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Assessment and Comparison of Machine Operators' Working Posture in Forest Thinning

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ABSTRACT

Background and Purpose: Due to technological progress and improvement of working processes, significant changes in the field of health protection and safety at work have occurred in the forestry sector. Accordingly, this paper presents the assessment and comparison of the working posture for operators of three different types of forest machines: chainsaw, forwarder and harvester.

Materials and Methods: The analysis was carried out from an ergonomic point of view using ErgoFellow 3.0 software, i.e. two ergonomic methods: Ovako Working Posture Analyzing System (OWAS) and Rapid Entire Body Assessment (REBA). Field measurements and data collection were carried out during the summer of 2017, when different wood harvesting technologies were applied within the same forest stand. The operators' body posture was recorded during effective work by a video camera and was taken as a relevant comparison factor of different types of forest machines and three observed operators. From the video recordings, the working body postures were defined in accordance with the snapshot method with the aim of obtaining an equal number of observations for all three operators of forest machines.

Results and Conclusions: The results of the analysis of the working posture for operators of all three types of forest machines show that, in terms of the level and type of their impact on the worker, the work of the chainsaw operator is more demanding and much more risky than that of the harvester or forwarder operators. The comparison of the two risk categorization methods, from the aspect of the working posture, shows that the REBA method has higher risk ratings than the OWAS method for all three types of forest machines. The need to implement preventive measures established in Scandinavian countries and to define the guidelines for future research of the working postures of forest machine operators is presented in the discussion of this paper.

Keywords: Croatia, forest thinning, machine operators, OWAS, REBA, working posture

INTRODUCTION

In today's dynamic market environment, due to the need for competitiveness and constant pressure to reduce production costs and the duration of the production cycle, industries increasingly tend to automate specific aspects of work and production processes. Many industries, however, still rely on motor-manual or manual work, either as a consequence of a low technological level or because of the unavailability of modern technologies in underdeveloped countries. The forestry sector, i.e. the operations in the harvesting process, is also characterized by a large share of manual and motor-manual work. The reason for such a situation is the level of mechanization of forestry production, which largely depends on factors such as stand type, mode of management, field and climatic conditions [1]. Today, globally, a large number of wood harvesting systems/technologies are currently used in forestry [2], and most of them still use a lot of manual work in the production process. In these work processes in forestry, workers are exposed to a high level of physiological [2] and physical stress and to possible musculoskeletal disorders [3].

Musculoskeletal Disorder (MSD), i.e. cumulative Work-Related Musculoskeletal Disorders (WMSD) of the neck and upper limbs, usually occur due to repetition of the same movements, prolonged use of vibrating tools and non-ergonomic working posture. These disorders represent an important occupational problem that reduces workers' productivity and increases costs in terms of remuneration, medical expenses, etc. [4]. In forestry practice, there are many conditions due to which forest loggers are exposed to WMSD: tough field conditions (low temperatures, slippage and uneven terrain), hard physical work and non-ergonomic body posture (load handling, hunched back), and dangerous tools and machines such as chainsaws [3]. With the development of machine cutting and processing, the work is transferred from the outside work environment into the cabin, which reduces the physical strain of work and the exposure to most of the risk factors within the working site. On the other hand, with machine cutting and processing (harvester and forwarder), new types of injuries and diseases, such as repetitive movement syndrome [5], occur as a result of the musculoskeletal disorder, along with new cognitive risk factors that are increasingly present. Harvester and forwarder operators often suffer WMSD-related pains in the area of the neck, lower back and shoulders [6-8], while Østensvik *et al.* [9] conclude that the occurrence of WMSD in machine cutting and processing largely depends on the organization of work. Therefore, the old ergonomic paradigm "less is better" for traditional wood harvesting systems/technologies should be replaced with "more can be better", where reduced physical activity in modern wood harvesting technologies can also have adverse impact on workers' health [10].

Furthermore, ergonomic research is most often carried out with the purpose of evaluating, classifying and, if necessary, implementing corrective measures related to the working posture of workers throughout the day, all with the aim of finding the optimal balance of the two basic components of the working system - human ability and working conditions. Therefore, the ergonomic assessment of the worker's posture during work may provide valuable information aimed at designing or redesigning workplaces and work tools, which can ultimately help to improve work performance, while at the same time meeting the safety level important for the musculoskeletal stress. Bearing in mind the above, the survey carried out in the area of Forest Office Bjelovar covered the assessment and comparison of the body posture for the operators of three different types of forest machines (chainsaw, forwarder, harvester), for which two ergonomic observation techniques were applied: Ovako Working Posture Analyzing System (OWAS) and Rapid Entire Body Assessment (REBA). An additional benefit of this work is the presentation of examples of good practice of the Western countries in relation to the implementation of measures to reduce overtime and workload with the application of modern technologies (e.g. harvesters, forwarders) in forestry.

MATERIALS AND METHODS

Research Area

Field research, i.e. the main experiment of the use of machine cutting and processing in thinning of deciduous forest stands, was carried out in compartments 14b and 14c of the Management Unit (MU) Bjelovar-Bilogora managed by Forest Office (FO) Bjelovar, Bjelovar branch of the company Hrvatske šume d.o.o. Zagreb (Figure 1). As part of the main experiment of measuring the productivity of harvester and forwarder operations, the video camera was used to record the postures of the harvester and forwarder operators and forest chainsaw operator (Figure 2). The aim was to evaluate and compare the working risk of forest machine operators based on the analysis of the working postures, and the type and level of their impact on the worker.

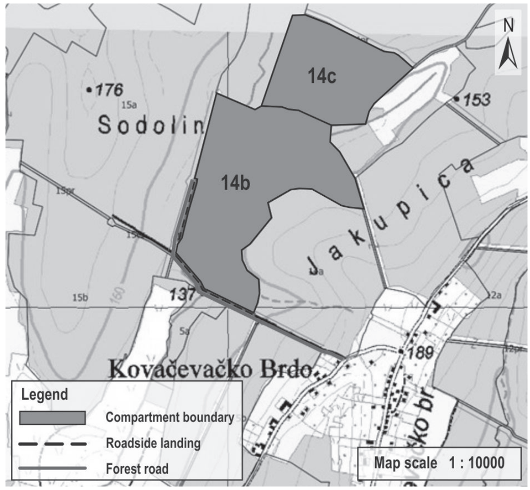

FIGURE 1. Test sites of the main research in MU Bjelovar-Bilogora.

Compartment 14b represents a mixed stand of European hornbeam (84%), common beech, pedunculate oak, black alder and sessile oak, with an area of 18.28 ha and 79 years old. The compartment belongs to the management class of European hornbeam seedlings. The growing stock is 5.330 m^3, i.e. 291.58 $m^3 \cdot ha^{-1}$, and the management plan prescribes thinning intensity of 11.67% in the first semi-period. During marking for motor-manual cutting and processing, a total of 1,455 trees were marked with the total volume of 741.81 m^3. Subsequently, by marking trees on "harvester lines" and by correcting the previous markings, the total number of trees marked for machine cutting was 1,782 with the total volume of 731.24 m^3. For compartment 14b average breast height diameter of felled trees is 21.7 cm.

Compartment 14c is a mixture of common beech (50%), European hornbeam (44%), sessile oak and pedunculate oak, with an area of 9.07 ha and 79 years old. The compartment belongs to the management class of common beech seedlings managed on a 100-year rotation. The growing stock is 3.681 m^3, or 405.84 $m^3 \cdot ha^{-1}$, and the management plan prescribes thinning intensity of 11.08% in the first semi-period. During marking for motor-manual cutting and processing, a total of 423 trees were marked with the total volume of 407.02 m^3. Subsequently, by marking trees on skid trails and by correcting the previous markings, the total number of trees marked for machine cutting was 559 with the total volume of 446.3 m^3. For compartment 14c average breast height diameter of felled trees is 26.4 cm.

Applied Machines and Workplace Organization

Mechanized harvesting system for cut-to-length logs, i.e.

FIGURE 2. Three types of forest machines used for the main experiment.

the parallel work of harvester and forwarder, was used in leaf forest thinning. Six-wheel (6WD) Timberjack 1470D harvester (Figure 2) was used for cut-to-length logging operations. The dimensions of the machine used are: 7700 mm long, 3050 mm high, 3000 mm width and weighs 18800 kg. Timberjack 1470D harvester uses a parallel hydraulic crane model TJ 200 H 97 with a built-in harvester head. The crane reaches 10 m and the angle of rotation is 220°. The machine does not have a rotating cabin, i.e. the harvester's cabin does not simultaneously move when changing direction of the crane to left or right.

For extracting logs an eight-wheel (8WD) Timberjack 1710D forwarder was used (Figure 2). The length of the machine used is 10,900 mm, while its width is 3050 mm. The height of the forwarder to the top of the crane is 3900 mm, and its weight depends on the degree of equipment and can range from 18,500 to 19,500 kg. The Timberjack 1710D forwarder is equipped with a Boom CF885 hydraulic crane, which has a grasper. Maximum reach of the crane is 8500 mm. The machine used does not have a rotating cabin, but it has a rotating seat with commands.

On the field site harvester trails, with appropriate spacing (20 m) and spatial distribution, were marked vertically to the existing main skid trails in compartments 14b and 14c. Larger diameter trees, which the harvester could not cut down, were felled and processed by a chainsaw operator.

Methods

The available literature describes a large number of developed and used ergonomic methods/observation techniques for assessing working body postures, with numerous methods intentionally developed for specific research objectives [11, 12]. Observation techniques include: OWAS [13], Task Recording and Analysis on Computer (TRAC) [14], Posture, Activity, Tools and Handling (PATH) [15], Rapid Upper Limb Assessment (RULA) [16], REBA [17], Loading on the Upper Body Assessment (LUBA) [18], etc. The main advantage of these methods is that they can easily adapt to the needs of a specific industry, depending on the scope of ergonomic assessment. As part of the research carried out in the area of FO Bjelovar, the assessment of the strain of the harvester and forwarder operators and loggers was carried out by assessing the operators' working posture using the ErgoFellow 3.0 software (Figure 3). Within the aforementioned software, two observation techniques (Figure 3) were applied: OWAS and REBA.

The OWAS was developed by a Finnish steel company (Figure 3). The OWAS method allows estimating the degree of static load of the workers at the workplace by analysing their posture, thus identifying four work postures for the back, three for the arms, seven for the legs, and three categories for the weight of load handled [19]. Each of these factors have an attributed code value. The technique classifies combinations of these four categories by the degree of their impact on the musculoskeletal system for all posture combinations. According to the OWAS method, the degrees of the assessed harmfulness of these posture–load combinations are grouped into four action categories which indicate the urgency for workplace intervention [4, 20]:

- Action category 1: normal and natural postures with no harmful effect on the musculoskeletal system – no action required;
- Action category 2: slightly harmful postures – corrective action required in the near future;
- Action category 3: distinctly harmful postures – corrective action should be taken as soon as possible;
- Action category 4: extremely harmful postures – corrective action for improvement is required immediately.

FIGURE 3. Software interface and two techniques for observing body postures.

The REBA is a postural analysis system sensitive to musculoskeletal risks in a variety of tasks, especially for the assessment of working postures found in health care and other service industries [17]. The basic idea of REBA is to assess positions of individual body segments which are observed. Postural scores increase when postures deviate from the neutral position. The posture classification system, which includes upper arms, lower arms, wrist, trunk, neck, and legs, is based on body part diagrams. Group A includes trunk, neck, and legs, while group B includes upper and lower arms and wrists. These groups are combined into one of 144 possible posture combinations that are transformed to a general postural code [21]. The method reflects the extent of external load/forces exerted, muscle activity caused by static, dynamic, rapid changing or unstable postures, and the coupling effect. These scores are summed up to give one score for each observation [21]. This technique provides five action levels for evaluating the level of corrective actions:

- Action level 0: corrective action including further assessment is not necessary;
- Action level 1: corrective action including further assessment may be necessary;
- Action level 2: corrective action including further assessment is necessary;
- Action level 3: corrective action including further assessment is necessary soon;
- Action level 4: corrective action including further assessment is necessary now.

OWAS classifies postural load for the urgency of corrective actions into four action categories, while REBA groups postural loads into five action levels, which have slightly different meaning from the action levels of OWAS. To enable a comparison of REBA and OWAS, the risk levels of REBA had to be reclassified into four levels with consideration of the meaning of action categories for both techniques [4]. The new four action levels of REBA are classified in Table 1.

Research Design and Data Analysis

Field measurements and data collection were carried out during the summer of 2017, when different wood harvesting technologies were applied within the same forest stand. Details of the field research, i.e. the work of harvester, forwarder and chainsaw operators, were recorded using a video camera. In the field work of the harvester operator, 9 h and 29 minutes of effective time recorded was related to machine cutting and processing, in the field work of the forwarder operator, 8 h and 29 minutes of effective time was related to timber extraction, while in the field work of the chainsaw operator, 45 minutes of effective time was related to motor-manual cutting and processing. Body postures were determined from video recordings in accordance with the snapshot method. When using a harvester for machine cutting and processing, the defined interval of observation is 6 minutes, which makes a total of 88 sampled working postures of the operator during effective work. When using a forwarder for timber extraction, the defined interval of observation is also 6 minutes, which makes a total of 79 sampled working postures of the operator during effective work. On the other hand, due to the shortness of video recording, in the case of motor-manual cutting and processing, the defined interval of observation is 0.5 minutes, which makes a total of 88 sampled working postures of loggers. All sampled postures were evaluated using the ErgoFellow 3.0 software through two observation techniques: OWAS and REBA methods, which ultimately results in two posture loads of the operator's body by each applied technology. Table 2 shows the planned and achieved number of sampled working postures for all three operators.

Processing of the sampled and assessed postures of operators of three different types of forest machines was made by the method of analysis and synthesis, and comparison. The method of analysis and synthesis was used in the process of work, where various sources were ultimately summarized in a single text. The method of comparison was applied in the practical part of the work when showing and comparing the risk category of body postures with respect to the machine used in the process of wood harvesting.

TABLE 1. Reclassified risk levels of REBA.

Regrouped action level	Original action level	Meaning
1	0	Normal posture
2	1 and 2	Low risk posture
3	3	Medium risk posture
4	4	High risk posture

TABLE 2. Structure of sampled working postures for all three operators.

Means of work	Working posture		
	Defined by calculation, N	Sampled from video recording, N	Efficiency, %
Chainsaw	88	88	100.00
Harvester	88	84	95.45
Forwarder	79	76	96.20

RESULTS

The analysis of the working postures of the operators of three machines against the action category (Figures 4 and 5) showed that the work of the chainsaw operator was more demanding and much more risky than the work of the harvester and forwarder operators. According to the OWAS method (Figure 4), 40.91% of the sampled body postures were classified in the normal posture category, 37.50% were classified in the category of low risk posture, 20.45% in the category of medium risk posture, and 1.14% in the high risk category. On the other hand, 82.14% of the sampled postures of the harvester operator (Figure 4, N=84) were classified into the category of normal posture and 17.86% in the category of low risk posture during work. According to the OWAS method (Figures 4, N=76), 97.37% of the sampled body postures of the forwarder operator were classified in the category of normal posture and 2.63% in the category of low risk posture during effective work. The rating of the action category of the posture according to the REBA method (Figure 5) for the chainsaw operator was as follows: 60.23% of the sampled postures were classified in the category of low risk posture, 21.59% in the category of medium risk posture and 18.18% in the category of high risk posture. For the harvester operator (Figure 5), 98.81% of the sampled postures were classified in the category of low risk posture and 1.19% in medium risk category, while for the forwarder operator all sampled postures (100%) were classified in the category of low risk posture. The comparison of the two risk categorization methods, from the point of view of the working posture, shows that the REBA method gives sharper results in relation to the OWAS method for all three sampled machines (Figures 4 and 5).

A more detailed comparison of the sampled operator postures, according to the OWAS and REBA methods, for all three machines was performed according to groups of work operations. In the analysis of the posture of the chainsaw operator (Figures 6 and 7), there were three groups of work operations: felling elements (N=29; they included clearing of the working site, root collar clearing, making the undercut and back cut), processing elements (N=38; they included delimbing, cross-cutting, bucking and sorting, etc.) and other activities (N=21; they included determining and checking the felling direction, retreating from the tree/trunk and choking activities). According to the OWAS method (Figure 6), the results of the analysis show that the highest share of medium risk posture (19.32%) and high risk posture (1.14%) are present in the felling elements. According to the OWAS method (Figure 6), the largest share of the medium risk posture (26.14%) is present in the processing elements, and the largest share of normal working posture is present in other activities. On the other hand, the more severe categorization of the working posture risk according to the REBA method (Figure 7) shows a higher share of high-risk posture (17.05%) in the felling elements and a slightly lower share of medium-risk posture (11.36%). With the processing elements, the category of low risk posture accounts for 31.82%, while the category of the medium risk posture accounts for 10.23% (Figure 7). In other activities (Figure 7), all sampled postures are classified in the category of low risk posture.

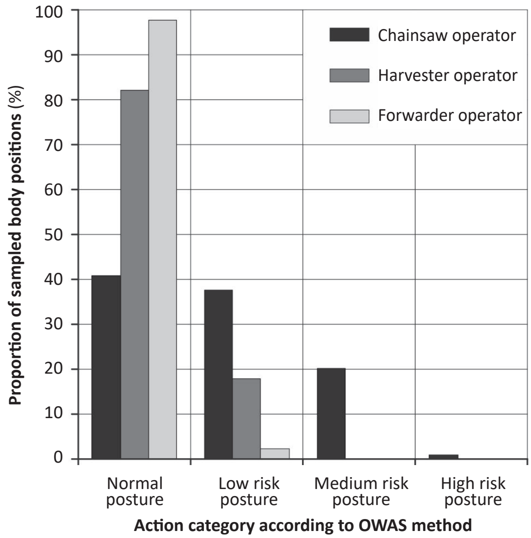

FIGURE 4. The share of sampled operator postures according to OWAS method.

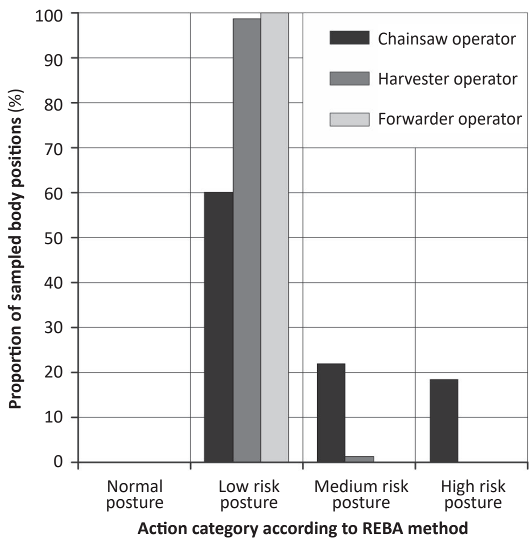

FIGURE 5. The share of sampled operator postures according to REBA method.

A more detailed analysis of the harvester operator posture (Figures 8 and 9) was performed within three groups of work operations: operations related to harvesting head (N=56), forward and reveres drive (N=23) and other activities (N=5; they included cooler cleaning, discussion of work issues with colleagues via cell phone, etc.). The results of the analysis according to the OWAS method (Figure 8) show that the largest share of low risk posture (10.71%) is present in forward and reverse drive because

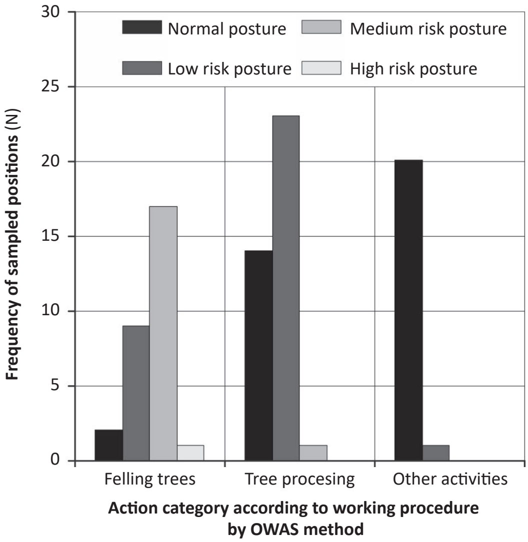

FIGURE 6. The number of sampled postures of chainsaw operator according to OWAS method.

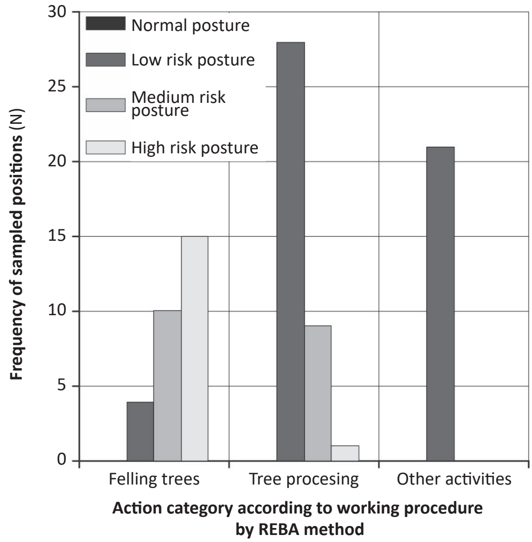

FIGURE 7. The number of sampled postures of chainsaw operator according to REBA method.

the operator's seat cannot rotate 360°, i.e. during reverse drive, the operator's working posture is physiologically quite unfavorable. When working with the harvester head (Figure 8), the normal working posture accounts for 63.10% and medium risk posture for 3.57%. In other activities (Figure 8), low risk posture accounts for 3.57% because this category includes the cleaning of the cooler from leaves, etc. The categorization of body posture risk according to the REBA method (Figure 9) showed sharper results in all three groups of work operations. The category of medium risk posture of the operator working with the harvester head accounts for 66.67% (Figure 9), and when driving, it accounts for 27.38%. The category of medium-risk posture of the harvester operator with the share of 1.19% is included in other activities.

The analysis of the forwarder operator postures (Figures 10 and 11) was carried out within three groups of work operations: work with crane (N=39), driving and/or moving backwards and forwards (N=36), and other activities (N=1; stopping at roadside landing for truck loading). The results of the analysis according to the OWAS method (Figure 10) show

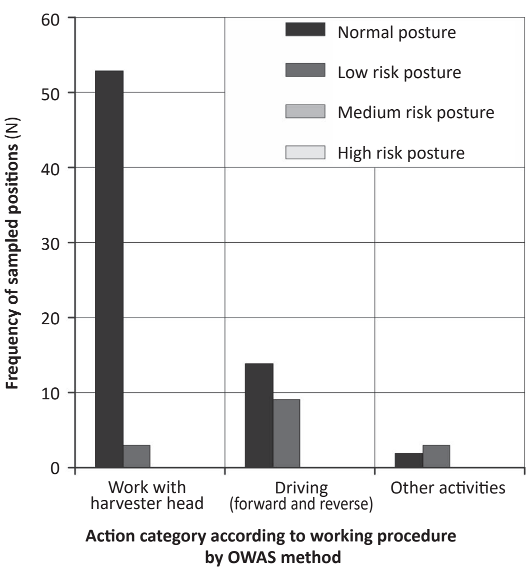

FIGURE 8. The number of sampled postures of the harvester operator according to OWAS method.

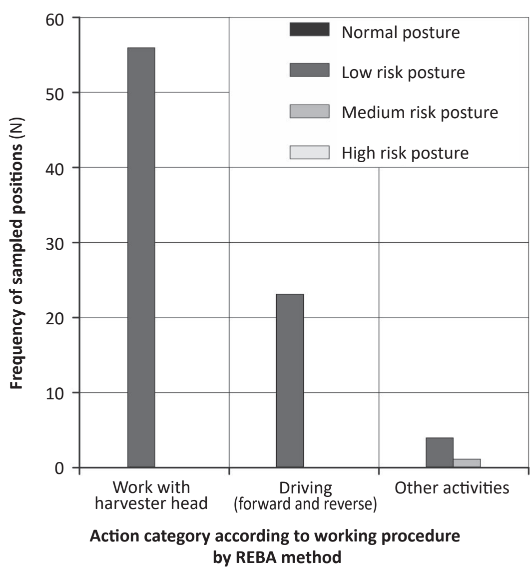

FIGURE 9. The number of sampled postures of the harvester operator according to REBA method.

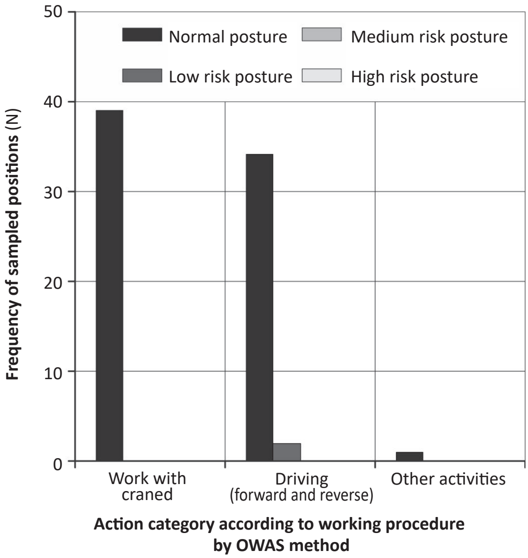

FIGURE 10. The number of sampled postures of the forwarder operator according to OWAS method.

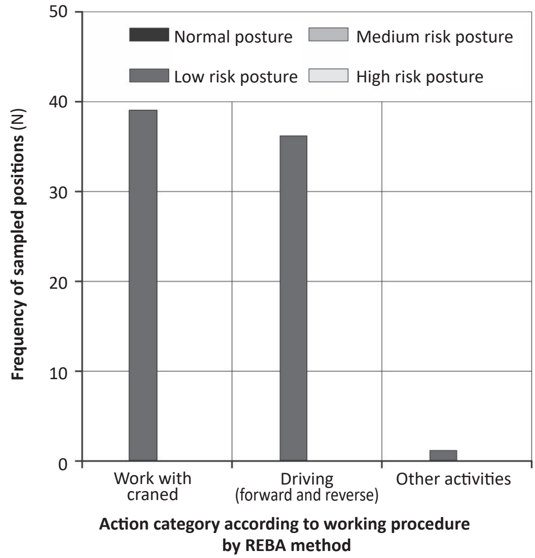

FIGURE 11. The number of sampled postures of the forwarder operator according to REBA method.

that the only portion of the low risk posture (2.63%) is present when driving or moving backwards and forwards because with the combination of loading and moving, the operator does not turn the seat, which is possible. When working with the crane (Figure 10), the normal posture accounts for 51.32% and when driving or moving backwards and forwards for 44.74%. Categorization of the forwarder operator's risk posture according to the REBA method (Figure 11) showed a low risk posture within all three groups of work operations.

DISCUSSION

The categorization of work risk depending on body posture, according to the OWAS and REBA method, was performed on the example of motor-manual work (chainsaw logger), and on the example of machine cutting, processing and extracting (harvester-forwarder) of wood assortments in timber harvesting. During the field survey, and the assessment and comparison of the posture, only the effective working time of the forest machine operator was analyzed. The results of the research showed that, regardless of the group of work operations and work equipment, the OWAS method underestimated the work risk associated with the operator's posture compared to the REBA method. Considering summarily the work equipment, the OWAS method rated the majority of chainsaw operator postures as low postural load in action category 1 and 2 (78.41%), while the REBA method rated 39.77% of the postures as action category 3 and 4 (Figure 4 and 5). In machine cutting and processing (using a harvester) and extracting (using a forwarder), the OWAS method rated the operator's posture of both machines as 100% low postural load in action category 1 and 2 (Figure 4). With the REBA method, only 1.19% of the operator's posture was rated as action category 3 (Figure 5). Considering the assessment and comparison of postural loads regarding the group of work operations, the results showed that the elements of tree felling were significantly more risky than the elements of wood assortment processing according to both assessment methods (Figures 6 and 7). Data analysis showed that, during tree felling, the logger's body was mostly bent and crooked, and his legs were unstable, i.e. the weight of the body relied on one leg or on a bent knee. Consequently, the work risk in tree felling is considered high. The categorization of the risk of the harvester and forwarder operators' working posture, according to the REBA method (Figures 9 and 11), showed slightly sharper results in all three groups of work operations compared to the OWAS method (Figures 8 and 10).

A visible difference in the assessment of occupational risk based on the postural load of forest machine operators, especially those working with the chainsaw, can be explained by higher sensitivity of the REBA method in detecting the working risk, as it has several more rating degrees for the assessment of the position of individual body parts than the OWAS method. The second reason is related to an extended work risk assessment using the REBA method in terms of activity type, work dynamics, etc. The third reason is related to the technological structure of the working time considered (effective working time), which also limits the research. This limitation is particularly important for machine cutting and processing as well as extracting, where the greatest part of postural load is within the additional time, which includes maintenance and repair activities during field work, such as hydraulic hose replacement, chain repair on the harvester bar, etc. Both observation techniques have been developed for a different purpose and need to cover different types of risks. When selecting the most appropriate techniques/methods in specific working conditions, the researcher should clearly define the needs and the impact of the information obtained on the decision-making process [21]. Along with choosing the most appropriate method, the sampling strategy is very important if the results are generalized outside the observed sample.

The new ergonomic paradigm "more can be better" in machine cutting, processing and extracting can have an adverse effect on the health of forest machine operators. An example of such effect comes from Swedish forestry, where many research results and organizational measures have been implemented in practice with the aim of reducing work safety problems for forest machine operators. Research shows that the average weekly working time in hours of the forest machine operator is 61 hours [22], and the 8-hour daily work load of an operator working in a harvester and/or forwarder for the whole time is considered too high and causes excessive strain and stress [23]. The Swedish Authority for Occupational Health and Safety, as an example of a corrective mechanism, has introduced a legal measure where forest machine operators must spend daily at least two hours engaged in some other activities that do not include mechanized work [24]. Another example is related to designing a worker list within a work shift, which includes exchanging jobs and enriching the work with additional tasks. This example of good work practice uses the method of workload points (WLP) for the identification of workload and for the substitution of work activities [24] if more points than allowed are accumulated during the working day, which means excessive fatigue for the machine operator.

CONCLUSIONS

The most acceptable way of increasing the aspect of health and safety for forest machine operators in the Croatian forestry is the application and implementation of the achievements of the international best practice. Considering all the above, most important conclusions are:

- regardless of the work task and work equipment in forestry, the OWAS method underestimated the work risk associated with the operator's posture compared to the REBA method;
- from the aspect of working posture, motor-manual working risk in tree felling is considerably higher than mechanized work with a forwarder or harvester;
- at motor-manual work the elements of tree felling are significantly riskier than the elements of wood assortment processing according to both assessment methods;
- at mechanized work the REBA method showed slightly sharper results in all three groups of work operations compared to the OWAS method;
- mechanized work, carried out in particular by private contractors in Croatian forestry, should be subject to legal measures, i.e. organizational measures in accordance with the Swedish example of good practice.

In conclusion, a small share of the research of work risk of forest machine operators with respect to postural load in Croatian forestry, especially in the field of machine work, implies the need to conduct systematic research of the above-mentioned issues that should comprehensively cover the technological structure of working time.

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