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Article

Analysis of the Heart Rate of Operators of forwarding Machines during Timber Forwarding and the Dependence of its Values on the Performed Work Activities

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Abstract: This work deals with finding out whether the heart rate values of operators of forwarding machines during the work shift are influenced by the individual activities that the operator has to perform during timber skidding, or by the operators themselves. Furthermore, the work deals with determining the difficulty of individual activities in terms of physical load. For this purpose, the work shift of operators carrying out timber skidding was divided into individual activities: Driving, Maintenance, Forwarding, Break. During these work activities, the heart rate of each operator was taken for subsequent evaluation. The results show that the highest pulse rates of the operators were achieved during the Maintenance of the entrusted machine, while the highest pulse fluctuations in the operators were recorded during Forwarding. As part of this activity, the highest heart rate of the entire measurement process was recorded (132.0000 bpm), but also the lowest (42.0000 bpm). Furthermore, it was proven that both the operator and the activity he performs affect the pulse rate. The activities themselves did not differ from each other in only one of the six cases of comparison. Specifically, it was Driving and Forwarding.

Keywords: operator; forwarder; tractor with a timber trailer; ergonomics; heart rate; physical load

1. Introduction

Nowadays, there is a growing need for the use of fully mechanized technologies, logging and transport machines in the forestry, both because of higher productivity, and also because of the elimination of physically demanding work operations and increased work safety [1]. Fully mechanized logging technology, including harvesters and forwarding machines, is commonly used in forestry in many parts of the world [2], mainly due to its high productivity [3] and high work safety [4]. The forwarding machine is a self-loading forest tractor, used when skidding timber from the extraction site to the pick-up point [5]. Forwarding machines can basically be divided into 2 types, namely the tractor with a timber trailer and forwarding tractor or forwarder. While a tractor with a timber trailer is a combination of two otherwise separate means, namely a tractor and a trailer, a forwarding tractor is a special compact machine [1]. Of these two types of machines, the cheaper option is the first option, i.e. a forwarder trailer unit equipped with a hydraulic crane. Forwarder trailer units can be combined with agricultural tractors [6]. The advantage of such combination is that the tractor can also be used for other purposes, e.g. at a time when the amount of harvested wood decreases, and the cost of purchasing the trailer will thus be recouped more quickly [7]. A forwarder and a tractor with timber trailer normally skid wood harvested by a harvester, but also wood harvested by a chainsaw. The wood extracted and cut in this way is then loaded onto the load bed by

the forwarding machine and piled at the pick-up point, which is located along the forest roads. This point must be accessible in order for the trucks to be able to transport the wood from the forest [8].

The productivity of forwarding machines is affected by many factors. The first significant group are factors that are directly related to the machine operator. Specifically, it concerns the skills and experience of the given operator [9,10], which, among other things, is also related to the previous performance of the profession (e.g. storing wood, sorting assortments, ...) [2,8,11]. Productivity is further influenced by the approaching distance and the size of the load [12–14]. Other factors affecting productivity may include trunk volume [15] and number of assortments [11,16,17], terrain-related factors such as terrain slope [18,19]. Last but not least, these factors can include work organization factors [20] and technical parameters such as the load capacity of the used machine [17,21].

The operator is undoubtedly one of the most important components in the use of logging and transport technology [22,23]. Operating the machine puts significant physical and mental demands on the operator. Today's machines provide the operator with suitable ergonomic conditions, but despite this, the operator is forced to sit in ergonomically inappropriate positions during the work shift, and must also perform delicate, cyclically repetitive movements [5]. An important factor is the exposure of the operator to whole-body vibrations [4,24], which can be understood as the transfer of mechanical energy generated by the operation of the machine to the body of a sitting or standing operator [25]. Regarding the magnitude of whole-body vibrations, [26] proved in their research that the highest vibration values occur when the machine is moving, and the lowest when the machine is in a stationary position. Such a working environment can be the cause of physical and mental disorders of the operators and is therefore considered unhealthy [27–30]. The comfort of operators when operating unloading machines has a significant effect on productivity and work safety [31]. While operating the machine, the quality of the view from the cabin is also very important. If the operator's view from the cabin is insufficient, the safety of workers, their health and, last but not least, work performance may be at risk [32]. When developing forestry machines, it is necessary to follow ergonomic principles that contribute to reducing mental and physical stress and reducing the probability of operator errors [33].

In addition to mental stress, the operator of unloading machines is also exposed to physical stress, which is often assessed by the operator's heart rate [34,35]. Heart rate indicates the number of heartbeats in 1 minute [36], the heartbeat is a pressure wave that is caused by the ejection of blood from the heart [37]. Heart rate monitoring methods have been widely applied to understand real-time changes in physical and mental workload, as well as to determine cardiac workload as a predictor of cardiovascular activities to monitor operator health and safety [38–40]. In addition to monitoring the heart rate during physical load, it is also very important to monitor the operator's resting heart rate, which can be used as a predictor of cardiovascular diseases, cerebrovascular accidents and sudden death [41]. Thus, heart rate as a physiological marker of homeostasis can provide an early warning in certain abnormal conditions [42].

Currently, small wearable devices are widely used to measure heart rate. The most common type of device with a heart rate measurement function is the so-called smart watch, which is sold in large quantities today. Heart rate measurements with these devices are commonly used for the assessment of training intensity, sleep cycle monitoring, and in other health-related areas [43]. Furthermore, there are attempts to use this measurement to assess relaxation and stress [44], distinguish emotions [45] and distinguish between sleep and wakefulness [46].

2. Materials and Methods

2.1. Research Sample

This research was carried out in the territory of the Czech Republic, specifically in the territory of the South Moravian Region and the Vysočina Region in cooperation with five operators of tractor with a timber trailer and two forwarder operators. The age of the operators was diverse and ranged from 21 to 65 years. The operators were not taking any medication at the time of the research and had no health problems that could affect the measurement results. Anthropometric measurements of the

operators showed that their height ranged from 170-190 cm. The weight of the operators was quite variable and varied between 77-106 kg. The operators were very different from each other in terms of length of time in the profession, with the least experienced operator having 2 months of experience and the most experienced operator having had 20 years of experience.

2.2. Heart Rate Measurement

The heart rate of the operators was measured and recorded using a "Garmin fenix5X" smart watch. The watch was always put on the operator's left hand at the beginning of the shift and the measurement was then started. Each operator wore the watch for the entire duration of the work shift, after which the measurement on the watch was stopped and the acquired data was saved. The measurement took place for each operator in only one shift. Simultaneously with the measurement of the heart rate, the work activities performed by the operator during the working day were recorded in a time sequence. Subsequently, the acquired data was transferred via Bluetooth from the watch to the mobile application "Garmin Connect" from the developer Garmin. The data thus transferred was already available online on the "Garmin Connect" web application, where the data could be analyzed. All measured data of individual operators was available in this web application. The last step was to select the desired operator whose heart rate values were analyzed from the heart rate chart.

2.3. Sub-activities

For the purposes of evaluating the operators' heart rates, their work shifts were divided into several sub-activities. Specifically, the following activities were created:

- Maintenance - This activity started the operator's working day and included, for example, checking the hydraulic and engine oil levels, checking the air filter, checking the condition and inflation of the tires, checking and cleaning all tight spaces, checking for defects and cracks on the machine, optical inspection of the hydraulic crane (tightness of hoses, joints, hydraulic cylinders), replenishment of fuel, etc.
- Driving – This activity included driving on public roads, or a mere crossing between workplaces in a particular forest stand.
- Forwarding - This was a part of the production process that included the work operations of clearing, load assembly, forwarding, sorting at the pick-up point and landfilling of wood.
- Break – The operator used the break time for a snack or lunch, or to inspect the workplace.

In order to assign the obtained heart rate data to individual sub-activities, a simple picture of the working day was taken simultaneously with the measurement, which contained the name of the activity and its duration, on the basis of which the subsequent assignment to the timeline of the heart rate graph took place.

2.4. Statistical Data Processing

The data that was obtained as part of the heart rate sensing during the operators' working hours was divided into individual sub-activities, which were compared with each other. Specifically, the data from the individual sub-activities of the operator were compared with each other, and then the sub-activities of the work shift were also compared between individual operators. Furthermore, the possibility of affecting the pulse rate by the operator himself or by the given sub-activities was investigated.

For these purposes, data analysis was performed in TIBCO's STATISTICA 14 software. For correct evaluation, the data were first subjected to the Shapiro-Wilk test. This test verified whether

the data in the file has a normal distribution or not. The data were then evaluated as normally distributed if the test result exceeded the specified p-value of 0.05 (5% significance level). This p-value size was also used in the following test, which was a Two-Factor ANOVA to determine the influence of the pulse rate by the operator (1st factor) or the activity (2nd factor) that was performed. If there was a situation where the result of this test did not exceed the specified p-value for any of the factors, then the given factor affects the heart rate.

The second to last step in the statistical data processing was the use of a Post Hoc test to compare the sub-activities with each other. For this purpose, the Scheffe's test was used, the p-value of which was set at 0.05. If the test result did not exceed the selected value, then the given sub-activities differed from each other in their data. The last step was the processing of the data of the sub-activities of individual operators with descriptive statistics, while a box plot was created for a better representation of the data.

3. Results

The highest heart rate recorded was 132.0000 beats per minute (bpm). This value was reached by the heart rate of two operators (number 1 and 5) during the Forwarding activity, which can be seen in Figure 1. The lowest heart rate was also detected during this operation, and that was for operators 2, 3 and 4. The lowest heart rate was 42.0000 bpm and was recorded equally by Operator 3 and 4. In Figure 1, Operator 4 can be seen to have a significant spread of heart rate while Driving, which confirms the difference between the mean heart rate value (91.1786 bpm) and the median (99.5000 bpm), which shows the extreme values within the entire data set. A similar phenomenon was also observed with this operator and his heart rate during Maintenance. In this case, however, the mean pulse value was 109.0488 bpm and the median was 112.0000 bpm (see table 1). Furthermore, in Figure 1, one can notice the high heart rate in Maintenance, where there is a large concentration of data in high values.

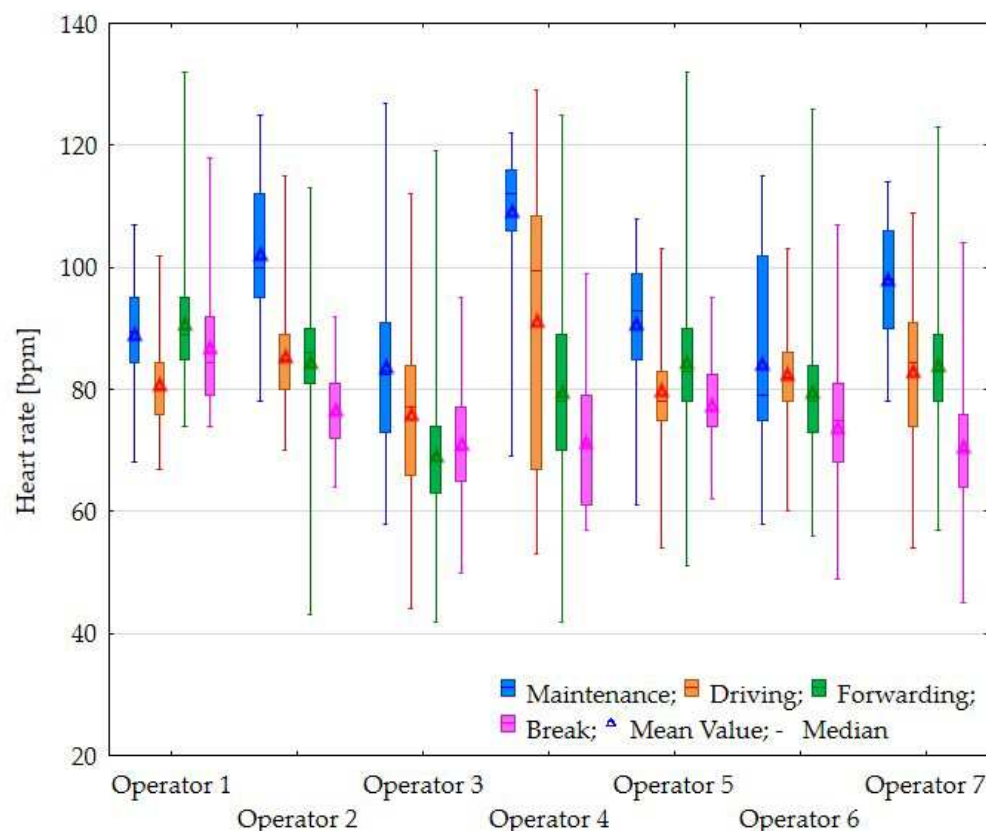


Figure 1. Heart rate of operators.

In Table 1, you can see basic statistical data on pulse frequencies in given activities for individual operators. Operator 1 had a mean heart rate of 89.0962 bpm during Maintenance, which was 12.9396 bpm less than Operator 2's. The difference between the mean heart rate of Operator 1 and 3 was 5.3961 bpm, with Operator 3 having a lower heart rate. When compared to Operator 4, the difference was 19.9526 bpm against him. A very small difference in the mean value of heart rate during Maintenance was achieved when comparing Operator 1 and 5, where the difference was only 1.5705 bpm in favour of Operator 1. Operator 6 had a mean heart rate of 84.2609 bpm during Maintenance, which was 8.8843 bpm less than Operator 7.

Lower heart rate values for all operators were achieved during Driving compared to Maintenance. A mean heart rate of 80.8250 bpm was recorded for Operator 1 and 85.4296 bpm for Operator 2. Operator 3 had a lower heart rate than Operator 1 by 4.9019 bpm. Another operator, i.e. number 4, on the other hand, exceeded Operator 1 with his mean heart rate by 10.3536 bpm. A small difference between the mean heart rate values within Driving was noted between Operator 1 and 5, where it was only 0.9548 bpm. Higher values, but still a small difference when compared to Operator 1, could be observed for Operators 6 and 7. Specifically, the difference between Operator 1 and 6 was 1.5632 bpm and between 1 and 7 only 2.0356 bpm, both values favouring Operator 1.

Table 1. Descriptive statistics.

Operator / Activity	Mean value [bpm]	Median [bpm]	Mode [bpm]	Frequency of mode	Min. [bpm]	Max. [bpm]	Standard deviation [bpm]
Operator 1 / Maintenance	89.0962	89.5000	Multiple	5.0000	68.0000	107.0000	8.2015
Operator 1 / Driving	80.8250	80.0000	Multiple	9.0000	67.0000	102.0000	6.3994
Operator 1 / Forwarding	90.6998	89.0000	Multiple	31.0000	74.0000	132.0000	8.9051
Operator 1 / Break	86.7963	84.5000	80.0000	6.0000	74.0000	118.0000	10.0684
Operator 2 / Maintenance	102.0357	100.0000	96.0000	4.0000	78.0000	125.0000	10.7685
Operator 2 / Driving	85.4296	85.0000	81.0000	13.0000	70.0000	115.0000	7.8201
Operator 2 / Forwarding	84.4548	86.0000	Multiple	41.0000	43.0000	113.0000	10.3740
Operator 2 / Break	76.5467	76.0000	Multiple	6.0000	64.0000	92.0000	6.4626
Operator 3 / Maintenance	83.7000	82.5000	Multiple	2.0000	58.0000	127.0000	15.5078
Operator 3 / Driving	75.9231	77.0000	80.0000	5.0000	44.0000	112.0000	11.8954
Operator 3 / Forwarding	69.0158	69.0000	74.0000	32.0000	42.0000	119.0000	10.7280
Operator 3 / Break	71.0092	70.0000	Multiple	8.0000	50.0000	95.0000	9.3189
Operator 4 / Maintenance	109.0488	112.0000	106.0000	4.0000	69.0000	122.0000	11.1981
Operator 4 / Driving	91.1786	99.5000	103.0000	4.0000	53.0000	129.0000	21.6519
Operator 4 / Forwarding	79.5497	78.0000	74.0000	26.0000	42.0000	125.0000	13.4346
Operator 4 / Break	71.3636	71.0000	Multiple	1.0000	57.0000	99.0000	12.3148
Operator 5 / Maintenance	90.6667	93.0000	Multiple	3.0000	61.0000	108.0000	11.5059
Operator 5 / Driving	79.8702	78.0000	77.0000	16.0000	54.0000	103.0000	7.4796
Operator 5 / Forwarding	84.3120	83.0000	83.0000	56.0000	51.0000	132.0000	10.6976
Operator 5 / Break	77.3125	76.5000	Multiple	2.0000	62.0000	95.0000	7.7522
Operator 6 / Maintenance	84.2609	79.0000	Multiple	2.0000	58.0000	115.0000	15.5599
Operator 6 / Driving	82.3882	82.0000	83.0000	8.0000	60.0000	103.0000	7.4739
Operator 6 / Forwarding	79.5571	78.0000	78.0000	34.0000	56.0000	126.0000	10.0631
Operator 6 / Break	73.7368	75.0000	Multiple	2.0000	49.0000	107.0000	12.1236
Operator 7 / Maintenance	97.9804	98.0000	Multiple	5.0000	78.0000	114.0000	8.6844
Operator 7 / Driving	82.8605	84.5000	89.0000	7.0000	54.0000	109.0000	11.5516
Operator 7 / Forwarding	83.8573	83.0000	83.0000	45.0000	57.0000	123.0000	9.4690
Operator 7 / Break	70.4490	70.0000	68.0000	4.0000	45.0000	104.0000	12.5051

In Table 1, we can also see the pulse frequency values of the operators during Forwarding, where the greatest dispersion of values was observed for all operators. Operator 1 had an average heart rate of 90.6998 bpm, which was 6.9998 bpm more than Operator 2. A very high difference in mean heart

rate magnitude was noted between Operator 1 and 3. The value of this difference was 21.6840 bpm to the disadvantage of Operator 1. A smaller difference, but still considerably high, was also between Operator 1 and 4, where it reached 11.1501 bpm. A similar value between the mean heart rate was also found between Operator 1 and 6. This was a difference of 11.1427 bpm. An already considerably smaller difference of 6.3878 bpm was noted between Operator 1 and 5, with the latter operator having a lower heart rate. Operator 7 then had a 6.8425 bpm slower heart rate during Forwarding compared to Operator 1.

Another activity recorded for all operators was Break. During this activity, the mean heart rate reached the lowest values compared to other machine operator activities. Operator 1 had the highest pulse value of all. Specifically, this value was 86.7963 bpm, which was 10.2496 bpm higher than Operator 2's mean heart rate and 15.7871 bpm higher than Operator 3's. Operator 4 had a heart rate of 71.3636 bpm during Break, which was 15.4327 bpm less than Operator 1, whose heart rate was 9.4838 bpm faster than Operator 5. The last two operators also had a lower heart rate compared to Operator 1 by 13.0595 bpm for Operator 6 and 16.3473 for Operator 7.

Table 2. Influence of operators and activities on heart rate.

Effect	Sum of Squares	Degree of Freedom	Mean Square	F distribution	p-value
Intersection	9576663	1	9576663	85555.53	0.00
Operator	32037	6	5339	47.70	0.00
Activity	41200	3	13733	122.69	0.00
Operator * Activity	51414	18	2856	25.52	0.00
Error	634560	5669	112	-	-
p-value < 0.05 = effect is significant					

Another sub-goal, apart from the detection of heart rate values for forwarder operators, was also an effort to demonstrate the influence of operators on heart rate. The result can be observed in Table 2, where the statistical evaluation is found. Specifically, the test result demonstrated the influence of operators on heart rate values, as the p-value of the test was less than the set significance level of the test (0.05). The same result was also achieved when determining the effect of individual activities on heart rate magnitude. In this case, the resulting test value was also less than 0.05 (see Table 2). The effect on the heart rate was also proven during concurrent action of operators and activities. In this case, the calculated value was again lower than the p-value (0.05). In summary, it can be said that the magnitude of the heart rate differs both between operators and between activities.

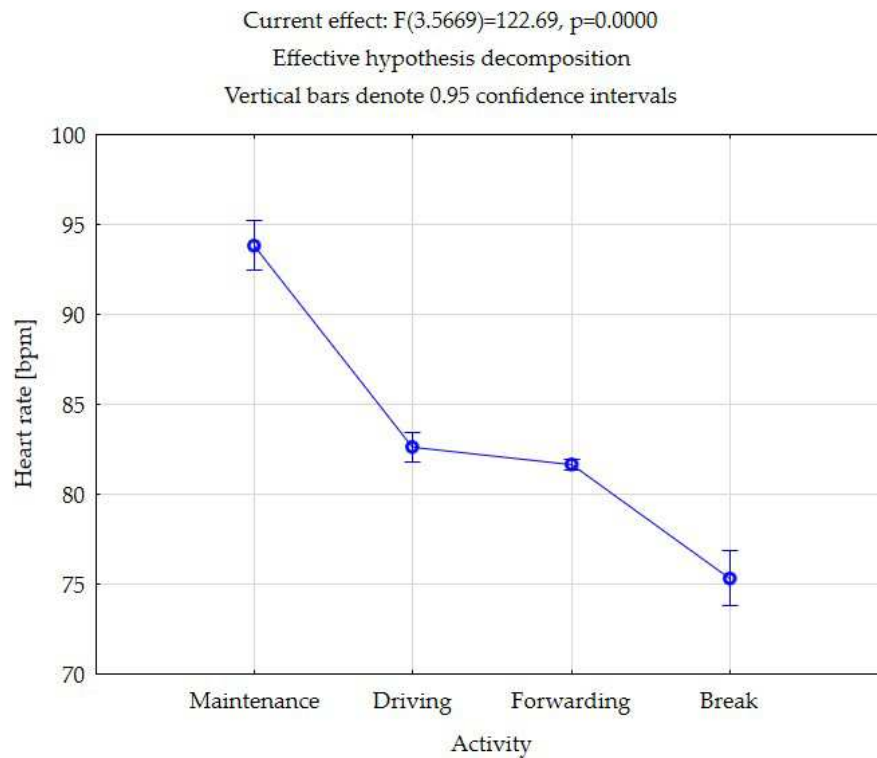


Figure 2. Heart rate during sub-activities.

Figure 2 shows a comparison of individual activities with one another without the influence of the operator. In particular, it is possible to see a significant equality of the pulse frequency between Driving and Forwarding, which is also confirmed by the results of the statistical test within the framework of their comparison in Table 3. The differences between these operations were not statistically proven (p -value of the test 0.674682). Furthermore, in Figure 2, we can notice the large differences in heart rate values between Maintenance and Break. This difference is statistically significant (p -value was less than 0.05). The statistical results then showed a difference between heart rates and all other combinations within the compared activities (see Table 3).

Table 3. Comparison of sub-activities.

Activity	Maintenance	Driving	Forwarding	Break
Maintenance	-	0.000000	0.000000	0.00
Driving	0.00	-	0.674682	0.00
Forwarding	0.00	0.674682	-	0.00
Break	0.00	0.000000	0.000000	-
< 0.05 = The activities are different				

In summary, it was found that the operators reached the highest heart rates during the Maintenance of the machine entrusted to them. However, the highest heart rate fluctuations were registered in the operators during the Forwarding activity. During this activity, the highest heart rate of the entire measurement process was recorded, which was 132.0000 bpm, but also the lowest heart rate. It was only 42.0000 bpm. Furthermore, the results showed that both the operator and the activity he performs affect the pulse rate. The activities themselves did not differ from each other in only one of the six cases of comparison. Specifically, it was Driving and Forwarding.

4. Discussion

At the beginning of this section, it is important to discuss the main limitations of this study, namely the small number of respondents, the difference of individual operators, the inaccuracy of the measuring device and the absence of repeated measurement of one operator.

The first limitation was the small number of respondents, 7 of whom were surveyed for the purpose of this study. During the preparatory work, there was of course an effort to get as many operators of the tractor with a timber trailer and the forwarder as possible, but it turned out that obtaining a larger sample of respondents is very difficult. The main reason was the small number of operators who work with these machines in a given location. The second reason was the inability of the operators to participate in the research, both due to time constraints and for personal reasons. As claimed by [1], this technique places significant demands on the worker with these machines, who must perfectly control the machine and be familiar with all the details of its deployment in various conditions. According to [5], operating the machine places significant physical and mental demands on the operator, which corresponds to the previous statement. [47], who in his work deals with the human factor in the use of logging and transport machines, mentions that the work of operator of forwarding machines is a demanding activity that requires a responsible approach and the ability to quickly make many complex decisions. These facts may contribute to the fact that this profession is less attractive for forestry workers, and it is also difficult to obtain a large sample of respondents. It should be noted, however, that despite the smaller number of operators, a relatively large amount of data was obtained, the analysis of which yielded results that are applicable for the purposes of determining the physical demands of individual activities.

As for the difference between individual operators, it was quite large. The age of the operators ranged from 21 to 65 years. This means that the performance of this profession is not strictly limited by age. However, more important than age was the state of health of the operator, which could significantly influence the results of heart rate measurements. However, none of the examined operators were found to have any health complications or use of medication that could affect heart rate values. The operators were also very different from each other in terms of length of time in the profession, which ranged from 2 months to 20 years. According to [9,10,48], the skills and experience of the given operator are an important factor in work productivity, but the heart rate during the performance of this profession was not affected by it. It should be noted that obtaining a sample of respondents whose mutual variability is small is practically impossible, mainly due to the reasons that are involved in a smaller number of operators.

Another limitation of this study is the possible inaccuracy of the heart rate recording device, specifically the "Garmin fenix5X" smart watch. Regarding the accuracy of heart rate measurement by Garmin watches, [49] in their study on the accuracy of the watch during rest and during activity found that the measurement provided valid heart rate values, but deviations can also occur, mainly due to changes in skin colour, poor tissue perfusion, imperfect contact between the skin and the optical device, changes in wrist positions, etc. These factors can be partially eliminated by using a chest belt. On the other hand, it should be noted that the reduced accuracy of this technology is to some extent compensated by better usability and comfort. [50] mention in their publication that these wrist-worn devices show good accuracy in measuring heart rate with only a small negative bias. However, the accuracy was significantly impaired in the case when, for example, the activity indicator was not used [50]. Based on the findings of these authors, it can be concluded that this device, a smart watch, is suitable for the purposes of this study, mainly due to its user-friendliness, as the device does not excessively burden the respondent and does not disturb his work comfort, etc.

Last but not least, a limiting factor of this study was the absence of repeated measurements, specifically measurements on several working days of individual operators. As part of this study, an attempt was made to perform repeated measurements of each operator, but in practice this procedure proved to be unfeasible. The reason was the complex planning of a multi-day field investigation depending on the operators' time options. One of the other reasons for the absence of repeated measurements was that, in addition to forwarding wood, some operators performed other activities as part of their work shift, such as harvesting wood, building fences, etc. In these cases, the measurement would have to be tied to the days when the worker is skidding wood.

This study clearly shows that the most demanding activity within the operator's working day in terms of physical load was machine Maintenance. During this activity, the machine operator performs tasks that require greater physical strength, a greater number of movements, more frequent changes in working positions, etc. According to [51,52], even small changes in working position can cause significant changes in heart rate. Among the tasks performed by the operator as part of maintenance can be listed, for example, cleaning the machine (snow, deposits, dirt, ...), checking defects and cracks on the machine, checking the tightness of hoses, etc. [53] mentions that a high heart rate during machine maintenance indicates a high physical demand, which corresponds with the results of this study. According to [54], heart rate is considered a good predictor of cardiovascular activities in the range of 100-140 bpm, which was also the case in this study. According to [55], heart rate correlates with workload and can be used to predict work-related health risks. The relationship between workload and heart rate is evident even when the operator was not working. The operator's Break turned out to be the least physically demanding activity in terms of physical load, which corresponds to [53], who found in his study that the operator's heart rate decreases during breaks. During the break, the operator is at rest and does not perform any physically or mentally demanding activities that would increase his heart rate. According to [1], operating the machine places great demands on the operator in terms of mental stress. As reported by [53] in their study, mentally demanding activities are associated with an increase in heart rate. By improving the ergonomic parameters of machine control, it is possible to reduce the burden on the operator during the work shift, or increase its performance. An example can be the use of the IBC (Intelligent Boom Control) system, which enables precise, quick and easy control of the hydraulic crane. According to [48], novice operators experienced a 27% increase in productivity and a 53% reduction in errors in hydraulic crane control when using the IBC system.

5. Conclusions

In our research we have analyzed the heart rate of the operator of the forwarding machine and the dependence of its values on the work activities that the operator performs during the work shift. It was found that the operator's heart rate reached the highest values during daily machine maintenance. The largest fluctuations in heart rate values were recorded during Forwarding, with both a high of 132.0000 bpm and a low of 42.0000 bpm. The results of this study demonstrated the influence of the pulse frequency by the operator himself, as well as by the activity he performs. The activities that did not differ from each other in terms of heart rate were Driving a machine and Forwarding wood.

The degree of physical strain of the operator can affect the productivity of the work, the safety and health of the operator, etc. The evaluation of the physical strain of operators of forwarding machines is therefore an important area that should be given attention in further research. For a future deeper understanding of this issue, it would be advisable to use more accurate devices, to carry out repeated measurements of operators and, for example, to provide a more homogeneous group of respondents. The heart rate sensing method described in this article is a relatively convenient, user-friendly, and research-friendly method of data acquisition. This method therefore meets the requirements that are placed on data collection as part of a field investigation.

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