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The cumulative effects of work-related factors increase the heart rate of cabin field machine operators

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ABSTRACT

Operating field machines causes little physical exertion. However, the combined effects of work-related factors strain the cardiovascular system, elevating the heart rate of the operator. Our goal was to determine what work-related factors increased the risk of cardiovascular disease of cut-to-length machine operators. We created two generalized linear models. A model consisting of 678 cases, explained 32% of the heart rate variability through the operators' height and weight, machine types, parts of the shifts, lighting, and whole-body vibrations. To identify which factors actually increased the risk of cardiovascular diseases, we assessed a subset (193 cases) of heart rates elevated above 90 beats per minute. We found that the operators' height, machine types, parts of the shifts, equivalent noise, lighting, and whole-body vibrations explained about 72% of the elevated heart rate variability. The elevated heart rate depended on variables, which can be optimized to decrease the risk of cardiovascular diseases.

Relevance to industry: Cabin field machines are widely used in various industries. Our findings show that factors of the work environment affect the circulatory systems of the operators less than shiftwork. In order to further reduce the effects of work on operators, we should put more focus on improving the work organization.

1. Introduction

Forestry ranks as one of the most hazardous industries in the world, with average costs for fatal and nonfatal injuries, and illnesses per worker higher than $7000 in the United States of America (US) in the year 1993. The industry was surpassed only by taxicab transport, and bituminous coal and lignite mining industries with circa $11,500 and $8600 respectively in the same year (Leigh et al., 2004). According to Wiatrowski and Janocha (2014) the rate of fatal work injuries in the agriculture, forestry and fishing industry was the highest in both European Union (EU) (9.4%) and the US (18.4%) in the year 2010. In the EU, it was followed by the construction industry with a 7.9% fatality rate, whereas in the US it was followed by transportation and storage with a 13.5% fatality rate. The accident rate in forestry can be partially decreased by employing cut-to-length (CTL) machines in forest harvesting, the most hazardous occupation in forestry (Bentley et al., 2005; Kawachi et al., 1994; Parker et al., 2002).

CTL machines were developed to carry out multiple tasks in forest harvesting. Forest harvesters fell trees, de-limb, buck, and pile them in the forest stands. They are usually teamed with forwarders – machines used to load the assortments produced by forest harvesters, forward them to roadside landings, and unload them on stacks. The physical work environment in which the operators of the CTL machines work is similar to other field machines used in agriculture or other industries and employing them in forest harvesting represents a shift in forest harvesting from physically demanding to mentally demanding work.

Because operators operate machines in a seated position inside the machine's cabin, working with CTL machines causes little physical exertion. However, the machines are not easy to operate;

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Gellerstedt (2002) states that CTL machine operators have to carry out 4000 control inputs in order to handle the machine. They also need to be able to react quickly and appropriately to their surroundings, which means processing a lot of information, fast decision-making, and retaining focus in monotonous and repetitive operations (Axelsson and Pontén, 1990; Gellerstedt, 1997; Tsioras, 2012). This, along with the complexity of the work task and the pressure to maintain high productivity, poses a new challenge in forestry – maintaining acceptable levels of mental loading of workers in forest harvesting.

Mental loading affects the well-being of CTL machine operators, however, despite ergonomically designed cabins, operators are exposed to considerable levels of other factors. Noise exposure (Aybek et al., 2010; Gerasimov and Sokolov, 2009; Marsili et al., 1998; Nieuwenhuis and Lyons, 2002), exposure to whole-body vibrations (Deprez et al., 2005; Hansson, 1995; Hostens and Ramon, 2003; Paddan and Griffin, 2002; Sherwin et al., 2004), operative temperature, and airflow velocity inside the cabin (Cengiz and Babalik, 2007; Farzaneh and Tootoonchi, 2008; Huang et al., 2006) can negatively influence the health of the operators.

Currently, these factors are assessed as if each particular factor was isolated, when it influences the operators. This single factor analysis has its advantages, e.g., relatively low costs, time consumption, and low labor intensity. On the other hand, the single factor analysis does not reflect the real effects of the work environment, as it does not account for the joint or synergistic effects of the multiple factors acting simultaneously upon workers. For this reason, researchers started to analyze the work environment through a multi-factor assessment. Several methods are available, most of them approach the assessment by means of expert opinions, e.g. simple or pairwise comparison of criteria, or through mathematical methods, e.g., the analytic hierarchy process (AHP) (Saaty, 1980). Using Saaty's AHP in risk evaluation enables a complex work environment assessment, because it is possible to account for practically an infinite number of factors through this method. AHP, however, lacks real objectivity, because it is not based on measured exposure to individual factors of the work environment, but instead on the opinions of the raters when they compare the particular criteria. However, information on the exposure of the workers to the particular factors of the work environment, the intensity of the worker's reaction to the work environment, and the possible health effects of their exposure to the work environment are vital for a true complex risk evaluation.

In this paper, we have focused on identifying how the particular work-related factors, such as the personal features of the operators, types of machines used, work organization, and various factors of the work environment affect the circulatory systems of the CTL machine operators. We have set two hypotheses: (i) if the heart rates of the operators are not elevated, the variability of the operator's heart rate is caused by factors other than the observed work-related factors, and (ii) when the heart rates of the operators are elevated, the increase is caused by the synergistic effects of multiple work-related factors acting upon the bodies of the operators, thus a significant portion of the variability of the heart rates of the CTL machine operators is explained by the effects of the work-related factors. We tested these hypotheses by creating generalized linear models on two sets of data – one on the whole dataset of the heart rates of the CTL machine operators and the corresponding levels of the factors of the work environment, and one on a subset of the said dataset, where the heart rates are elevated over the resting heart rates (HR_{REST}) of the operators.

2. Materials and methods

The measurements were conducted in the Czech and Slovak forests from November 2013 to March 2014. The forest stands were suitable for employing CTL machines, with a slope of up to 40%, coniferous tree species, and a sufficient volume of harvest. The detailed characteristics of the individual stands can be seen in Table 1.

Five machines were employed in the forest stands – a John Deere 1270D harvester (operator 1) joined with a John Deere 810 ECOIII forwarder (operator 2), a John Deere 1070D harvester (operator 3) joined with a John Deere 810 ECOIII forwarder (operator 2), and a Ponsse Ergo 6 W harvester (operator 4) joined with a Ponsse Buffalo forwarder (operator 5). The machines were operated by male operators with sufficient experience and training (Table 2). Overall, we recorded data during 10 days of forest harvesting.

2.1. Variable selection

Evaluating every factor present at the workplace is practically impossible, because of the costs, labor intensiveness, and time consumption, so there is a need to reduce the assessment to a more feasible number of factors. We selected binary and continuous predictor variables for the models. The binary predictors were: (i) type of machine – harvester (v_1), and forwarder (v_2); and (ii) part of the shift – beginning (v_3), middle (v_4), and end (v_5). The continuous predictors were: (i) height of the operator (v_6); (ii) weight of the operator (v_7); (iii) exposure to the equivalent noise (v_8); (iv) exposure to peak noise (v_9); (v) exposure to whole-body vibrations (v_{10}); (vi) the operative temperature in the cabins of the machines (v_{11}); (vii) the airflow velocity inside the cabins (v_{12}); and (viii) the illuminance inside the cabins (v_{13}).

The workload heart rate (HR_{WORK}) was selected as the response variable, because it correlates to the risk of developing a cardiovascular disease, the most prominent cause of death in many developed countries (Hjalmarson, 2007; Reil and Böhm, 2007; Valentini and Parati, 2009) and is relatively easy to measure continuously. HR_{WORK} was the arithmetic mean of heart rates recorded by the Biofeedback 2000 x-pert device within each minute of workload measurements. HR_{WORK} data were paired with the corresponding data from the measurements of the factors of the work environment based on the start time of the measurements.

We also recorded the HR_{REST} of the operators. Measurements of the HR_{REST} took place after all works were finished for the day, when the operators were at ease. We chose this mode of measuring the HR_{REST} after it provided more precise and consistent results in a preliminary study than measuring the HR_{REST} before the work.

Absolute heart rate (AHR) of the operators was calculated by subtracting the HR_{REST} values from HR_{WORK} values and served to show the increment of the heart rates of the operators due to work.

2.2. Measurement procedure

We measured the heart rate of the operators with the MULTI module of the Biofeedback 2000 x-pert device produced by Schuhfried GmbH, Austria. The device measures heart rate through a built-in photopletysmograph, with an accuracy of one beat per minute (BPM).

We used the measurement procedure described by (Jankovský et al., 2013). We took three 30-min heart rate samples during each measurement day – at the start of the work shift (approximately 1 h after the start of the work), in the middle of the work shift (before the lunch break), and at the end of the work shift (approximately 30 min before the end of the work). These samples were taken under a full work load. Each day, after the work ended, we took a 10-min HR_{REST} sample, when the operators were at ease.

We measured the equivalent continuous sound level (L_{aeq}) and peak noise level (L_{CPk}) with a class II accuracy Quest edge eg4

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