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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.

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

Numerous risk factors contribute to the development of WRMSDs, and each of these must be thoroughly investigated. WRMSDs prevention and identification involves many different experts, such as ergonomists, safety engineers, occupational psychologists, occupational healthcare professionals, etc. A sizeable knowledge base is essential to correctly identify risks and prevent the development of WRMSDs. A tool that is more sophisticated than a simple ergonomic checklist and that will identify the ergonomic risk factors that might lead to development of WRMSDs, especially in their early stages of development, make predictions about the risk of a disorder, and provide advice on suitable avoidance strategies to mitigate these risks is of considerable value to practitioners and workers. Consequently, over the past 20 years or so, several ergonomic expert systems have been developed that have been designed to progressively replace the traditional practice of using ergonomic checklists (Moynihan et al., 1995).

The development of computer-based expert systems began in earnest during the 1970s, but at that time the running of such a system required special purpose artificial intelligence hardware and software, and consequently most systems were expensive and development work invariably stopped at the prototype stage because they were not commercially viable for widespread use by ergonomists.

In the 1980s, the emergence of more powerful microprocessors and the development of desktop personal computers allowed microcomputer-based software expert systems to be developed for ergonomic applications. The initial focus of these expert systems was in the application of anthropometric data to improving the design of workplaces and workspaces. Here the goal was to develop a system that improved the fit between the physical body dimensions of a worker, the work equipment, and immediate work environment. Table 2 summarizes some of these early expert systems and for a more complete description the reader is referred to two excellent edited books by Karwowski et al. (1990) and Mattila and Karwowski (1992).

Other early development work focused on ergonomic analysis of manual materials handling and lifting tasks. One of these early ergonomic expert systems was LIFTAN, designed for the analysis of manual lifting tasks (Karwowski et al., 1986a,b; 1987). This system utilized a knowledge base comprised of 149 rules: 34 were task-related risk-analysis rules, 51 were operator-related risk rules, 30 were job redesign recommendations and 34 were operator-related explanations. The domain content of the knowledge base was derived from relevant published studies on manual lifting, biomechanics, anthropometrics, work physiology and epidemiology. LIFTAN also comprised an inference mechanism and a human interface to guide the user through the information needed by the system and to present the results of the analysis. Another expert system that was developed at around the same time by Genaidy et al. (1987, 1988) and Kabuka et al. (1988) focused on the ergonomic analysis of repetitive manual materials handling tasks. In this system the knowledge base included information on lifting, lowering, carrying, pushing and pulling activities. In addition, the system gathered information on worker characteristics (age, gender, body weight, and the level of training and the materials handling technique), lifting task variables (frequency of lifting, load height, load size as measured by the box width in the frontal plane and the box length in the sagittal plane, the body angle for asymmetric lifting and lowering), carrying, pushing and pulling task variables (task frequency, load height, horizontal travel distance), and finally environmental variables (temperature, humidity, air velocity and vibration). This system utilized the concept of a "job severity index" that was used by the expert system software to minimize the risks of injury for manual materials handling tasks. Based upon the imputed data the system provided the maximum acceptable weight for that situation and if the existing task was unacceptable then it suggested some possible solutions.

Laurig and Rombach (1989) developed another expert system designed to detect and minimize the health risks associated with manual material handling work. They emphasized that the kind of expert system typically being developed in ergonomics was not an artificial expert but rather a decision-support system for expert use by an ergonomist. They named their system ERGON-EXPERT, and it was an expert decision-support system comprising various analysis and assessment modules focusing on manual materials handling tasks. In this system the sequence of analysis and assessment began by checking for compliance with a LAW module that incorporated the requirements of the ergonomics regulations in Germany at the time. Following this there was a sequence of modules (BODY, SPINE, ENERGY, MOTOR and SUBJECT) that compared task requirements and biomechanical abilities. This system also included ENERGY and OXYGEN modules that predicted metabolic load based on a job description and personal variables (sex, age), an ENDURANCE module that predicted the possible length of uninterrupted work, and a SPINE module that calculated the compressive forces on the 5th lumbar, 1st sacral (L5-S1) intervertebral disc. Researchers had to use their best estimates of work capacity because of the lack of justifiable limit values based on empirical studies.

An interactive computer-assisted Ergonomics Analysis System (EASY) that comprised three major components, namely, an Ergonomic Information Analysis System (EIAS) designed to evaluate the characteristics of the worker and their tasks, a dynamic lifting analysis system (DLAS) for manual materials handling tasks, and a physical work stress index (PWSI) for more detailed investigation of

Table 2
Some early ergonomics expert systems.

Expert system focus	Software program
Anthropometric/Workplace	SAMMIE (Case et al., 1990)
	WERNER (Kloke, 1990)
	AutoCAD (Grobelny, 1990)
	TADAPS (Westerink et al., 1990)
	APOLIN (Grobelny et al., 1992)
Workspace design	ERGOSPEC (Brennan et al., 1990)
	COMBIMAN/CREW CHIEF (McDaniel, 1990)
	SAFEWORK (Fortin et al., 1990)
Workload Work measurement	OWLKNEST (Hill and Harris, 1990)
	MTM (Kühn and Laurig, 1990)
	MOST (Ramcharan and Martin-Vega, 1990)
Posture/Manual load handling	OWASCA (Väyrynen et al., 1990)
	ERGON-EXPERT (Rombach and Laurig, 1990)
Performance evaluation/decision support	SPES (Gamberale et al., 1990)
User-machine interface	INTUIT (Russell, 1990)

problem situations by supervisors or ergonomists, was developed by Chen et al. (1991). The system was experimentally tested for ease of use using 20 subjects who saw a series of photographic images of a dishwashing task and they completed ease-of-use questionnaires for the various interfaces, and there was a consensus that the system was easy to use. The system was evaluated by comparing the results of an analysis of a series of jobs by the software and by expert diagnosticians, and the results showed an overall 83% agreement between the results from the software and the expert evaluators.

McCauley-Bell and Badiru (1992) applied fuzzy set theory to the development of a fuzzy linguistic model designed to predict the risk of developing a workplace cumulative trauma disorder (CTD). They reviewed the literature and identified those personal characteristics, task variables and environmental factors that had been shown to contribute to the development of a work-related CTD (note that this term was used for WRMSDs in the late 1980s through mid-1990s). This work set the stage for subsequent ergonomic expert systems that utilized fuzzy set logic in their development and architecture.

A fuzzy set algorithm was incorporated into an object-oriented expert system, named ERGONOMIST V, which was developed by Moynihan et al. (1995) to analyze work-related CTD risks and to recommend possible solutions to these risks. This system comprised a database, knowledge base and logic base. The database focused on 29 risk factors for each of 12 CTDs. The knowledge base accepted user input and computed severity index values for all possible CTDs, and it activated the logic base and displayed the results and final conclusions. The logic base converted user input into numeric system variables. The logic base first sorted CTD risk values in descending order and then applied a priority first algorithm to generate the output that subsequently was used by the knowledge base to computer the final conclusions. This system was evaluated by a group of experts for its face validity and then it was tested in a manufacturing facility as part of their CTD prevention and control program.

Gilad and Karni (1999) developed a more comprehensive ergonomic expert system (ERGOEX) for the ergonomic analysis and evaluation of the workplace design by professionals (e.g. industrial engineers, ergonomists, medical staff) or workers. The system incorporates three categories of knowledge: workplace design (equipment, anthropometrics, posture), environmental conditions (light, noise, vibration, climate) and evaluation and failure analysis (biomechanics, methods and measurements, checklists, accumulated trauma). The system accepts input data on the anthropometry of the worker and the physical layout dimensions of his/her workplace, on the worker's tasks, and on the characteristics and the physical dimensions of the equipment that the worker uses. Based on the inputted data the system generates both general and specific recommendations along with suggestions for improving the design of the workplace and guidance on a recommended work layout.

To help to improve the physical design and organization of the computer workstation furniture Rurkhamet and Nanthavanu (2004) developed the EQ-DeX expert system. This system accepted input data on the characteristics of the worker, such as their anthropometric dimensions of the worker (e.g. stature), their personal characteristics (e.g. age, gender) their skill level (e.g. beginner, intermediate or professional typist), and their usage patterns (e.g. % input device use). Other input data included physical and visual interactions between the worker and their computer accessories (e.g. keyboard, mouse, monitor, document holder), as well as the adjustment ranges of the workstation furniture. The expert system then used analytic and rule-based algorithms to process the input data in the context of a built-in anthropometric dimensions database for Thai workers. The system provided both a visual and a written output of the recommended dimensions for the optimal layout of the computer workstation for that worker, but it did not ask workers about musculoskeletal problems, nor provide injury prevention advice and it is only applicable to computer workers.

A fuzzy expert system that is designed to assess both quantitative and qualitative ergonomic system factors in the context of health, safety and environment (HSE) issues has been developed and utilized at a gas refinery (Azadeh et al., 2008). This extensive system utilizes over 1000 rules to assess work environment injury risks, the effectiveness of the human–machine interface, and system design issues. The ergonomic risks focus on environmental conditions (lighting, noise, temperature), the incidence of musculoskeletal disorders and lifting tasks. Comparison of the output of the system with the results from manual analysis showed comparable results.

Nunes (2009) describes a fuzzy logic based ergonomic expert system named FAST ERGO-X that is designed to audit workstations for WRMSD risks. This system can combine subjective data on worker's opinions from questionnaires with objective data on variables such as the number of repetitions, duration and postural angles, and it also includes an ability to incorporate video recording of jobs and some motion analysis of these videos to extract postural angles. The software is designed to work on laptop computers to allow for *in situ* data recording, and it is designed to support the work of the expert ergonomist. The results from FAST ERGO-X are reported to show a good correlation with the results from analysis of various jobs using other ergonomic methods.

Table 3 summarizes a number of the systems that have been developed to date, with the exception of the SONEX system to be described here, for the analysis of manual materials handling and lifting work, the design of computer workplaces and the identification and mitigation of ergonomics hazards.

3. Expert system software (SONEX) for ergonomic risk assessment

For the current expert system, called SONEX, software development followed the general principles of software architecture for expert systems using a combined approach as described earlier in this paper. This primarily means that the system consists of two databases: a *knowledge database* derived from analysis of data from a large-scale literature review, and a *decision-making rules database*, derived from the extraction of knowledge from numerous experts and from the authors' own experience in the practical assessment of ergonomic risks in a wide variety of occupational settings. The system programming generally operates as a decision tree, with the numerous factors at the bases/bottom of the tree, which when placed inside a set of “rules”, established by the expert/experts produces some conclusion/result.

The SONEX system has been designed to be modular, expandable and customizable so that the bases (factors) are open (of course, with appropriate software security rights and protected levels of access by users of different expertise), so the user can change predefined facts that are used by the decision rules without changing the software architecture, i.e. without changing its “source code”. The system presents the user with a number of decision-making factors and a user (if they have permission to access) also can optimize and customize the rules. The system allows the user to define which question(s) will represent which factor, and which possible values may occur as a response to a question, and this then defines all possible outputs that could be a result of the analysis of given answers. The reason for this combined approach is that the aim of the software development was not to create a general level expert system that would be applicable

Table 3
Comparison of previous ergonomic expert systems for work-related musculoskeletal disorder risks.

Authors	Expert system	Domain focus	Architecture
Karwowski et al. (1986a,b)	LIFTAN	Manual lifting tasks	VAX LISP, VAX 8600 mainframe
Asfour and Genaidy (1987)	LIFTAN	Manual lifting tasks	IBM PC - XT
Karwowski et al. (1987)	M-LIFTAN	Manual lifting tasks	IBM-PC AT
Genaidy et al. (1988)		"Job severity index" for manual handling and lifting tasks	
Laurig and Rombach (1989)	ERGON-EXPERT	Work capacity for manual handling and lifting tasks	Modular, including analysis modules on Energy, Oxygen, Endurance, Spine and Regulations
Chen et al. (1991)	EASY	Ergonomic analysis system for use by the worker and/or supervisor, with a focus on manual handling	EAIS, DLAS and PWSI written in Foxbase Plus and QuickBASIC
Moynihan et al. (1995)	ERGONOMIST V	Upper limb cumulative trauma disorder risks	Object-oriented system in Visual Basic. Rule-based fuzzy logic.
Gilad and Karni (1999)	ERGOEX	Workplace design dimensions and adjustments; ambient conditions; biomechanics; methods and checklists.	Modular design incorporating 14 modules; calculations using dimension data; bibliography
Rurkhamet and Nanthavanu (2004)	EQ-DeX	VDT workstation adjustment and computer accessories arrangement.	GUI interface. Written in Visual Basic and Visual Rule Studio.
Azadeh et al. (2008)	HSEE	Safety, environmental, ergonomics, health and general factors in a decision support system.	Rule-based fuzzy logic.
Nunes, 2009	FAST ERGO-X	Ergonomic workstation analysis	Rule-based fuzzy logic.

to other areas of ergonomics as well, but rather to focus on developing a software system for decision support in the ergonomic risk assessment of jobs, which operates (and gives the results) as both a decision support system for an ergonomist and also as an independent "expert" providing ergonomic analysis advice to nonprofessional users, such as the workers themselves. The combined approach in the software development is illustrated by the example of the sub-module "Space" (part of the WORK CHAIR module). This part comprises 3 questions and Table 4 shows the different combinations and Table 5 shows an example of the appropriate results report that is generated.

In this way, if for example a series of answers is 01X (combination No. 3), this means that on question No. 1 the given answer is NO, for questions 2 the answer is YES and question 3 does not affect the final conclusion. This illustration of the coding principle for the SONEX applies to all other factors and conclusions, so that the SONEX system has a knowledge base of over 200 factors, and over 500 possible answers/results in response to queries involving these factors. The role of SONEX is to help users (both ergonomics experts and lay users) identify possible risk factors that may contribute to the development of WRMSDs. The SONEX knowledge database consists of a number of risk factors sorted into two main and four additional modules (DISCOMFORT, ERGONOMIC RISK FACTORS, WORK ENVIRONMENT, WORK CHAIR, TOOL, and ORGANIZATIONAL FACTORS). In the current version of the software all risk factors are assigned the same importance/weight ($W = 1.0$) but if necessary this can be modified in the future as more reliable additional information becomes available. Fig. 1 shows block diagram of the organization of the system and Fig. 2 shows the appearance of main screen of SONEX.

Each knowledge base module can be accessed individually using SONEX, because each of these modules itself is a unique single expert system. If a certain workstation is analyzed by some medical experts, as well as by the employees who feel the pain in same part of the body, they can run the DISCOMFORT module (Fig. 1). After selecting of the body parts with the most discomfort (the software allows the selection and analysis of all parts of the body - 9 parts - hand, arm, shoulder, neck, lower back, sitting/gluteal area, knee, ankle and foot), the software starts by asking a series of questions about the strength of discomfort, some predisposing/individual factors, and so on. At the end of analysis for a painful part of the body, the result is a diagnosis with a description of the symptoms, and also with a list of possible ergonomic risk factors that may influence the development of those symptoms. The software also suggests the appropriate knowledge base/additional module for further analysis (Fig. 3).

The final results from each module are appropriately color-coded, in accordance with the principles of ergonomic design given in the European standard (EN614-1, 1995). So, if the result is "No problem" it is shown with green letters, "a low level of risk" is displayed with yellow letters, while the "high level of risk," is presented with red letters. The ERGONOMIC RISK FACTORS module in the knowledge base allows the analysis of projected work task in order to assess the risk factors present (ergonomic shortcomings) (Fig. 1). This is the module that the most technical personnel will start the analysis/assessment of the risk of WRMSDs.

In this module there are questions that allow the presence of

Table 4
Possible combinations of answers to the questions and possible results for the "Space" sub-module of the WORK CHAIR module.

Number of combination	Questions	Conclusion
0	111	No problems with the space on and around the chair
1	110	Inadequate leg space
2	10X	Inadequate leg space
3	01X	Inadequate work chair dimensions
4	001	Inappropriate work chair design for the workplace
5	000	Inadequate work chair dimensions and inadequate leg space

0 – The question is answered with NO.
1 – The question is answered with YES.
X – The question does not affect the final conclusion.

Table 5
Example of one of the possible final result obtained after an analysis using sub-module Space of the Work chair module.

Inadequate work chair dimensions and inadequate leg space
Work chair size is ergonomically inappropriate. The recommended work chair dimensions are:
• Seat height 38–53 cm
• Chair back height(top) 33–42 cm above the seat pan
• Chair back height(bottom) 20 cm above the seat pan
• Chair back width 40–45 cm
• Seat pan depth 38–42 cm
• Seat pan width 32–36 cm
• Seat pan angle 4–6° incline
• Chair back angle 95–105°
The recommended dimensions may vary depending on the source, but there is general agreement that these dimensions provide sufficient space for changes in sitting position and at the same time they provide comfortable body support.
When the seat pan is too high this changes the natural lordotic curve and increases pressure beneath the thighs. Seat pan height should not be too low because this causes extreme bending of the knees and increased shoulder strain from elevated arms. The chair must be comfortable for the sitting area and must provide enough space for different sitting positions, which are appropriate for the work tasks.
An adequate or appropriate sitting position means the position in which the feet are flat on the floor, with the lower leg at an angle of at least 90° in relation to the upper leg. The space around the work chair must provide adequate clearance for the legs and for leg movement. Desks with drawers beneath the work surface often do not provide sufficient space for the legs. Lack of space for the legs can also be caused by the placement of different objects (materials, tools, etc.) below the working surface or around the work chair.
Possible disorders
Lumbar muscle strain, herniated lumbar discs or piriformis syndrome may be due to the lack of support for the lower back or the lack of a lumbar support which can cause an inadequate sitting position (either a poor personal sitting habit, inappropriate chair size or inadequate seat pan design).
Inappropriate work chair design can also lead to neck muscle strain and painful cervical syndrome.
Ischiogluteal bursitis may be due to poor seat pan design, the lack of upholstery, or due to inadequate upholstery, which leads to increase pressure on the ischial tuberosities.

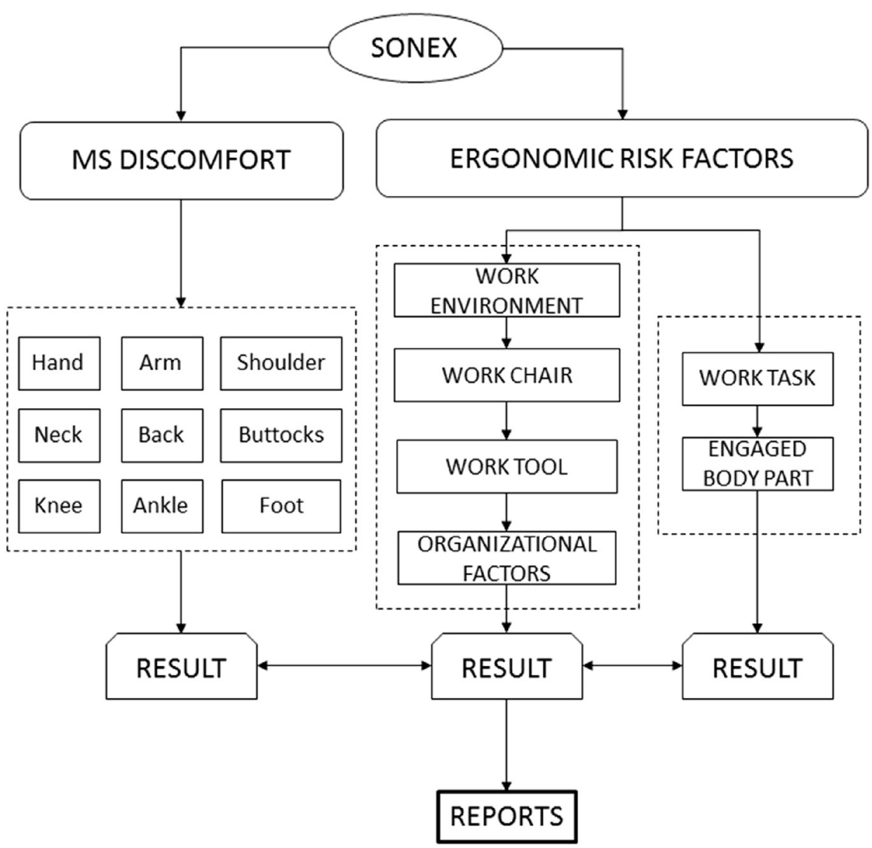

Fig. 1. Block diagram of the SONEX system.

risk factors, such as repetition, force, vibration, static or awkward positions and low environmental temperature, to be identified. Also this module allows the identification of the body part that is the dominant part that is most engaged in the performance of the tasks. Then, on the basis of responses about the types of movements and actions of the engaged body parts, it presents results in the form of work/ergonomic factors and the possible WRMSDs which are the result of exposure to these factors. As well as in the DISCOMFORT module, the results of the ERGONOMIC RISK FACTORS module also suggest additional modules which are useful to run for more in depth analysis (e.g., WORK ENVIRONMENT, TOOL, WORK CHAIR, or ORGANIZATIONAL FACTORS). At present the

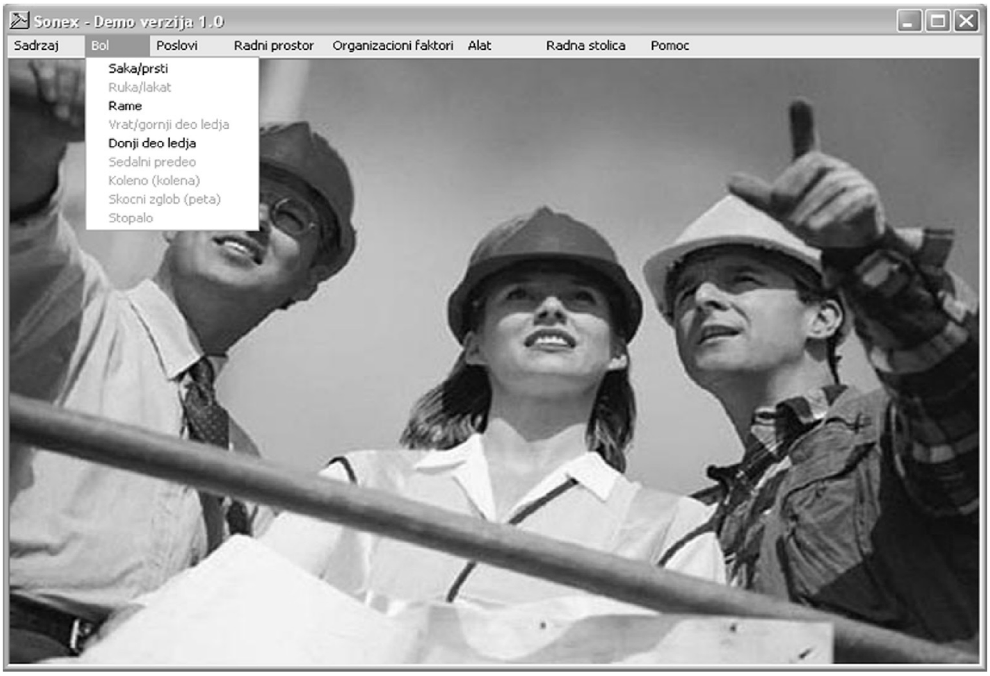

Fig. 2. The appearance of the initial screen of the SONEX system (screen text is in Serbian).

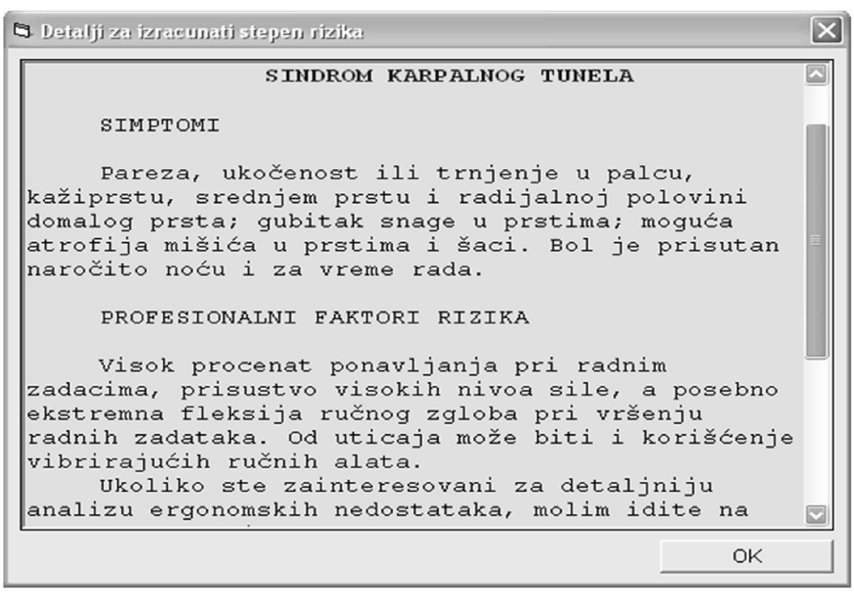

Fig. 3. An example of the results of the analysis of pain in hand and fingers (example is in Serbian).

software is written in the Serbian language and has been developed for application in this country, but the same architecture can be adapted to any language.

4. Testing of the SONEX expert system

The SONEX system was tested in two ways. First, four workers, two men and two women) were selected from diverse workplaces (tailor, mailman, data entry, barber) who were known to have some work-related issues, although the researchers were initially blind to the details of their WRMSDs (see Table 6, ID#s 1–4). For each of these workers the work place was initially analyzed with standard ergonomic methods, which enabled gathered data on ergonomic risks for subsequent comparison with the results obtained by the SONEX software.

The following standard ergonomic methods were used to validate the software for these four workers:

- the anthropometric dimensions of the worker and anthropotechnical dimensions of their workplace, for those sedentary parts of work task, were evaluated for their ergonomic compliance.
- three ergonomic checklists (General Risk Factors Checklist, Office Work Environment Checklist, Manual handling Checklist), based on those from NIOSH (2007), were used to identify potential ergonomic risks in the job,

Table 6
Comparison of software diagnosed injuries with physician diagnoses.

ID#	Work place/employee	SONEX result for chosen body part using discomfort module	SONEX result using ergonomic risk factors module	Actual diagnosed condition	Agreement
1	Tailor/female, age 53, works 30 years, smoker, in poor physical condition	Shoulder: Neck strain Neck/upper back: Cervical spondylosis	High risk work for hand, arm (elbow and shoulder) and back	Cervical spondylosis	++
2	Mailman/male, age 45, works 24 years, in good physical condition	Shoulder: Subacromial bursitis Lower back: Lumbar disc herniation	High risk work for whole body/arm (elbow and shoulder) and back	Subacromial bursitis and Lumbar disc herniation	++
3	Data entry/female, age 39, works 17 years, smoker, in good physical condition	Hand/finger: Carpal tunnel syndrome	High risk work for hand High risk work for neck and eyes	Carpal tunnel syndrome, irregular use of anti-rheumatic drugs due the pain in the neck	++
4	Barber/male, age 42, works 18 years, smoker, in good physical condition	Hand/finger: De Quervain's syndrome Knee: Knee bursitis	High risk work for fingers and forearm	De Quervain's syndrome and knee bursitis	++
5	Lathe operator/male, age 50, smoker, works 30 years, in good physical condition	Hand/finger: Carpal tunnel syndrome Neck/upper back: Cervical disc herniation	High risk work for fingers and forearm	No specific diagnosis. Regular use of anti-rheumatic drugs due the pain in hands and neck.	+
6	Driver of the truck with trailer/male, age 60, works 35 years, obese	Hand/finger: Nerve compression syndrome Lower back: Insufficient data Foot: Interdigital neuroma	High risk work for whole body	No specific diagnosis. Irregular use of anti-rheumatic drugs due the pain in hands, foot and lower back.	+
7	Exhibitor of the goods in the freezers/female, age 48, works 8 years, in good physical condition	Lower back/hip: Piriformis syndrome	High risk work for arm (elbow and shoulder) and back	No specific diagnosis. Regular use of anti-rheumatic drugs due the pain in back.	+
8	Taxi driver/male, age 46, works 23 years, smoker, obese	Lower back/hip: Lumbar disc herniation Gluteal area: Ischial bursitis	High risk work for whole body	Lumbar disc herniation	++
9	Dentist/male, age 38, works 9 years, in good physical condition	Hand/finger: Nerve compression syndrome	High risk work for fingers and forearm	No specific diagnosis. Regular stretching exercises due the pain in the hand, arm, neck and foot	+
10	Cleaning woman/female, age 52, works 24 years, in good physical condition	Shoulder: Cervical pain syndrome	High risk work for arm (elbow and shoulder)	Cervical pain syndrome	++
11	Nurse-dialysis/female, age 47, works 28 years, smoker, in good physical condition	Hand/finger: Carpal tunnel Syndrome Shoulder: Subacromial bursitis Lower back: Lumbar disc herniation	High risk work for whole body/hand, arm and back	Lumbar disc herniation	++
12	Female hairdresser/female, age 45, works 21 years, in good physical condition, obese	Hand/finger: Nerve compression syndrome Lower back/hip: Lumbar strain	High risk work for fingers and forearm	No specific diagnosis. Irregular use of anti-rheumatic drugs due the pain in hands and lower back	+
13	Hole digger in the mine/male, age 48, works 24 years, in good physical condition, obese	Hand/finger: Carpal tunnel syndrome Shoulder: Neck strain Lower back/hip: Lumbar strain	High risk work for whole body/hand, arm and back	No specific diagnosis. Irregular use of anti-rheumatic drugs due the pain in hands, neck and lower back, and rehabilitations for back pain	+
14	Programmer/male, age 31, works 7 years, in good physical condition	Hand/finger: Guyon's canal syndrome Neck/upper back: Cervical disc herniation	High risk work for hand High risk work for neck and eyes	No specific diagnosis. Irregular use of anti-rheumatic drugs due the pain in hands and neck	+
15	Assembler of the furniture/male, age 41, works 18 years, in poor physical condition	Hand/finger: Carpal tunnel syndrome Shoulder: Subacromial bursitis Lower back/hip: Piriformis syndrome	High risk work for whole body (hand, arm and back)	Subacromial bursitis	++

+ software-physician agreement on the affected body parts. Software indicates a medical condition or high risks for that condition, but a specific medical diagnosis not made by a physician.
++ software-physician agreement on the affected body parts and on the medical diagnosis.

- the OWAS method was used to evaluate the work posture while performing different tasks, and some postural angles were measured with a goniometer,
- the workers were observed and interviewed about their job, the possible injury risk factors and the symptoms that were being experienced, using the Nordic discomfort questionnaire (Kuorinka et al., 1987).

This conventional ergonomic analysis by an ergonomist took 3–4 h to complete for each worker.

Each worker was then allowed to use the SONEX program and within 10 min each worker had completed this and the program had identified the possible WRMSDs and as provided information on general risk factors (occupational and non occupational) that can contribute to the development of a WRMSD. The results that are presented for workers 1–4 in Table 6 show that the results from the SONEX system for the discomfort and ergonomic risk factors modules correctly identify the nature of the WRMSD and in addition they identify the ergonomic risk factors relevant to this injury.

To further test the system, an additional 11 workers from a wide variety of workplaces were selected for study. A gain, the researchers were blind to the injuries that each of these workers had suffered. Each worker was allowed to interact with the SONEX system and the results for the discomfort and ergonomic risk factors modules are also shown in Table 6. It is clear from this table that there is a high level of agreement between the results from the software and the injuries experienced by the workers. Moreover, the software provided a more extensive indication of injuries and also of the associated ergonomic risk factors, and in the reports generated by the software guidance is given on how to reduce or eliminate injury risks and improve the ergonomic design of the workplace.

5. Discussion and conclusions

The history of the development of a number of ergonomic expert systems has been summarized. Given the rich history in the development of these expert systems some 20 years ago and the relatively good agreement between the outputs of these systems and the judgments of human experts it is puzzling that virtually none of these systems is in commercial use today, even in limited use. In part this may be because many of the systems developed in the 1980s were programmed in languages for now defunct computers (see Table 3). In part it may be because many of the systems were developed as experimental systems and they were never fully commercialized. Whatever the reason, there remains a pressing need to augment the skills of the ergonomist by providing them with a software system that is capable of identifying and predicting of possible WRMSDs, using the subjective symptoms of the workers and the observed ergonomic shortcomings present in their workplace.

This paper has outlined the development of an ergonomic expert system (SONEX) that has been designed to be implemented for widespread everyday use buy ergonomists, other experts, and even end-users themselves. Testing of SONEX capabilities has been undertaken for several different types of jobs to identify ergonomic shortcomings that contribute to the development of the WRMSDs, as well as its ability to predict the appearance of a musculoskeletal disorder that might develop as a consequence of the observed shortcomings. In each instance the job was first analyzed with standard ergonomic methods to determine all present problems. Then the same job was analyzed using the SONEX software. The results obtained by using the SONEX software have shown its ability to predict, with high accuracy, the WRMSDs associated with different jobs, as well as the correct diagnosis of some of the WRMSDs, on the basis of symptoms which employees feel and describe. The software has also identified the ergonomic shortcomings in the work. The software also can compare subjective symptoms with ergonomic shortcomings present in the workplace. This means that SONEX can be used as a diagnostic tool for the ergonomic analysis of the work place, and that the software can be offered to different users as a tool that will enable early detection and prevention of a number of different WRMSDs.

Finally, unlike previous ergonomic expert systems that have been developed either to run on specific computers, or specific operating systems, or written in specific programming languages as standalone applications that are difficult to modify, the SONEX system has been designed with an architecture that is completely expandable and editable, and that is amenable to deployment as a web-based application.

The results of the evaluation testing show that SONEX can correctly diagnose possible WRMSDs in different work places and also identify ergonomic deficiencies present in the workplace. This means that SONEX can be used as both a diagnostic tool and an advisory tool for ergonomic analysis of the workplace.

References

Asfour, S.S., Genaidy, A.M., 1987. A knowledge-based system for assessment of human physiological abilities in manual lifting tasks. Comput. Indust. Eng. 13 (1-4), 319–322.

Azadeh, A., Fam, I.M., Khoshnoud, M., Nikafrouz, M., 2008. Design and implementation of a fuzzy expert system for performance assessment of an integrated health, safety, environment (HSE) and ergonomics system: the case of a gas refinery. Inf. Sci. 178, 4280–4300.

Boose, J.H., 1986. In: Salvendy, G. (Ed.), Expertise Transfer for Expert System Design. Advances in Human Factors/ergonomics. Elsevier Science Publishers B.V., North-Holland, Amsterdam.

Brennan, L., Farrell, L., McGlennon, D., 1990. ERGOSPEC: a prototype expert system for workstation design. In: Karwoski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 117–127. Chap. 9.

Case, K.J., Porter, M., Bonney, M., 1990. SAMMIE: a man and workplace modeling system. In: Karwoski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 31–56. Chap. 3.

Chen, J., Schlegel, R., Peacock, J., 1991. A computer-assisted system for physical ergonomic analysis. Comput. Ind. Eng. 20 (2), 261–269.

Cumulative trauma disorders in the workplace, bibliography, 1995. NIOSH Comments from the NIOSH on the Occupational Safety and Health Administration Proposed Rule on Ergonomic Safety and Health Management, 1993. U.S. Department of Health and Human Services, Public health services, Centers for disease control and prevention, National Institute for Occupational Safety and Health, pp. 19–20.

Fortin, C., Gilbert, R., Beuter, A., Laurent, F., Schiettekatte, J., Carrier, R., DeChamplain, B., 1990. SAFEWORK: a mircocomputer-aided workstation design and analysis. New advances and future developments. In: Karwowski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 157–180. Chap. 12.

Gamberale, F., Iregren, A., Kjellberg, A., 1990. SPES: assessing the effects of work environment on man with computerized performance testing. In: Karwoski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 379–380. Chap. 27.

Genaidy, A.M., Asfour, S.S., Kabuka, M., 1987. An expert system for the design of manual materials handling tasks. In: Asfour, S.S. (Ed.), Trends in Ergonomics/Human Factors IV, pp. 559–566. North-Holland, Amsterdam.

Genaidy, A., Duggal, J., Ayoub, M., 1988. Ergonomic job design in frequent manual lifting tasks: a microcomputer-based model. Comput. Ind. Eng. 17 (4), 455–468.

Gilad, I., Karni, R., 1999. Architecture of an expert system for ergonomics analysis and design. Int. J. Ind. Ergon. 23, 205–221.

Grobelny, J., 1990. Anthropometric data for a driver's workplace design in the AutoCAD system. In: Karwowski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 80–89. Chap. 6.

Grobelny, J., Cysewski, P., Karwowski, W., Zurada, J., 1992. APOLIN: a 3-Dimensional ergonomic design and analysis system. In: Mattila, M., Karwowski, W. (Eds.), Computer Applications in Ergonomics, Occupational Safety and Health, Proc. Int. Conf. Of Computer-aided Ergonomics and Safety '92 – CAES'92, Tampere, Finland, New York, North-Holland, pp. 129–136.

Hill, S.G., Harris, R.M., 1990. OWLKNEST: a knowledge-based expert system for selecting operator workload techniques. In: Karwowski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 213–225. Chap. 15.

Järvinen, J., Karwowski, W., 1992. Applications of knowledge-based expert systems in industrial ergonomics: a review and appraisal. In: Attila, M., Karwowski, W. (Eds.), Computer Applications in Ergonomics, Occupational Safety and Health. Elsevier, North-Holland, New York, pp. 45–54.

Kabuka, M., Genaidy, A.M., Asfour, S.S., 1988. A knowledge-based system for the design of manual materials handling. App. Ergon. 19 (2), 147–155.

Karwowski, W., Ward, T.L., Palenque, L.E., Wiseman, S.E., 1986a. Building an expert system for ergonomics application: a LIFTAN experience. In: Karwowski, W. (Ed.), Trends in Ergonomics/Human Factors III, pp. 51–61. North-Holland, Amsterdam.

Karwowski, W., Mulholland, N., Palenque, L.E., Ward, T.L., Jagannathan, V., Kirchner, R.L., 1986b. LIFTAN: an experimental expert system for the analysis of manual lifting tasks. Ergonom. 29, 1213–1234.

Karwowski, W., Mital, A., Palenque, L.E., Ward, T.L., 1987. Development of a microcomputer-based expert system for the analysis of manual material handling tasks in industrial settings. Int. J. Ind. Ergon. 2 (1), 49–59.

Karwowski, W., Genaidy, A.M., Asfour, S.S. (Eds.), 1990. Computer-aided Ergonomics. A Researcher's Guide. Taylor & Francis, London.

Kern, P., Bauer, W., 1992. Expert systems in ergonomics: perspectives applications in industrial practice. In: Attila, M., Karwowski, W. (Eds.), Computer Applications

in Ergonomics, Occupational Safety and Health. Elsevier, North-Holland, New York, pp. 37–44.
Kloke, W.B., 1990. WERNER: a personal computer implementation of an extensible anthropometric workplace design tool. In: Karwoski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 57–67. Chap. 4.
Kühn, F.M., Laurig, W., 1990. Computer-aided workload analysis using MTM. In: Karwowki, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 226–242. Chap. 16.
Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K., 1987. Standardized nordic questionnaires for the analysis of musculoskeletal symptoms. App. Ergon. 18 (3), 233–237.
Laurig, W., Rombach, V., 1989. Expert systems in ergonomics: requirements and an approach. Ergonomics 32, 795–811.
Mattila, M., Karwowski, W., 1992. Computer applications in ergonomics, occupational safety and health. In: Proceedings of the International Conference of Computer-aided Ergonomics and Saftey '92 – CAES'92, Tampere, Finland, New York, North-Holland.
McCauley-Bell, P., Badiru, A., 1992. A fuzzy linguistics model for job-related injury risk assessment. Comput. Ind. Eng. 23 (1), 209–212.
Moynihan, G.P., Fonseca, D.J., Merritt, T.W., Ray, P.S., 1995. An object-oriented system for ergonomic risk assessment. Expert Syst. 12 (2), 149–156.
McDaniel, J.W., 1990. Models for ergonomic analysis and design: COMBIMAN and CREW CHIEF. In: Karwoski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 138–156. Chap. 11.
NIOSH, 1997. Musculoskeletal disorders and workplace factors. In: A Critical Review of Epidemiologic Evidence for Work-related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back. NIOSH. Publication no. 97–141.
NIOSH, 2007. Ergonomic Guidelines for Manual Material Handling. NIOSH. Publication no. 007–131.
Nunes, I.L., 2009. FAST ERGO-X – a tool for ergonomic auditing and work-related muscuoskeletal disorders prevention. Work 34 (2), 133–148.
Ramcharan, D.J., Martin-Vega, L.A., 1990. Easy task Analysis: a prototype expert system for computerized work measurement. In: Karwoski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 243–257. Chap. 17.
Rombach, V., Laurig, W., 1990. Easy ERGON-EXPERT: a modular knowledge-based approach to reduce health and safety hazards in manual materials handling tasks. In: Karwowski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 279–298. Chap. 21.
Russell, A.J., 1990. INTUIT: intelligent user interface design tool. In: Karwoski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 451–465. Chap. 31.
Rurkhamet, B., Nanthavanu, S., 2004. Analytic and rule-based decision support tool for VDT workstation adjustment and computer accessories arrangement. J. Hum. Ergol. 33, 1–17.
Stanton, N., Hedge, A., Brookhuis, K., Salas, E., Hendrick, H., 2004. Handbook of Human Factors and Ergonomics Methods. CRC Press, Boca Raton, FL.
Väyrynen, S., Ojanen, K., Pyykkönen, M., Peuraniemi, A., Suurnakki, T., Kemppainen, M., 1990. OWASCA: computer-aided visualizing and training software for work posture analysis. In: Karwowski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 261–272. Chap. 19.
Westerink, J., Tragter, H., Van Der Star, A., Rookmaaker, D.P., 1990. TADAPS: a three-dimensional CAD man model. In: Karwowski, W., Genaidy, A.M., Asfour, S.S. (Eds.), Computer-aided Ergonomics: a Researcher's Guide. Taylor & Francis, London, pp. 90–103. Chap. 7.