

# Physiological Workload of Chainsaw Felling and Processing Workers in Uneven-aged Mixed Stands

Opterećenje radnika tokom sječe i izrade motornom pilom u raznodobnim mješovitim sastojinama

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## ABSTRACT

Forest harvesting in Bosnia and Herzegovina is done by chainsaws in felling and processing phase, and cable skidders in skidding phase in most cases. The aim of study was to determine physiological workload of chainsaw operator in felling and processing of wood assortments on the basis of the measurement of a heart rate. The research was carried out in mixed uneven-aged stands of Silver fir (*Abies alba* L.), European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) Karst.) managed by two Cantonal Public Enterprise in Bosnia and Herzegovina. Heart rate was measured using Garmin Forerunner 35 GPS Running Watch with Wrist-based Heart Rate (Garmin Ltd., United States) with continuous data logging and storage of heart rate readings. Felling and processing works were recorded with action camera during whole working day. Time study was performed based on made videos. The average working heart rate (effective time and delays) was 117 bpm (beats per minute) for subject A and 113 bpm for subject B. The results of Kruskal-Wallis test showed significant differences for average heart rate in relation to time study element. The average heart rate reserve (%HRR) was 47.15% for subject A and 50.00% for subject B. The study results showed that heart rate reserve of chainsaw operator during tree felling and processing exceeded value of 40% which corresponds to heavy work and may have negative impacts on the health of the workers.

**Keywords:** forest harvesting, ergonomy, heart rate reserve, Bosnia and Herzegovina.

## INTRODUCTION – Uvod

The forests in Bosnia and Herzegovina are mostly uneven-aged with natural regeneration. Forest harvesting is done by chainsaws in felling and processing phase, and cable skidders in skidding phase in most cases (Sokolović & Musić, 2009; Halilović et al., 2013; Marčeta et al., 2014; Halilović et al., 2015).

Works in forestry have specific characteristics that distinguish them from other industry sectors, which are

manifested through the subject of work and working conditions (Kulušić, 2000; Lipoglavšek & Staudt, 2005). The forestry workers are exposed to above-average physiological workload for almost entire working lifetime (Vondra, 1995; Martinić, 2006) due to a significant share of manual work, work with machines with proven harmful effects and constantly changing outdoor working conditions. All these factors make the work site of a forest worker one of the most dangerous, with a high probability of injury during working lifetime or suffering

from occupational diseases, which shortens working and life expectancy (Šporčić et al., 2015; Eroglu et al., 2015a).

The negative effects of works in the forestry to worker's health and safety are especially expressed in forest harvesting. This study is based on the phase of felling and processing of wood assortments due to partial mechanization of works, ie the use of motor-manual means of work (chainsaws) which causes significant physiological workload. Tree felling is a physically demanding and dangerous job (Grzywiński, 2015; Bačić et al., 2020) which involves training, use of protective equipment and continuous attention (Melemez & Tunay, 2010). It may have negative impacts on the health of the forest workers and increase the prevalence of work-related musculoskeletal disorders (Arman et al., 2021). The most share of forced working postures occurs during tree felling with a chainsaw (Grzywiński, 2015).

Ergonomic research conducted in forestry for decades (Tomanić, 1995) aims to humanize work by improving the characteristics of means of work, as well as determining the organization of work in which workers are exposed to the least physiological load.

The physiological stress of workers in forestry can be established on the basis of the measurement of a constant heart rate (Robek & Medved, 2006; Grzywiński et al., 2017). Maximum heart rate (HRmax) is a standard indicator of the highest acceptable individual exertion in work physiology. Variations in the heart rate during work are directly proportionate to the intensity and duration of work, the more intense and longer is the work, the higher is the heart rate (Martinić et al., 2006). Determining the physiological workload on the basis of heart rate is a very suitable method for research in the forestry due to its practicality (Martinić, 1995; Grzywiński et al., 2017). Researchers used heart rate measuring for determination of physiological workload of forestry workers in previous studies (Kirk & Sullman, 2001; Yovi et al., 2006; Stampfer et al., 2010; Silayo et al., 2010; Melemez & Tunay, 2010; Çalişkan & Çağlar, 2010; Ottaviani et al., 2011; Spinelli et al., 2014; Huber & Stampfer, 2015; Eroglu et al., 2015b; Ottaviani Aalmo et al., 2016; Bačić et al., 2018; Borz et al., 2019; Spinelli et al., 2020; Arman et al., 2021).

Physiological workload (%HRR) of workers during harvesting operation was 40.9% according to Eroglu et al. (2015b). Based on a review of the available literature, Martinić (1995) states that the average heart rate of workers during felling and processing of wood by chainsaw is 108-116 bpm.

Çalişkan & Çağlar (2010) determined that average working heart rate of chainsaw operator during felling in spruce forest was 122.8 bpm, while the pre-work resting heart rate was 70.5 bpm. The average physical workload (%HRR) rate was 44.79%. Huber & Stampfer (2015) found the relative heart rate (%HRR) during felling in spruce dominated stands range from 23.43% to 35.26% and the highest physiological workloads during the felling task. According to Leszczyński & Stańczykiewicz (2015) the maximum heart rate (HRmax) of chainsaw operator 29 years old, 170 cm high and 76 kg weight was 191 bpm, while heart rate at rest (HRrest) was 69 bpm during tree felling and processing in late thinning of coniferous stands. The relative heart rate (%HRR) in same research was 39.05% for effective work time. Melemez & Tunay (2010) established the following: average working heart rate of chainsaw operator 115 bpm, average heart rate reserve 42% and resting heart rate 73 bpm. According to Cheța et al. (2018) average heart rate during felling and processing in old hybrid poplar dominated stand ranges from 93.5 to 132.1 bpm, and %HRR ranges from 21.76 to 57.49%. The highest physical strain to the worker was reported during technical delay, and the lowest during work preparation. Arman et al. (2021) cited that the mean level of physical workload during clearcut operations in the pine plantation was 43.54% of the relative heart rate (HRR) which corresponds to heavy work. Silayo et al. (2010) calculated percentage of heart rate increase during work compared to resting heart rate and found that the physical workload was 65% heart rate increase for chainsaw operator. Resting heart rate of chainsaw operator 32 years old was 55 bpm (Huber & Stampfer, 2015). Grzywiński et al. (2017) found that a working posture influence the level of physiological workload of a chainsaw operator. Higher heart rate values were found during standing bent forward body postures compared to squatting and half-kneeling.

The aim of the study was to determine physiological workload of chainsaw operator in felling and processing of wood assortments because similar researches were not conducted in Bosnia and Herzegovina.

## MATERIALS AND METHODS – Materijal i metode

### Study area – Područje istraživanja

The research was carried out in mixed uneven-aged stands of Silver fir (*Abies alba* L.), European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) Karst.) managed by Cantonal Public Enterprise "Sarajevo šume" Ltd. Sarajevo (SF) and Public Enterprise "Šumsko - pri-

Table I. Terrain characteristics of the study area

Tabela I. Terenske karakteristike područja istraživanja

Compartment	Forest Enterprise	Average elevation (m)	Slope (%)	Terrain topography	Exposure
1	SF	1100	5-50	downhill with coves	S, E, SE
2	ZDF	1050	15-40	slightly downhill	E
3	ZDF	1100	15-25	slightly downhill	S, SW
4	ZDF	1150	15-30	steep downhill/slightly downhill	E, NE

vredno društvo Zeničko - dobojskog kantona” Ltd. Zavidovići (ZDF) in Bosnia and Herzegovina (figure 1). The trees were felled and processed into wood assortments with Husqvarna 372XP chainsaw in four compartments (table 1).

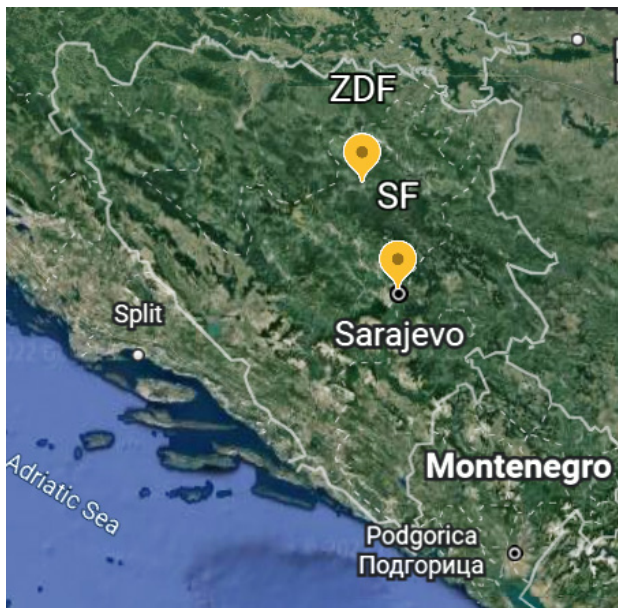


Figure 1. The location of study area

Slika 1. Područje istraživanja

### Heart rate measurements - Mjerenja otkucaja srca

Two male workers were chosen in order to measure the physiological workload during tree felling and processing (table 2). The workers were considered representative of the felling worker population in enterprises in terms of age, skill and productivity. Subject A felled and processed trees in one compartment in the area of SF and subject B in three compartments in the area of ZDF.

Heart rate was measured to assess the level of physiological workload, using a Garmin Forerunner 35 GPS Running Watch with Wrist-based Heart Rate (Garmin Ltd., United States) with continuous data logging and storage of heart rate readings (figure 2). The measurements were performed during whole working day including delays for 17 days in March and April 2019. Felling and processing works were recorded with action camera during whole working day. Time study was performed based on made videos. Heart rate monitor was placed on workers left hand so it did not interfere with work activities. Recorded heart rate data was downloaded via Garmin Connect users interface and sorted out in MS Excel 2016. Statistical analyses were carried out using the Statgraphics Centurion XVI software. After checking for normality (Shapiro-Wilk W test) and homogeneity of variance (Levene's test), the Kruskal-Wallis non-parametric multiple-comparison test was used to test the effect of the factor “time study element” on the average heart rate.



Figure 2. Garmin Forerunner 35 GPS Running Watch on chainsaw operator hand

Slika 2. Garmin Forerunner 35 GPS pametni sat za trčanje na ruci rukovaoca motornom pilom

The working day was divided into: a) effective time

Table 2. Anthropometric characteristics of the felling workers

Tabela 2. Antropometrijske karakteristike sjekača

Subject	Age (years)	Weight (kg)	Height (cm)	HR <sub>rest</sub> (bpm)	HR <sub>max</sub> (bpm)	BMI (kg/m <sup>2</sup> )
A	38	106	186	59	182	30.64
B	41	86	187	47	179	24.59

HR<sub>rest</sub>, resting heart rate; HR<sub>max</sub>, maximum heart rate (calculated as 220 - age); BMI, body mass index; bpm, beats per minute.

including moving, felling, delimiting and processing, dealing with hung up trees tasks and b) delays including preparatory-final time, technical delay, personal delay and moving to landing site (table 3).

Table 3. Time study elements

Tabela 3. Elementi studija vremena

Time study element	Description
<b>Effective time</b>	
Moving	Walking from felled and processed tree to another marked tree
Felling	Preparing of workplace, choosing of felling direction and tree felling. Task ends when a tree fell to the ground
Delimiting and processing	Cutting of branches from stem and processing of wood assortment by chainsaw horizontal cut
Dealing with hung up trees	Bringing in hung up trees to the ground
<b>Delays</b>	
Preparatory-final time	Taking of work orders, chainsaw preparation, cleaning, service and regular maintenance
Technical delay	Service of chainsaw and chainsawbar by worker himself
Personal delay	Resting and meal time
Moving to landing site	Walking from felling site to landing site on the forest truck road

Relative heart rate was calculated as follows (Vitalis, 1987):

$$\%HRR = \frac{HR_{work} - HR_{rest}}{HR_{max} - HR_{rest}} \times 100,$$

where %HRR is relative heart rate at work (%), HR<sub>work</sub> is average heart rate during work (bpm), HR<sub>rest</sub> is resting heart rate (bpm), HR<sub>max</sub> is the maximum heart rate (bpm), bpm is a abbreviation for beats per minute.

Maximum heart rate (HR<sub>max</sub>) was calculated as follows: HR<sub>max</sub> = 220 - age (Rodahl, 1989). The minimum measured heart rate value during working day was taken as the resting heart rate (HR<sub>rest</sub>).

Grading the physiological workload on the basis of heart rate determinations was done by scale from Apud et al. (1989).

Table 4. Grading the physiological workload (Apud et al., 1989)

Tabela 4. Procjena radnog opterećenja (Apud et al., 1989)

Physiological workload	Average heart rate (bpm)
Very low	<75
Low	75 – 100
Moderate	100 – 125
High	125 – 150
Very high	150 – 175
Extremely high	>175

## RESULTS – Rezultati

The average working heart rates for time study elements range from 104 to 128 bpm for subject A and 91 to 131 bpm for subject B. The average working heart rate (effective time and delays) is 117 bpm for subject A and 113 bpm for subject B (table 5). The results of Kruskal-Wallis test showed significant differences for average heart rate in relation to time study element (table 5). The minimum heart rate was recorded during the preparatory-final time for both subjects and maximum during the moving to the landing site for subject A and dealing with hung up trees for subject B (table 5).

Heart rate reserve exceeded value of 40% - a permissible value as described by Potočnik & Poje (2017) for all work tasks of effective time and delays expect preparatory-final time and personal delay for subject A and preparatory-final time for subject B. Moving to landing site caused the highest heart rate reserve (56.10%) for subject A and dealing with hung up trees for subject B (63.63%). Workers during moving to landing site work task walk on difficult terrain carrying chainsaw, fuel and tools which causes physical strain. Also, dealing with hung up trees cause significant physical strain because of characteristics of work task and workers posture. The heart rate reserve for the whole study time was estimated at 47.15% for subject A and 50.00 for subject B (table 5) indicating a high physiological strain.

Physiological workload for most time study element was moderate according to Apud et al. (1989) expect moving to landing site for subject A and dealing with hung up trees for subject B where it was high and preparatory-final time for subject B where it was low (figure 3).

Table 6. Results of Kruskal-Wallis test

Tabela 6. Rezultat Kruskal-Wallis testa

Time study element	Heart rate (bpm)	
	Subject A	Subject B
Moving	123b	113c,d
Felling	121b	115c
Delimiting and processing	123b	120b
Dealing with hung up trees	-	131a
Preparatory-final time	104d	91f
Technical delay	110c	110d
Personal delay	107c,d	105e
Moving to landing site	128a	121b
Kruskal-Wallis p	0.0000	0.0000

Different letters show significant differences among time study elements according to the Kruskal-Wallis test

Table 5. Descriptive statistics of heart rate

Tabela 5. Deskriptivna statistika izmjerenog pulsa

Time study element	Heart rate (bpm)									
	Min	Max	Mean	SD	%HRR	Min	Max	Mean	SD	%HRR
	Subject A					Subject B				
Moving	96	152	123	14,29	52,03	52	159	113	17,32	50,00
Felling	81	162	121	13,84	50,41	47	162	115	18,10	51,52
Delimiting and processing	71	157	123	13,79	52,03	60	172	120	17,54	55,30
Dealing with hung up trees						97	169	131	14,34	63,63
Preparatory-final time	72	142	104	15,70	36,59	67	120	91	15,60	33,33
Technical delay	59	138	110	14,13	41,46	70	165	110	18,56	47,73
Personal delay	66	173	107	15,70	39,02	53	185	105	18,23	43,94
Moving to landing site			128		56,10	95	140	121	9,89	56,06
Total	59	173	117		47,15	47	185	113		50,00

Min, minimum value; Max, maximum value; SD, standard deviation; %HRR, heart rate reserve

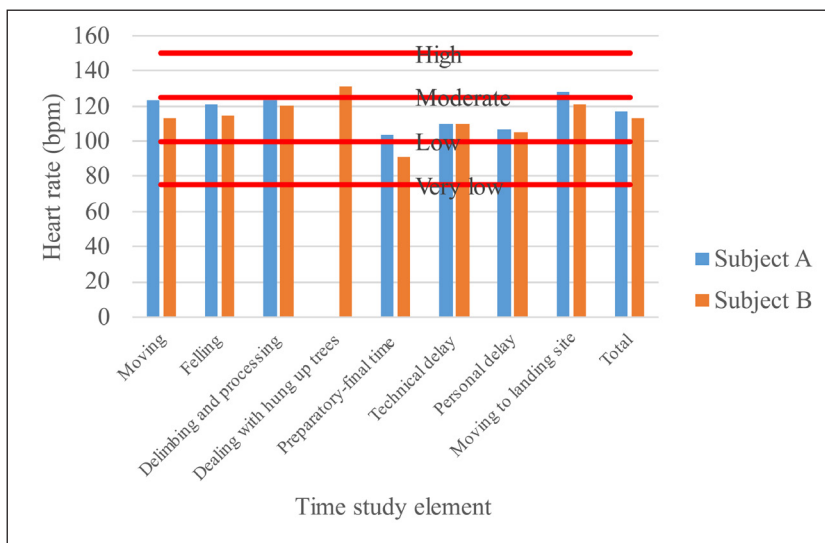


Figure 3. Grading the physiological workload

Slika 3. Ocjena radnog opterećenja

## DISCUSSION – Diskusija

The average working heart rate for subject A (117 bpm) and subject B (113 bpm) from this study were similar to result (115 bpm) cited by Melemez & Tunay (2010) and Arman et al. (2021) for clear cut in the pine plantation (116.08 bpm). The determined average working heart rate for subject B is within the interval 108 – 116 bpm cited by Martinić (1995) for workers in felling and processing phase, while average working heart rate for subject A is slightly greater. Çalişkan & Çağlar (2010) found higher value of the average working heart rate of chainsaw operator during felling in spruce forest (122.8 bpm), and Cheța et al. (2018) smaller during felling and processing in old hybrid poplar dominated stand (107.1 bpm).

The maximum heart rate values were measured during the moving to the landing site for subject A (128 bpm) and dealing with hung up trees for subject B (131 bpm), while Arman et al. (2021) found the the highest mean heart rates during the tree processing (117.7 bpm), back cut (115.6 bpm), and undercut (114.8 bpm).

The resting heart rate (HR<sub>rest</sub>) for subject A (59 bpm) and subject B (47 bpm) from this study were similar to results determined by Huber & Stumpfer (2015) for felling in spruce dominated stands (55 bpm), and smaller than values founded by Çalişkan & Çağlar (2010) for chainsaw operator during felling in spruce forest (70.5 bpm), Leszczyński & Stańczykiewicz (2015) for chainsaw operator during late thinning in coniferous stand (69 bpm) and Melemez & Tunay (2010) (73 bpm).

The average physical workload (%HRR) for subject A (47.15%) and subject B (50.00%) from this study were higher than values founded by Çalişkan & Çağlar (2010)

for chainsaw operator during felling in spruce forest (44.79%), Arman et al. (2021) for clear cut in the pine plantation (43.54%), Huber & Stumpfer(2015) in spruce dominated stands (23.43 – 35.26%), Cheța et al. (2018) during felling and processing in old hybrid poplar dominated stand (34.38%). According to Leszczyński & Stańczykiewicz (2015) the relative heart rate (%HRR) for effective work time was 39.05% which is smaller than values of relative heart rate for effective time work tasks determined in this study (50.00-63.63%).

The highest physiological workloads were measured during the moving to landing site (56.10%) for subject A and dealing with hung up trees (63.63%) for subject B, while Huber & Stumpfer (2015) found the highest values of relative heart rate for felling task in spruce dominated stands. According to Cheța et al. (2018) the highest physical strain to the worker was reported during technical delay. The lowest physiological workloads were measured during the preparatory-final time for both subjects. According to Cheța et al. (2018) the lowest physical strain to the worker was reported during work preparation which corresponds to the results of this study.

## CONCLUSIONS – Zaključak

This study aim to determine physiological workload of chainsaw operator during felling and processing of wood assortments in mixed uneven-aged stands in Bosnia and Herzegovina. The study results showed that heart rate reserve of chainsaw operator during tree felling and processing exceeded value of 40% which corresponds to heavy work and may have negative impacts on the health of the workers and increase the prevalence of work-related musculoskeletal disorders.

Considering a slightly higher heart rate reserve (%HRR) of the chainsaw operator compared to results of other research it is necessary to consider measures that would lead to its reduction including the training of workers, changes in the organization of work and continuous medical examination of workers with the aim of determining ability to perform felling and processing works.

The presented results contribute to establishing physiological workload of chainsaw operator during felling and processing in Bosnia and Herzegovina.

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## SAŽETAK

Negativni efekti izvođenja radova u sektoru šumarstva sa aspekta zdravlja i sigurnosti radnika posebno su izraženi u okviru tehnološkog procesa iskorištavanja šuma. Sječa stabala i izrada šumskih drvnih sortimenata u Bosni i Hercegovini obavlja se motornim pilama, a privlačenje drveta skiderima u najvećem broju slučajeva. Cilj istraživanja prikazanog u ovom radu je utvrđivanje opterećenja radnika u fazi sječe i izrade šumskih drvnih sortimenata iz razloga djelimične mehanizacije radova, tj. upotebe motor-manuelnog sredstva rada. Težina rada može se procijeniti na osnovu pulsa radnika, poređenjem pulsa mjenenog tokom odmora i rada, što je zbog praktičnosti veoma pogodan metod za istraživanja u oblasti šumarstva. Mjerenje pulsa sjekača obavljeno je uz upotrebu Garmin Forerunner 35 pametnog sata za trčanje (*Garmin Ltd., United States*) sa kontinuiranim mjerenjem i čuvanjem podataka. Rad sjekača sniman je akcionom kamerom tokom cijelog radnog dana. Istraživanje je provedeno u mješovitim raznodobnim šumama bukve i jele sa smrčom na području kojim gazduju KJP „Sarajevo šume“ i JP „Šumsko - privredno društvo Zeničko - dobojskog kantona“ d.o.o. Zavidovići. Prosječan puls tokom rada uključujući produktivno vrijeme i prekide rada iznosi 117 o/min (otkucaja u minuti) za radnika A, odnosno 113 o/min za radnika B. Rezultati Kruskal-Wallis testa su pokazali postojanje statistički značajnih razlika u vrijednostima prosječnog pulsa u zavisnosti od elementa studija rada (radne operacije i prekidi rada). Najmanje vrijednosti pulsa evidentirane su tokom pripremno-završnog vremena za oba radnika, a najveće vrijednosti tokom hoda do radilišta za radnika A, odnosno rješavanja ustave za radnika B. Prosječni puls tokom rada (%HRR) za radnika A iznosi 47.15%, odnosno 50.00% za radnika B. Rezultati istraživanja su pokazali da opterećenje sjekača prelazi dozvoljenu vrijednost od 40% što odgovara teškom radu i može imati negativni uticaj na zdravlje radnika. Uzimajući u obzir da su utvrđene nešto veće vrijednosti prosječnog pulsa tokom rada (%HRR) u odnosu na rezultate drugih istraživanja neophodno je razmotriti mjere za njegovo smanjenje a koje bi podrazumijevale obuku radnika, promjene u organizaciji rada i kontinuiranu procjenu radne sposobnosti radnika.

