CNC MACHINE TOOL SAFETY FROM THE ASPECT OF HAZARD PERCEPTION BY OPERATING PERSONNEL

PETR BLECHA[1], JIRI MAREK[1], RADIM BLECHA[1], JANA ROZEHNALOVA[1], PETR HEINRICH[2], PETR PACHER[3]

[1] Brno University of Technology, Faculty of Mechanical Engineering, Institute of Production Machines, Systems and Robotics, Brno, CZ

[2] KOVOSVIT MAS Machinetools, a.s, Sezimovo Usti, CZ

[3] University of Applied Management Inc., Brno, CZ

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Petr.Blecha@vutbr.cz

Safety of machinery, including CNC machine tools, must be ensured in all phases of their life cycle. The operation and maintenance phase is the most important as it represents the longest period in the machine´s technical life linked to occurrence of work injuries. Every designer of a safe machine must consider also any reasonably foreseeable incorrect behaviour of the machine operator. The latest revision proposal of the Machinery Directive 2006/42/ES [EUR-LEX 2021] sets new requirements on solution of CNC machine tools safety. Aside from assessing the impact of cybersecurity on the machinery safety, the manufacturers will now have to take into account also the psychological stress arising from human-machine interaction. From the psychological point of view, the operating personnel of multifunctional CNC machine tools experience high level of stress when machining complicated and complex-shaped workpieces as the material often costs as much as 30% of the price of the machine; therefore, any mistake of the operator resulting in a nonconforming product causes high financial loss. Influence of various stressors on the operating personnel leads to their impaired concentration on the performed tasks, which may be accompanied by insufficient perception of the hazards associated with the machine operation and thus may lead to occurrence of work injuries. The presented paper discusses the factors that may put the operators of multifunctional CNC machine tools under psychological stress and analyses possible application of the virtual reality technology to assess the ability to perceive the hazards linked to such a complex machine on a group of university students representing both operators (beginners) and designers of a multifunctional CNC machine tool.

KEYWORDS

machine tool, human error, hazard perception, safety analysis, psychological stress, work stressor, virtual reality

1 INTRODUCTION

A current trend among machinery producers and their customers is the effort to integrate the maximum number of splinter machining operations, additive manufacturing technology and eventually also other Industry 4.0 elements in a single machine. Besides, the built-up area after installation of such a machine should be the smallest possible. As a result, some very advanced machine tools for hybrid technological processes are being placed on the market. In the presented study they are represented by a multifunctional CNC WELDPRINT machine (Figure 1) by KOVOSVIT MAS Machine Tools, combining additive manufacturing and splinter machining.

Figure 1. Machine WELDPRINT MCV 5X with hybrid technology (material adding and splinter machining) [KOVOSVIT MAS 2016a]

Such integration of several operations into one multifunctional CNC machine with simultaneous high requirements on accuracy and productivity of production require fast and precise setting-up of the machine and positioning of the workpiece. This situation may put the operating personnel under pressure and affect their decision-making activities. On the other hand, the multifunctionality of such machine increases the complexity of the risk analysis and of the process of risk reduction in the significant hazards during the design and development phase [Pacaiova 2018], [Leder 2018], [Oravec 2019].

2 SOURCES OF PSYCHOLOGICAL STRESS IN HUMAN-MACHINERY INTERACTION

Risk analysis of a newly designed machine must count with a variety of foreseeable behaviours of the human operators affected by psychological stress including their reasonably foreseeable incorrect decisions and unsuitable choice of the work procedures. It is necessary to consider all of the activities that the machine operator is responsible for and in which impaired perception of hazard may lead to financial loss or work injury:

- setting up and fitting of a semi-finished workpiece by fixtures and clamps prior to the work itself;
- visual prevention of collisions between the tool and the fixtures or clamps;
- multi-sense (hearing, sight and touch) monitoring of the machining process;
- performing subsequent corrections of the tools after inter-operation measurements in relation to blunting of the tool´s cutting edge;
- making decisions about eventual changes of the machining strategy according to the machining conditions in an unplanned situation (i.e. hidden failure in the semi-finished workpiece);
- interrupting the machining process due to the need to top up the operating fluids (lubricant, cutting fluid and coolant) with subsequent restart of the machining programme from the point where it was interrupted;
- interrupting the machining programme during machining following an alert from the machine´s diagnostics on a failure of some part of the CNC machine tool with subsequent restart of the machining programme from the point where it was interrupted.

Especially the last two actions can be very psychologically demanding due to the strict requirements on the shape and accuracy of the product (Figure 2) and so they are often a source of mistakes resulting in financial losses and/or damage to health.

Figure 2. An example of a complex-shaped workpiece with high requirements on manufacturing accuracy made with a multifunctional machine tool [KOVOSVIT MAS 2016b]

As risk managers, we should attempt to put ourselves in the place of the machine operators and during identification of hazards and risk assessment, we should think about the goal of the required action as well as about the dangers that may be threatening the operators during realization of that specific task. However, the real-life machine operators are in a different situation: they are under the influence of a number of other factors that can distract their focus and therefore they may perform an activity reflexively, without considering other consequences, including the residual risks that are specified in the instructions for use. Based on our own experience and literature review [Bridger 2007], [Coggon 1996], [Ong 1982], [Kotek 2015], [Kawada 2016], [Thackray 1981], [Ezenwa 2001], [Johannsen 1982], [Holub 2019], [Pacaiova 2021], we have performed an analysis of the stress factors affecting the operating personnel from the aspect of the applied technology, organizational processes and psycho-physical capabilities of the operators. The result is shown in Figure 3.

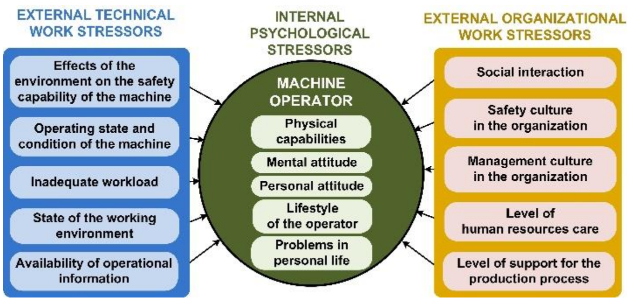

Figure 3. Work stressors as psychological aspects affecting perception of hazards during work

The internal psychological stressors are linked to the person of the operator and they usually change over time in relation to the operator´s age, experience and knowledge, in causal relationship to the external work stressors associated with the operated technology and setting of the processes within the company. The same internal psychological stressors also affect the designer of a machine and may lead to underestimation of hazards during the safe machine design process or during work on the safety warnings in the instructions for use. Besides, something that the designer regards as a totally obvious hazard can be completely overlooked by the machine´s operator.
The internal psychological stressors can be divided into the following groups:

- **Physical capabilities**, including mainly the person´s height, visual and hearing acuity, skilfulness, physical strength (especially in manual manipulation of objects), age and intellect.
- **Mental attitude**, affecting the extent to which the operator takes eventual criticism personally, his tendency to exaggerate problems, his ability to accept compromises, whether his expectations regarding the machine or technology are unrealistic, how he interacts with his co-workers in terms of self-centred behaviour or egoistic thinking.
- **Personal attitude**, which can hamper the correct course of work operations, for example due to pessimistic thinking, low self-confidence caused by inadequate self-criticism, excessive analysing of work operations and inclination towards improvisation during work.
- **Lifestyle of the operator**, whose health may be impaired as a result of caffeine consumption, smoking, lack of sleep or unhealthy diet, thus making the operator more vulnerable to the influence of the common working environment.
- **Problems in personal life**, such as family issues (i.e. illness of close relatives or financial problems) that may divert the operator´s attention from the correct work procedures and distract his concentration during routine activities.

After closer investigation of the external work stressors associated with the technology and technological procedures used at work, we can identify the following categories:

- **Effects of the environment on the safety capability of the machine**, which may lead to a loss of its expected safety characteristics. Surrounding noise, temperature or cramped space may play a role here as they affect the multisensory control of the machining process by the operator. Unsuitable background colour or insufficient cabin ventilation can cause operator fatigue.
- **Operating state and condition of the machine**, which may vary during the machining process either over short time (change of working accuracy, stability of the operating parameters setting) or over long time in relation to regular adjustment or maintenance of the machine (shortcomings of the protection measures or operation information).
- **Inadequate workload** caused for example by unrealistic expectations leading to setting the production tasks at the limit of the machine´s production capability, overestimation of the possibilities of the selected production technology or excessive complexity of the required work operations under challenging hygienic or ergonomic conditions.
- **State of the working environment** must be monitored with respect to the safety and health protection of the operating personnel. This group of stressors includes for example the level of lighting, air freshness, level of noise, ergonomic conditions, dustiness or thermal comfort. Their suitability must be ensured in order to comply with the requirements of the nineteen individual directives issued in association with the Directive 89/391/EEC.
- **Availability of operational information** must be maintained from the aspect of unambiguity of the instructions for operation of the machine provided in the operation manual as well as from the aspect of their easy realization under operational conditions. It is also necessary to provide the operator with real-time information on the operational state of the machine and its production process capability and to ensure their logical presentation.

Of the work stressors listed above, the state of the machine, state of the working environment and availability of operational information can be positively influenced by employment of smart applications featuring elements of artificial intelligence within the development of machines for Industry 4.0. In this way, we can decrease the risk linked to psychological stress of the machine operators through preventive measures built in design using some elements of artificial intelligence.
However, such preventive measures also entail new threats associated with digital information and possible cyber-attacks. Human behaviour is then affected mainly by external organizational work stressors. In our analysis of the possibilities how to influence human behaviour by means of suitable design of the machine, we have considered the following aspects:

- **Social interaction** may affect timely sharing of information due to the fear of recourse or loss of interest of the workers in safe and productive company environment, for example in consequence of arrogance or aggressive behaviour of the executives or some reluctant co-workers. Incorporation of autonomous monitoring of the state and condition of the machine´s safety elements and monitoring of the reasonably foreseeable incorrect work procedures of the operators with a suitable sensory system featuring elements of artificial intelligence would enable automatic notification of the company executives. Therefore, timely sharing of information necessary for sustainable safety of production facilities would be ensured without the need of social interaction with problematic persons.

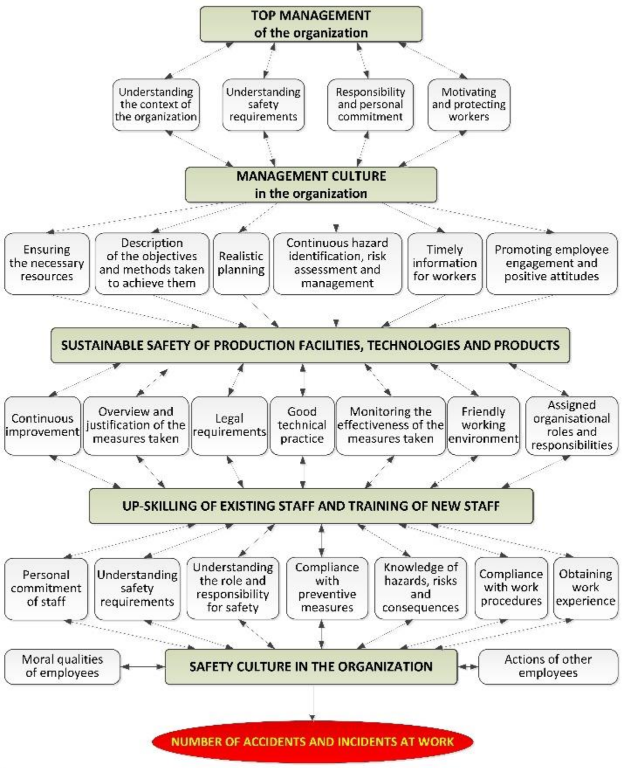

Figure 4. Overview of the factors affecting safety culture in a company from the aspect of hazard perception and occurrence of work injuries and incidents

- **Safety culture in the organization** can be simply described as the real level of adherence to the rules, regulations, prohibitions, limitations and safe work procedures by the staff during work. Safety culture is affected by a number of factors (Figure 4), which are reflected also in the work stressors and psychological aspects of product and work procedure safety. From the viewpoint of safety assessment of a newly developed multifunctional CNC machine it is necessary to pay more attention especially to the factors "Understanding safety requirements" and "Knowledge of hazards, risks and consequences". Instructions for use, as well as safety instructions on the machine, must therefore be elaborated with regard to the impaired hazard perception of the machine operators due to psychological stress. The owner of the machine is then responsible for incorporation of these safety instructions into the organizational measures for risk reduction within the company.
- **Management culture in the organization** is an integral part of the work safety culture and besides good social interaction it also includes the correct way of design, verification, realization and maintenance of the company´s internal rules and activities in accordance with the good technical practice and requirements of the relevant legislation. From the aspect of safety assessment of a newly-developed multifunctional CNC machine, it seems appropriate to stress the owner´s responsibility for "Sustainable safety of production facilities" in the instructions for use. The introductory part of the instructions should include the responsibility of the management regarding "Legal requirements", "Continuous hazard identification, risk assessment and management" and "Understanding safety requirements" (Figure 4) with reference to the part of the instructions dealing with requirements on the maintenance of the machine.
- **Level of human resources management** focuses on improvement of qualification and experience of the staff. It includes evaluation and improving the level of employee training, encouragement of more experienced employees in sharing their work experiences and use of company benefits for relaxation and regeneration after work in order to support healthy lifestyle of the workers. The newly-developed machines can be visualized in the virtual reality environment even prior to production of a physical prototype. Such visualization enables early detection of possible design flaws on the part of the designers and allows to start training of the future operating personnel even before the machine is delivered. In case of development of machines with Industry 4.0 elements, it is possible to connect this virtual model to the physical control and sensory system of the machine to create a so-called digital twin of the machine, which can be used for training of new operators without the risk of financial losses due to their mistakes.
- **Level of production process support** includes, on one hand, the technologically feasible design of the multifunctional CNC machine itself and information from the sensory system on the current state and condition of the machine; on the other hand, the way of handling of the machine on the part of its user, which can be markedly affected by interpretation of the results of the machine´s capability monitoring and unambiguous interpretation of the instructions for use and safety warnings on the machine.

Deviations of the above-mentioned aspects from the ideal state can also be considered as stressors, which act together with the personality traits (i.e. conscientiousness, carefulness, responsibility) and safety culture within the company, affecting the operator of the machine as well as its designer or the risk manager who assesses the design of the machine and proposes preventive measures for reduction of the unacceptably high risks. In this case, risk reduction should focus mainly on the incorporation of suitable safety warnings into the instructions for use of the machine, corresponding descriptions of the correct work procedures and a list of suitable personal protective equipment. The owner of the machine can use this information in preparation of the occupational health and safety training within the "Up-skilling of existing staff and training of new staff" (Fig. 4*)*. According to the Machinery Directive 2006/42/ES [EUR-LEX 2006], it is necessary to take into consideration also any reasonably foreseeable incorrect work procedures that may result for example from the above-mentioned decline of the operator´s attention caused by some internal or external stressors. For this purpose, we have proposed and performed three case studies aimed at the level perception of hazards in a complex multifunctional CNC machine. Our goal was to identify the possibilities how to improve hazard perception by revision of safety warnings in the instructions for use of the machine, which would allow targeted training in safe operation of a multifunctional CNC machine including suitably targeted visualization of the machine in question in the virtual reality environment, or in augmented reality applied at a produced machine.

3 CASE STUDY

Participants of the experimental case study were 31 students in the first year of the follow-up master-level study programme Quality, reliability and safety, who had already finished their mechanical-engineering-oriented bachelor-level studies and therefore already had some previous experience with machine tools operation. Each of these students represented a newly trained operator of the machine in question, affected by a number of external and internal stressors. This group of students was set a task to identify all hazards associated with the WELDPRINT MCV 5X machine with hybrid technology (Figure 1). The objective of the case study was to find out which hazards associated with the design of the machine are difficult to identify by the persons with lower level of hazard perception. There was no purpose to investigate the psychological stressors as such and their effect on the study participants, but to assess the impact of impaired concentration of the operators on their ability to perceive all of the hazards occurring at a multifunctional CNC machine. This focus of the experiment reflects the current legal duties of the machinery producers in the field of their safe design. The experiment was divided into three steps with gradually increasing level of risk management training. The results were compared with an etalon worked out by a group of experts prior to placing the assessed machine onto the EU market. The numbers of hazards identified by these experts are shown in Table 1 in the START column.

3.1 Step 1 – Initial hazard perception study

In the first step of the experiment, the machine was presented to the students and its functions and handling were explained with the use of the pictures and videos provided by its manufacturer (Figure 5). This part corresponded to the simplified instructions for use of the machine not including safety warnings for its handling.

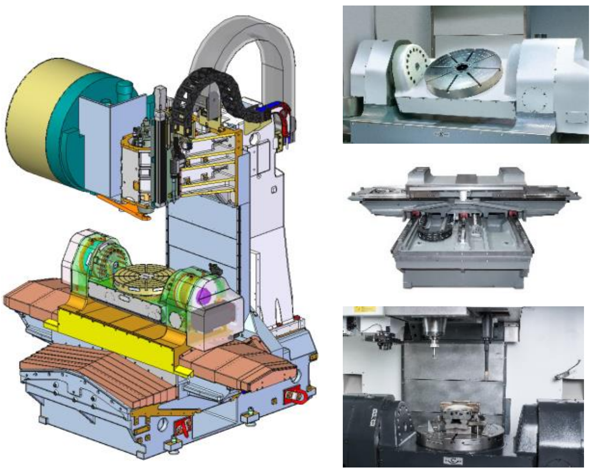

Figure 5. Visualisation of machine WELDPRINT MCV 5X with hybrid technology in STEP 1 (example) [KOVOSVIT MAS 2016a]

Furthermore, the students were acquainted with the terms "hazard" and "risk" according to the Machinery Directive 2006/42/ES and with the individual types of hazards according to the ISO 12100 [ISO 2010] international standard, which they were supposed to identify on the machine in question. After that, they worked individually, filling in the identified hazards into a provided table. The first step of the experiment provided information about the initial ability of each student to perceive hazards associated with the analysed machine. The results of this step are shown in Table 1, section "Step 1". For example, the row "Mechanical hazards" in this section shows that the best result was identification of 12 mechanical hazards ("max." column) of the total of 63 mechanical hazards identified by the experts (ETALON column). This result represents identification of 19% of the mechanical hazards. The worst result was identification of just one mechanical hazard (i.e. 2%; "min." column). The "AM" column shows the arithmetic mean value of the number of the identified hazards in the whole group of 31 students. On average, 7.1 mechanical hazards were identified per one student, which represents 11% hazard identification success. This percentage value therefore characterizes the level of hazard perception in the group of students participating in the study during the first step of the experiment.

3.2 Step 2 – Hazard perception after targeted training in risk management and machinery safety

Within the second step of the experiment, the students got familiarized in detail with the requirements of the Machinery Directive 2006/42/ES on the machinery producers and mainly with the essential health and safety requirements relating to the design and construction of machinery according to Annex I of this directive. They also learned in detail about the requirements of the ISO 12100 [ISO 2010] international standard on risk assessment and risk reduction. Special attention was paid to the strategies of risk assessment and the iterative three-step method of risk reduction (according to chapter 4 of this standard) and risk assessment (according to chapter 5 of this standard) with regard to the system methodology of risk assessment in machine tools [Blecha 2008]. This level of training corresponds to the good technical practice for assurance of the minimum required safety level of the assessed machine.
After that, the students worked individually again, filling in the identified hazards into a provided table. Therefore, the second step of the experiment provided information about the ability to perceive the hazards linked to the machine in question not only from the position of its operator, but also from the viewpoint of the designer responsible for safe design of that machine.

3.3 Step 3 – Hazard perception during visualization of the machine in virtual reality

In the third step of the performed experiment, a simplified model of the assessed machine was presented to the students in the immersion virtual reality environment. It was the same model that served during the design phase of the machine for assessment of the construction variants, and which was also used by the group of experts who worked on the documentation of the risk analysis and assessment used as an etalon for comparison of the results obtained by the individual students. This level of training with its detail went beyond the requirements of the good technical practice for achievement of the minimum required level of safety of the assessed machine. Besides, the students got the same visual sensation as the machine operator and even had a possibility to explore the parts of the machine that are hidden from the operator´s sight.

Case study	START	STEP 1			STEP 2			STEP 3		
Identified hazards	Etalon	max. (% max.)	min. (% min.)	AM (% AM)	max. (% max.)	min. (% min.)	AM (% AM)	max. (% max.)	min. (% min.)	AM (% AM)
Total number of hazards	**99** (100 %)	26 (26 %)	4 (4 %)	**14,4** (15 %)	52 (53 %)	24 (24 %)	**36,2** (37 %)	65 (66 %)	44 (44 %)	**57,3** (58 %)
Mechanical hazards	**63** (100 %)	12 (19 %)	1 (2 %)	**7,1** (11 %)	31 (49 %)	13 (21 %)	**21,6** (34 %)	42 (67 %)	29 (46 %)	**35,9** (57 %)
Electrical hazards	**2** (100 %)	2 (100 %)	0 (0 %)	**1,3** (65 %)	2 (100 %)	1 (50 %)	**1,8** (89 %)	2 (100 %)	1 (50 %)	**1,9** (94 %)
Thermal hazards	**5** (100 %)	5 (100 %)	0 (0 %)	**2,2** (44 %)	5 (100 %)	1 (20 %)	**3,9** (79 %)	5 (100 %)	2 (40 %)	**4,5** (89 %)
Noise hazards	**1** (100 %)	1 (100 %)	0 (0 %)	**0,6** (65 %)	1 (100 %)	0 (0 %)	**0,9** (94 %)	1 (100 %)	1 (100 %)	**1,0** (100 %)
Vibration hazards	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Radiation hazards	**1** (100 %)	1 (100 %)	0 (0 %)	**0,1** (6 %)	1 (100 %)	0 (0 %)	**0,2** (19 %)	1 (100 %)	0 (0 %)	**0,4** (42 %)
Material/substance hazard	**7** (100 %)	3 (43 %)	0 (0 %)	**0,7** (10 %)	5 (71 %)	0 (0 %)	**2,2** (31 %)	5 (71 %)	2 (29 %)	**3,4** (48 %)
Ergonomic hazards	**14** (100 %)	6 (43 %)	0 (0 %)	**2,0** (14 %)	10 (71 %)	1 (7 %)	**4,4** (31 %)	12 (86 %)	2 (14 %)	**8,2** (59 %)
Hazards associated with environment	6 (100 %)	2 (33 %)	0 (0 %)	**0,5** (8 %)	3 (50 %)	0 (0 %)	**1,2** (20 %)	4 (67 %)	1 (17 %)	**2,1** (34 %)

Table 1. Development of the hazard perception level by the study participants during the three steps of the experiment.

Figure 6. Visualisation of the machine in Cave Automatic Virtual Environment (CAVE)

For the study, a VR CAVE system with a four-sided projection (Figure 6) was used to allow for additional persons (aside from the test subject) attending the VR-scene for pedagogical observation. To make sure that the results of the experiment were not affected by lack of experience with the control of the model in the virtual reality environment [Puschmann 2016], the same teacher instructed every student during the individual visualizations and, if necessary, performed the more difficult visualization operations according to the student´s wishes. The outcome of the third step of the experiment was information on the ability to perceive a hazard in direct interaction with the assessed machine in the virtual reality environment. From the aspect of the designer, in this experiment we have obtained data about the ability to perceive the hazards during a safety review before releasing the machine for production. From the operator´s perspective, it gave us information on the ability to identify hazards occurring during machine operation and it helped us determine the most suitable places on the machine for placement of safety warnings and pictograms.

3.4 Results

The results obtained in the individual parts of the experiment (Step 1 to Step 3) are summarized in Table 1, both in absolute and in relative values.

Examination of the initial level of hazard perception by the students participating in the study, who were affected by various external and internal stressors, revealed that they struggled especially with the identification of radiation hazards (see Figure 7). Identification success of this hazard was only 6 % of the participating students, which is shown in Table 1 by the % AM value.

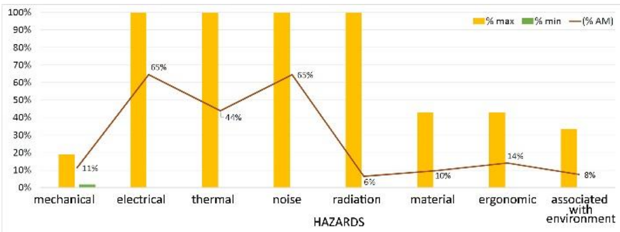

Figure 7. Initial hazard perception

Identification success of 6 % means that this hazard associated with electromagnetic field radiated by electric arc during welding [Pacaiova 2018] was identified only by 2 students from the 31 participating students, i.e. each student was able to identify 0.1 hazard from the 1 hazard identified by the experts. In Table 1, the best result achieved by the students is shown in the max. (% max.) column and the worst result in the min. (% min.) column.

The second group of hazards that turned up to be difficult to identify were the hazards associated with environment in which the machine is used, where the best result was identification of 2 hazards from the total 6 by one student. The average value of identification success for the whole group of students was 8 %.

The third most problematic group were the material/substance hazards where the average identification success reached only 10 % of the relevant hazards. The best result was identification of 3 out of 7 relevant hazards and the worst result was zero identified hazards. Identification of mechanical hazards was similarly difficult as the students were surprisingly able to find only 11 % of the relevant hazards on average.

Prior to the second part of the experiment, the participating students were thoroughly acquainted with the requirements of the harmonization EU legislation, harmonized standards, and risk assessment methodology.
The best effect of such targeted training in machinery safety on the level of hazard perception in the participating group of students was seen in thermal hazards, which reached the highest average improvement of hazard perception by 35 % (% AM increase from 44 % in step 1 to 79 % in step 2- see Table 1). The second most significant improvement of hazard perception by 29 % was reached in noise hazards, while the smallest average improvement by 13 % was observed both in radiation hazards and hazards associated with environment in which the machine is used.

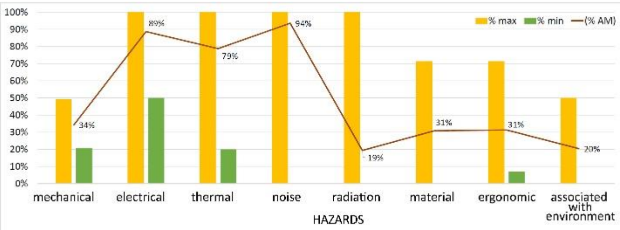

Figure 8. Hazard perception after targeted training in the safety of machinery

Figure 8 indicates that in four groups of hazards (noise hazard, radiation hazard, material/substance hazard and hazards associated with environment), there were still some students who were unable to identify any hazards from these groups. Besides, in mechanical hazards, material/substance hazard, ergonomic hazard and hazards associated with environment, none of the students succeeded in identification of all relevant hazards. The highest success appeared in identification of electrical hazards, where all of the participants managed to find at least 50 % of the relevant hazards and 97 % of the participants were able to identify the hazard associated with the possible direct contact with the live part under electrical voltage. The fact that a failure in the electric circuit could cause other parts of the machine to become live and thus dangerous as well was apparent to 81 % of the students. Here we have seen how difficult it is to realize a possible hazard and to be aware of the risk associated with it in those cases where this hazard is not evident at first glance. We presume that this aspect markedly affected also the ability of some study participants to identify noise hazard, radiation hazard, material/substance hazard and hazards associated with environment.

Therefore, the third part of the experiment focused on visualization of the machine in the immersion virtual reality environment with the aim to find out to what extent it would improve the ability of the participating students to perceive the hazards. Such a targeted experiment reflects a very current topic – the proposal for revision of the EU regulation on machinery products [EUR-LEX 2021], which will most probably allow the manufacturers to provide documentation in digital format and thus they will be able to use multimedia for presentation of the instructions for use. In this part of the case study, the students applied the theoretical knowledge obtained in the previous step of the experiment and they were instructed to proceed according to the system methodology of risk management [Blecha 2008]. The levels of hazard perception reached within the third step of the case study are shown in Figure 9.

The highest average improvement of hazard perception (as compared to the initial values) by 46 % was found in mechanical hazards (improvement of % AM from 11 % to 57 % - see Table 1). The second most profound improvement of hazard perception (by 45 %) was reached both in thermal hazards and in ergonomic hazards. The smallest average improvement (by 27 %) appeared in hazards associated with environment in which the machine is used.

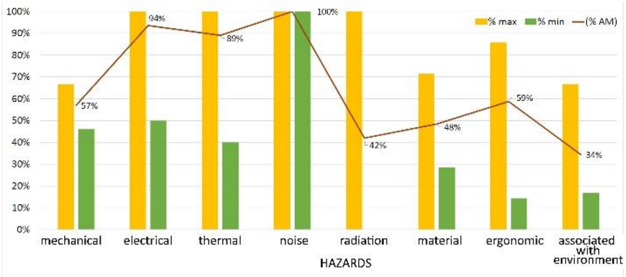

Figure 9. Hazard perception with the use of visualization of machine in virtual reality

Figure 9 shows that only in radiation hazards there were still some students who failed to identify any relevant hazard. Besides, in mechanical hazards, material/substance hazard, ergonomic hazard and hazards associated with environment, none of the participants succeeded in identifying all of the relevant hazards. The best success rate was reached in identification of noise hazards as all of the participants were able to find 100 % of the relevant hazards. Excellent results were also seen in electrical hazards and in thermal hazards with 94 % and 89 % (respectively) of students identifying them correctly.

4 CONCLUSION

The aim of the presented analysis of the psychological stressors linked to operation of multifunctional CNC machines was to respond to the currently discussed revision of the requirements in the EU harmonization legislation, which will present a challenge for the machinery producers in the field of increasing the safety level of the newly-developed CNC machines. Consideration of psychological stress associated with operation of a complex multifunctional CNC machine may therefore soon become one of the obligatory aspects of safety assessment. The goal of the performed experiment was to analyse the level of hazard perception in the participating group of students qualified for CNC machinery operation. We have assumed that all individuals are affected by a number of stressors in their work or personal life, which impair their concentration on the performed work tasks and limit effective application of their expertise. Our objective was to find out, which of the hazards are difficult to identify and therefore they are likely to be overlooked by machine operators, for example in consequence of exposure to work stressors (Figure 3). Such hidden hazards should be appropriately implemented into the training of workers, both the present and the new ones (Figure 4). This can be achieved through adaptation of the instructions in the existing manual, by adding safety warnings onto the machine itself, through the use of digital format of these instructions enabling multimedia visualization of the machine in virtual reality, or by visualization of just the safety warnings and pictograms on the real machine with the use of augmented reality technology. We therefore recommend that the most problematic hazards which most of the participants or even all of them failed to identify (Table 2), should be stressed out both in the instructions for use and on the machine itself in the form of safety warnings and pictograms. The results also indicate that it would be suitable to use the augmented reality technology for the work safety and health training of the operators and to overlay these warnings onto the real machine, as it would help mainly the newly trained staff to obtain and to automate the necessary correct routine. In case of older machines that cannot be visualized in virtual reality environment, we recommend to perform the following adapted version of the presented experiment:

1. To carry out standard training of the operating personnel at the real machine.
2. At the end of the training, to perform a test in the form of identification of hazards linked to that real machine.
3. To evaluate the test.
4. To present the results of the test to the operators and to provide explanation to the hazards that were not identified.
5. To consult the test results with the designer of the machine and to incorporate the findings into the instructions for use.
6. Repeated validation and assessment
7. End of the process.

Hazard description	Identification success
Fall of a handled part of the machine due to overload of the hoisting apparatus and accessory equipment (i.e. ropes).	0 %
Fall of the handled machine or its part due to inconvenient incorporation of the hoisting apparatus accessories into the machine structure.	0 %
Hazard of being hit by a cover that had been deformed by an ejected part.	0 %
Hazard of fatal injury from safety glass fragments in case of its breaking.	0 %
Fall of the handled machine or its part due to not knowing its weight or having incorrect information about it.	3 %
Fall of a handled part of the machine due to bad choice of hoisting apparatus accessories.	3 %
Fall of a loose part of the machine or of a bulk object after tilting the manipulated part of the machine.	3 %
Fall of a handled part of the machine due to under sizing of the element used for gripping the manipulated part of the machine.	3 %
Personnel fall hazard (fall from height).	3 %
Hazard caused by external factors (electromagnetic interference) during operation, adjustment or maintenance (unexpected starting or running).	6 %
Hazard caused by external factors (interference of other persons) during adjustment or maintenance (unexpected starting or running).	6 %
Hazard of fire or explosion during cleaning of the machine.	6 %
Hazard of stabbing or puncture injury caused by movement of the welding torch (welding wire).	6 %
Failure to adhere to the instructions for incorporation into the final machinery provided by the manufacturer of the machine.	10 %
Hazard caused by power supply failure at a selected speed of movement (excess speed due to self-weight and gravity forces).	10 %
Hazards caused by human mistakes during selecting the machine´s mode.	13 %
Hazard of contact with contaminated cutting liquid when handling the chips or the workpiece	13 %
Hazards caused by insufficient protection against unauthorized reconfiguration of machine´s safety-related software.	13 %

Table 2. List of hazards identified by less than 15 % of participants

Another benefit of the performed experiment was its implementation into the curriculum at the university within the seminars dealing with machinery safety. This innovation helped us improve the ability of the students to identify the hazards linked to machinery and therefore to better prepare them for industrial practice.

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CONTACTS:

Assoc. Prof. Ing. Petr Blecha, Ph.D.
Brno University of Technology
Faculty of Mechanical Engineering
Institute of Production Machines, Systems and Robotics
Technicka 2896/2, 616 69 Brno, Czech Republic
e-mail: Petr.Blecha@vutbr.cz , websites https://www.vutbr.cz/en/people/petr-blecha-2489