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An ergonomic expert system for risk assessment of work-related musculo-skeletal disorders

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ABSTRACT

A computer-based expert system (SONEX) was developed to identify ergonomic risks for work-related musculoskeletal disorders (WRMSDs) in a wide variety of jobs and provide expert prevention advice. SONEX uses a rule base and 6 knowledge base modules: WRMSD risk factors are grouped into two main knowledge base modules (symptoms, engaged body part) with four supplementary knowledge base modules (work environment, work chair, work tools, organization factors). SONEX uses a menu-based interface and a series of simple questions that lead a user through each of the two main modules. Based on user responses it then recommends other knowledge base modules that are relevant for a detailed analysis of work risks. The SONEX rule base has over 140 questions, the knowledge base includes over 200 risk factors, and around 500 possible answers can be generated. SONEX relates ergonomic shortcomings in the job with worker's subjective symptoms; it predicts possible WRMSDs; and it offers preventive suggestions for ergonomic improvements to the job to prevent WRMSDs. It has been tested in a variety of work places with known ergonomic problems and with known employee WRMSDs by comparing its performance with conventional analytical methods and results show that it accurately predicts possible WRMSD risks and identifies ergonomic shortcomings. The advantages of SONEX are that it is much faster than other ergonomic analysis methods and it can be used by ergonomists and other professionals and also by workers themselves.

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1. Introduction

The development of expertise in any profession requires an accumulation of factual information and the acquisition of rules and skills for appropriately applying those facts. This is a lengthy and costly process, and experts are scarce resources. For example, there are some 100 million workers in the USA, but there are less than 5000 members of the Human Factors and Ergonomics Society, and of those members there are less than 2000 Certified Professional Ergonomists (CPE) who are available to undertake any kind of workplace intervention such as improving the ergonomic design of jobs to eliminate the risks of work-related musculoskeletal disorders (WRMSDs). WRMSDs are of concern worldwide because they account for a significant portion of all workplace injuries, they are a drain on the economies of countries through direct and indirect medical costs and lost productivity, costing between 0.5 and 2% of the Gross Domestic Product (Nunes, 2009), they are distressing and even life-changing for workers, yet invariably they are preventable by ergonomic early interventions. A ratio of one CPE per 50,000 workers cannot ever result in a widespread positive impact of ergonomics.

The number of employees with some type of WRMSDs is high in the USA and is on the rise in countries like Serbia, but the situation with the number of ergonomists in Serbia (and all other countries of former Yugoslavia) is much worse than in U.S. The development of an ergonomic expert system is a valuable tool that can replicate some of the skills of the ergonomist and allow even workers themselves to undertake some evaluation of the ergonomic risks in their jobs to help to reduce WRMSD risks.

Expert systems are computer software programs that are designed to replicate the problem-solving abilities of human experts in a knowledge-based reasoning system. Human expert knowledge is not simply a collection of facts, but it comprises information about a particular domain, an understanding of domain problems, and where possible skill at solving these problems

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(Boose, 1986). As An expert system generally comprises the following 4 components in its knowledge base (Kern and Bauer, 1992):

- Declarative knowledge (factual knowledge)
- Procedural knowledge (knowledge of irregularities and correlations)
- Vague knowledge (knowledge of probabilities, assessment of facts)
- Heuristic knowledge (empirical knowledge, intuition)

This knowledge base then is interrogated and interacts with rule-based expertise to generate a probability-based decision outcome.

Kern and Bauer (1992) note, "knowledge-based systems are software systems which permit the specialist knowledge and the problem solving capability of qualified specialists, so-called experts in a specific field of application, to be reconstructed." (p.38). Unlike conventional software systems that only use factual input and algorithms to arrive at an optimal solution, expert systems require factual information and also try to encapsulate heuristic knowledge that involves the methods and strategies used to solve problems with the factual knowledge. In short, knowledge-based expert systems try to encapsulate the decisions that a real expert would exercise given the set of factual information at hand (Järvinen and Karwowski, 1992). Expert systems can be developed as customized system from the ground up or then can be modifications of an existing expert system shell environment, or they can use a combined approach.

The benefit of an expert system is that it can guide users at almost any level of skill, even a novice user, to an appropriate decision about the factual information, and also it can serve as a decision-support system by providing an ergonomics expert with additional reassurance about a decision. Thus, a validated expert system has the potential to dramatically expand the potential applications of ergonomics to improving the design of jobs in a cost-effective way. The development of ergonomic expert systems offers a way of multiplying the capabilities of ergonomics experts to potentially benefit a much larger number of workers than can be analyzed by the current numbers of human expert ergonomists.

Laurig and Rombach (1989) identified four sets of general requirements for the development of an ergonomic expert system: hardware requirements, software requirements, knowledge-base requirements, and user-interface demands, and these general requirements for the development of an ergonomic expert system are summarized in Table 1.

Concerns about hardware and software requirements are less these days than at the time of Laurig and Rombach (1989). Modern computer technology is relatively inexpensive and it has fast processors and large and expansive storage media. Current software development allows for both stand-alone expert system programs and also the deployment of these via the world-wide web. However, knowledge-base requirements and the development of usable interfaces remain issues of paramount importance.

2. Brief history of ergonomic expert systems

During the past twenty years work-related musculo-skeletal disorders (WRMSDs) have become a major problem in worldwide and as previously noted both the economic and human costs are immense. There is a variety of WRMSDs with these varying in their symptoms and by body locations. The National Institute for Occupational Safety and Health (NIOSH) defines WRMSDs as:

> *"those diseases and injuries affecting the musculo-skeletal, peripheral nervous, and neurovascular systems that are caused or aggravated by occupational exposure to ergonomic hazards … .Ergonomic hazards relative to WRMSDs refer to physical stressors and workplace conditions that pose a risk of injury or illness to the musculo-skeletal system of the worker. Ergonomic hazards include repetitive motions, forceful motions, vibration, temperature extremes (especially cold), and awkward posture caused by improper design of workstations, tools or equipment, and improper work methods."*

The effects of the above ergonomic hazards may be amplified by organizational factors such as shift work, paced work, imbalanced work-rest ratios, demanding work standards, lack of task variety, etc. (Cumulative trauma disorders in the workplace, bibliography 1995)

Considerable worldwide effort and research has been devoted to finding appropriate strategies for analyzing and preventing WRMSDs. There is general scientific agreement that ergonomics plays a decisive role in these efforts and a failure to adhere to ergonomic principles of work design are believed to be the leading factors in the development of WRMSDs (NIOSH, 1997). The term "ergonomic risk" is relatively new, and it is used to identify risk factors related to the work process, which affect the development of WRMSDs. Ergonomic risk refers to the physical stress factors and work place conditions, which in themselves carry the risk of damage or disease to an employee's musculo-skeletal system. Different researchers have developed tools that enable better and more reliable analysis and ergonomic risk assessment of work. The most common approach to the problem has been to develop a questionnaire or a check-list to determine any ergonomic shortcomings (see Stanton et al., 2004).

Table 1
General requirements for the development of an expert system (Laurig and Rombach, 1989).

Hardware requirements	Software requirements	Knowledge-base requirements	User interface demands
General requirements for expert system development			
• suitable for but not limited to expert system applications • compatible/integrated with end-user software environment • low cost	• machine-independent development • extendable software design • flexible and intuitively understandable • knowledge-representation concepts • acceptable runtime behavior	• modular structure for easy maintenance • extendable design • modularization - clear separation between chunks of unrelated knowledge (i.e. knowledge about different ergonomic domains)	• unequivocal terminology • ability to explain terminology used by the system • explanation module according to user needs • robustness against incorrect input

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