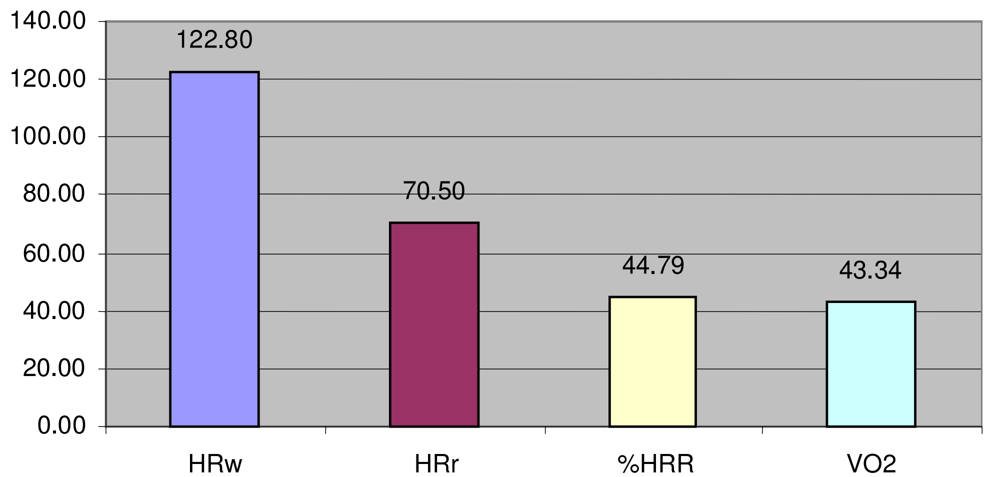

Figure 2. The average distribution of cutting workers' heart beat.

falls at the lower end of the range found by Kirk and Parker (1993) (107 - 120 bt. min^{-1}).

Slope and hindrance

Ground slopes ranging from 25 to 45%, has a mean of 35%, while hindrance ratings from 1 to 4, has a mean of 2.7. This equates to the high and extreme hindrance.

Hazards

An average production per faller of 86 m^3 for every day generated an average of 20 hazards per 100 stem, with 30% of the hazards occurring in the cutting-falling phase and 70% occurring in the branch cleaning of the operation. The most frequently occurring type of hazard was kickback, followed by poor technique and slip/fall hazards. Poor technique included such things as using the chainsaw one-handed or above shoulder height, incorrect placement or use of felling cuts (Figure 3).

Bentley et al., (2002) reports that in New Zealand, 17.5% of all lost time injuries were a result of slips, trips and falls. Material risks in forest harvesting include falling trees and loose branches which are a direct result of forestry operations themselves. Even small trees and branches on the ground can be extremely dangerous and can cause serious injury. The handling of trees during felling, cross-cutting, debarking, stacking and transporting is risky and the forces involved may lead to serious injuries (ILO, 1998). In contrast to other tasks in forestry, harvesting is particularly hazardous, thereby contributing between 38 and 90% of all the accidents in the industry (ILO, 1998; Manyuchi et al., 2003). Although, falling trees and hand-held machinery increase this risk, it has been argued that injuries in forestry are predominantly due to the tremendous biomechanical and physiological load associated with the type of work required (Kirk and Parker 1994; Parker et al., 1999; Manyuchi et al., 2003; Kukkonen and Rauramaa, 1984; Gaskin, 1990; Straker et al., 2009).

Production

Average hourly production decreased from 8.5m^3 in the morning to 7m^3 in the afternoon. The fallers spent most of

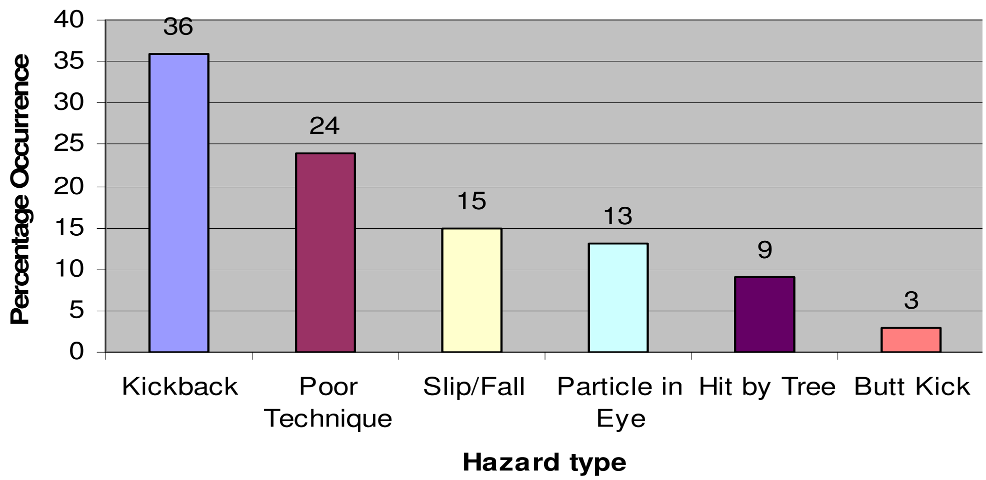

Figure 3. Hazard type and percentage occurrence.

Figure 4. The Chainsaw Operator; a: cutting, b: falling, c: walking and d: branch cleaning.

their working time, during the entire working day, undertaking the tasks of branch cleaning (46%), felling (23%) and selecting the next tree to fall (10%). Figure 4 (a to d) highlights some of the many tasks undertaken by the chainsaw operator. These include the main tasks of cutting (Figure 4a) and falling (Figure 4b), in addition to several sub-tasks such as preparation of the work area, walking between trees and logs (Figure 4c) and branch cleaning (Figure 4d).

Conclusions and recommendations

In this study, the physical strain experienced by the chainsaw operator and the applicability of heart rate indices for measuring physical strain were examined in forest felling operations in north eastern Turkey. The conclusions from this study were briefly given below. The average work heart was 122.8 bt. min^{-1} when the pre-work resting heart was 70.5 bt. min^{-1}. The average physical workload (%HRR) rate range was 44.79, while the ratio of working heart rate to resting heart rate was 1.74. The average ratio of working heart rate to 50% level was 0.97. The workers had a mean estimated maximum aerobic capacity ($Vo_{2\ max}$) of 43.34 milliliters per kilogram for every minute (ml kg^{-1} min^{-1}). According to those values, all physiological measures were placed to the task of chainsaw operations in the heavy workload categories.

Average hourly production decreased from 8.5 m^3 in the morning to 7 m^3 in the afternoon. The hazard was calculated as 30% for the cutting-falling phase and the remaining 70% for branch cleaning. This study also shows that heart rate indices can be used as an effective means of determining the physiological strain of subjects in applied field situations. The workers will achieve optimum physical and mental performance if they are provided with adequate fluid and food throughout the day.

Forest workers, undertaking chainsaw operations, should have some rest, observe frequent short pauses and take fluid to achieve an optimal work rate in terms of constant productivity, sustainable physical strain and low hazard ratios over the full working day. Likewise, providing a good working environment that includes safety tools and meals could greatly reduce the physical workload and improve productivity.

ACKNOWLEDGEMENT

The authors wish to thank Dr. Selahattin Şimşek for his contributions to this paper.

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