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COMPUTERIZED ESTIMATION OF COMPATIBILITY OF STRESSORS AT WORK AND WORKER'S HEALTH CHARACTERISTICS

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A system of computerized estimation of compatibility of stressors at work and worker's health characteristics is presented. Each characteristic is defined and scored on a specific scale. Incompatible workplace characteristics as related to worker's characteristics are singled out and offered to the user for an ergonomic solution. Work on the system started in 1987. This paper deals with the system's further development, which involves a larger number of topics, changes of the algorithm and presentation of an applicative case. Comparison of the system's results with those of medical experts shows that the use of the system tends to improve the thoroughness and consistency of incompatibility evaluations and consequently to make working ability assessment more objective.

Key terms:
computerized expert system, work-related stressors, working ability evaluations

The expert system for computerized estimation of compatibility (CEC) seeks to establish and identify interactions between stressors at work and the capacities of worker's particular organic subsystems. It is designed as computer support for estimation of working ability.

The system's theoretical concept was first described in the Archives of Industrial Hygiene and Toxicology - Arhiv za higijenu rada i toksikologiju (1). It was based on the scoring of worker's and workplace characteristics, reliability factors and levels of assessment as well as on an algorithm searching for compatibility between the workplace characteristics and those of the worker.

Subsequent development of the expert system went in the direction of adding characteristics of other organic subsystems to those of the cardiovascular sub-

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system (2-6). At the same time it was recognized that different incompatibilities were not equally important for working ability and should therefore be weighted. In 1993 the system was tested in practice for the first time (7).

In this article we present the current state of the expert system for the estimation of working ability. First, we describe its structure. Next, we give an example of evaluation of the system's results for a selected worker and his workplace and of comparison between the system's suggestions and the assessment made by the disability assessment panel. At the end, we discuss the results.

STRUCTURE OF THE CEC EXPERT SYSTEM

The system consists of three sets of data: worker's health characteristics, workplace characteristics and incompatibility rules that relate the first two sets.

Worker's health characteristics serve to describe his capacities. They are grouped into categories with respect to different organic subsystems, e.g. those of the cardiovascular subsystem, respiratory subsystem, auditory subsystem, etc. Presently, there are 102 health characteristics organized into 11 subsystems. They are scored on a 2-6-point scale, starting with 1.

Workplace characteristics are based on analysis known as assessed workplace analysis (8, 9). There are 377 basic workplace characteristics in the expert system. They are scored on a 2-6-point scale, starting with 0.

Incompatibility rules form the fundamental part of the system by relating the worker's characteristics to those of the workplace. Their principal task is to identify incompatibilities between the scores obtained for the two sets of characteristics. Basically, they contain the essential knowledge that enables the system to make complex decisions. The rules were provided by pertinent medical experts.

Let us illustrate the above by means of examples. A worker's health characteristic from the auditory subsystem has the code no. 2005 and is termed "audiogram in relation to hearing". It can be scored on a scale from 1 to 3. The descriptions of all the scores for this characteristic are presented in Table 1. A medical expert will examine the patient in order to determine the proper score. A workplace characteristic is "noise at the workplace". It can be scored on a scale from 0 to 5. The descriptions of all the scores are shown in Table 2. In workplace analysis an expert will score this specific characteristic at a particular workplace.

Table 1 *An example of scoring a worker's characteristic from the auditory subsystem*

2005 Audiogram in relation to hearing	
Score	Description
1	normal audiogram
2	moderate hearing damages
3	essential hearing damages

Table 2 *An example of scoring a workplace characteristic*

153 Noise	
Score	Description
0	silent
1	moderately noisy (1/3<t<2/3)
2	moderately noisy (t>2/3) or very noisy (t<1/3)
3	very noisy (1/3<t<2/3) or extremely noisy (t<1/3)
4	very noisy (t>2/3) or extremely noisy (1/3<t<2/3)
5	extremely noisy (t>2/3) or exceptionally noisy (t<1/3)

Worker's health characteristics are combined with those of the workplace in incompatibility rules. For each pair of worker's and workplace characteristics there is a rule that says which scores are mutually incompatible. For the example above, the rule that relates "noise" to "audiogram in relation to hearing" is shown in Table 3. In the table every "X" denotes one incompatible pair of scores. For example, X in column 3 and row 4 indicates that a worker with a severe hearing damage (score 3) is not able to work at a very noisy (t>2/3) or extremely noisy (1/3<t<2/3) workplace (score 4).

Table 3 *An example of an incompatibility rule. Incompatible pairs of scores are labelled x*

153 Noise	2005 Audiogram in relation to hearing		
Score	1	2	3
0	.	.	.
1	.	.	.
2	.	.	.
3	.	.	.
4	.	.	x
5	.	.	x

The incompatibility rules in the form of a table are segmented according to the field of worker's characteristics. The rules for each field were provided by pertinent medical experts.

The basic algorithm that determines the worker's ability for a specific job gives a simple yes/no answer to the compatibility question. Besides, it provides also a list of incompatibilities. It is reasonable to expect that not all incompatibilities are of equal importance for the final decision. Therefore, a weight (a measure of importance) is assigned to each incompatibility. From a worker's point of view it is desirable to compute the sum of all weights that include a specific worker's characteristic. The sum is called "joint weight" for the worker's characteristic and can be used to identify major and minor causes of incompatibility. The sum of joint weights which belong to a common organic subsystem divided by the number of joint weights i.e. the number of incompatible characteristics belonging to the same organic subsystem makes the average weight of all incompatibilities due

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to this subsystem. The global incompatibility weight can be computed as the sum of all weights and gives an estimate of the biological potential (working ability) of a certain person or even of a certain population.

EVALUATION

In this section we present the interaction between the capacities of a selected worker (let us label him Wx) and the stressors of his job ("welder of exacting casts"). Besides, we compare the results of our expert system with the assessment of the disability panel.

Let us first observe how the data about the worker and his job were collected. The worker's capacities were assessed on the basis of the evaluation made by an occupational health specialist. The same data were used by the disability assessment panel. The worker's job was analysed by the method of assessed workplace analysis (9). Both assessments were made at the same level of knowledge (1) and were then accepted by the programme as comparable.

The crucial step in the system is to identify incompatibilities. Here, the characteristics of the worker and the workplace are matched. First, the computer singles out the assessed characteristics of the worker and the assessed characteristics of the workplace. Some of the assessed characteristics of worker Wx are shown in Table 4, and some of the assessed characteristics of the job "welder of exacting casts" are shown in Table 5.

Table 4 *Some of the assessed characteristics for worker Wx*

Code	Description of the characteristics	Score	Possible score
0502	Sex	2	1–2
0503	Age	2	1–3
0401	History – cardiovascular subsystem	4	1–4
0402	Clinical status – cardiovascular subsystem	3	1–4
0403	Blood pressure	3	1–6
0404	ECG	1	1–4
0405	Maximal aerobic capacity	3	1–5
0701	History – respiratory subsystem	1	1–4
0702	Dyspnoea	2	1–5
0705	Clinical course – respiratory subsystem	4	1–5
0706	Status – respiratory subsystem	2	1–4
0707	Spirometry	2	1–4
2001	Oriented history – auditory subsystem	1	1–4
2004	Audiogram in relation to the noise exposure	3	1–4
2005	Audiogram in relation to hearing (verbal communication)	3	1–3
2006	Audiogram in relation to space perception	3	1–3

Table 5 *Some of the assessed characteristics of the job "welder of exacting casts"*

Code	Description of the characteristics	Score	Possible scores
153	Noise	4	0–6
157	Hot climate in closed area	2	0–6
162	Sensitizing substances	1	0–2
170	Bad odour	3	0–6
172	Personal protective means	1	0–6
180	Overtime work	1	0–6
202	Interpersonal conflicts	3	0–6
261	Need for sound localisation	3	0–6
267	Need for equilibrium	2	0–6
280	Need for relative judgement	1	0–2
304	Time pressure	3	0–6
327	Energy output	1	0–4
348	Health risks at transport of material objects	4	0–6
502	Application of force at isometric muscle load	2	0–6

Next, the computer singles out the worker's characteristics that are incompatible with the workplace and those of the workplace that are incompatible with the worker's characteristics. Table 6 shows the characteristics of worker Wx that are not compatible with the job "welder of exacting casts". Likewise, Table 7 shows the workplace characteristics that are incompatible with the health characteristics of the worker Wx. Incompatible job characteristics direct ergonomic measures.

Table 6 *Characteristics of worker Wx incompatible with the job "welder of exacting casts".*

Code	Score	Description of a characteristic	Description of incompatibility
0401	4	History – cardiovascular subsystem	Symptoms essentially influence working ability
0702	2	Dyspnoea	Able to keep pace with a healthy person on the flat surface, but not uphill
0705	4	Clinical course – respiratory subsystem	The disease is unalterable, changes are not expected
0707	2	Spirometry	Low level of ventilatory insufficiency
2004	3	Audiogram in relation to noise exposure	Essential hearing damages
2005	3	Audiogram in relation to hearing	Essential hearing damages
2006	3	Audiogram in relation to space perception	Severe hearing damages

At the end, computer selects joint incompatibilities of the worker's and job characteristics and the weights of those incompatibilities. Joint incompatibilities of the characteristics of worker Wx and his job of "welder of exacting casts" and the weights for incompatibilities are presented in Table 8. In column 1 (Code),

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Table 7 *Characteristics of the job "welder of exacting casts" incompatible with those of worker Wx*

Code	Score	Description of a characteristic	Description of incompatibility
153	K4	Noise	Environment very noisy (t>2/3) or extremely noisy (1/3<t<2/3)
157	K2	Hot climate in closed area	Small deviation from neutral (1/3t<2/3) or considerable deviation from neutral (t<1/3)
162	A1	Sensitizing substances	Yes
170	K3	Bad odour	Strong, absorbs on the cloth
172	T1	Personal protective devices	Less than 1/10 of the working hours
180	K1	Overtime work	1-2 hours
202	K3	Interpersonal conflicts	Slight but almost continuous, or moderate but frequent, or big but rare
261	V3	Need for sound localisation	Moderate
267	V3	Need for equilibrium	Moderate
280	A1	Need for relative judgement	Yes
304	I3	Time pressure	Moderate
327	K1	Energy output	Moderate uptake
348	I4	Health risks at transport of material objects	High
502	S2	Application of force at isometric muscle load of upper arms and shoulder girdle (320, 337)	With lower frequency/duration at low to moderate intensity

there is a code for each incompatible worker's characteristic (for details see Table 6). Column 2 stands for the number of incompatibilities. In column 3 (Joint weight), there is a sum of all weights that include a specific worker's characteristic. Codes for workplace characteristics incompatible with a specific worker's characteristic and the weights for each incompatibility are given in column 4.

The highest joint weight belongs to the characteristic 0401 "medical history - cardiovascular subsystem" (2.60). The second highest weight of incompatibility belongs to the characteristic 0705 "clinical course - respiratory subsystem" (2.29). The next three characteristics, ranked according to the joint incompatibility weight, address the affected audiogram. The last two weights, which are the lowest, refer again to the respiratory subsystem; they are 0702 "dyspnoea", and 0707 "spirometry".

The highest average weight of incompatibility belongs to the "cardiovascular subsystem" (2.60/1=2.60). The next average weight belongs to the "auditory subsystem" (1.33+2.17+2.00)/3=1.83) and the lowest weight to the "respiratory subsystem" (0.82+2.29+0.50)/3=1.20).

According to the assessment of the disability panel, the worker was assigned the third disablement category, which usually involves adjustment to a more suitable workplace. The panel's report indicates that their decision was based on the diagnosis of arterial hypertension.

Table 8 *Joint incompatibilities of the characteristics of worker Wx and the job "welder of exacting casts"*

Code of worker's characteristic	Number of incompatibilities	Joint weight	Code of incompatible job characteristic and weight (in parentheses)					
0401	6	2.60	157 (0.42)	180 (0.42)	202 (0.42)	304 (0.42)	327 (0.50)	502 (0.42)
0702	2	0.82	172 (0.37)	327 (0.45)				
0705	5	2.29	157 (0.37)	162 (0.70)	170 (0.40)	172 (0.37)	327 (0.45)	
0707	1	0.50	327 (0.50)					
2004	2	1.33	153 (0.58)	280 (0.75)				
2005	2	2.17	153 (1.00)	280 (1.17)				
2006	4	2.00	153 (0.50)	261 (0.50)	267 (0.50)	348 (0.50)		

The panel obviously underestimated the damage of the inner ear, which indicates not only a noise-induced hearing loss, but also impaired ability for communication and equilibrium. Besides, the panel underestimated also the impairment of the respiratory subsystem. The consequences of disregarding both the damage of the inner ear and the impairment of the respiratory subsystem might show out more dramatically in the search for a more suitable workplace. It can be observed that, compared to the judgement of the panel, the evaluation of the working ability for the selected worker by our expert system was more complex and appropriate.

CONCLUDING REMARKS

Comparison of the results obtained with the help of the CEC expert system and the conclusions reached by the disability assessment panel shows that the system tends to improve the completeness of incompatibility evaluation. Namely, it examines all available worker's health characteristics not stopping only at those that seem to be the most important. Such judgement is often influenced by non-medical causes or based on the knowledge of the workplace. In this way, the system gives a more complete insight into the compatibility problem. The results of the system can, hence, serve as an influential decision-aid to the panel.

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If the disability assessment panel decides to use the results of the CEC system as a decision-aid, the objectivity of the working ability evaluations will increase. It can be noticed that the system's results reveal problems that would otherwise stay hidden. So, they stimulate a discussion that typically results in a better and more elaborate solution.

In conclusion, the computerized expert system, which provides a support for human experts, will add a new quality to the estimation of working ability. When fully built, the system will have primarily practical applicability. It will improve the estimation of the working ability which will be reflected not only in better quality of specialist work, but also in more economical spending of funds. Furthermore, it will stimulate relevant analyses of the worker and his workplace, and direct ergonomic measures in enterprises.

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Sažetak

PROCJENA SUKLADNOSTI OPTEREĆENJA PRI RADU I SPOSOBNOSTI RADNIKA S POMOĆU RAČUNALNOG SUSTAVA

Visokostručni računalni sustav za procjenu sukladnosti opterećenja pri radu i sposobnosti radnika traži i otkriva međudjelovanja između sposobnosti pojedinih organskih podsustava radnika i zahtjeva radnog mjesta. Građen je na znanju koje su s pomoću literature i rada u praksi stekli autori sustava u suradnji s 22 specijalista pojedinih medicinskih struka. Temeljne podatke sustava čine značajke radnika i značajke pojedinog radnog mjesta. Svaka je značajka označena kodom i ocijenjena stupnjem i faktorom pouzdanosti. Računalnim algoritmom procjenjuje se sukladnost određenog stupnja zahtjeva radnog mjesta s određenim stupnjem zdravstvene sposobnosti radnika. Nepodudarne značajke usmjeravaju liječnika-specijalista medicine rada na traženje ergonomskih rješenja. Ovaj sustav počeo se razvijati 1987. godine. Nastavak rada na sustavu sastoji se u dopunjavanju novim podsustavima, promjeni algoritma te u praktičnom isprobavanju sustava. Budući da su nepodudarnosti različite, razvijen je sustav ponderiranja pojedinačne osobne značajke s nepodudarnim značajkama radnog mjesta. Prosječni ponder odnosi se na organski podsustav a opći ponder služi za ocjenu radne sposobnosti pojedinca ili određene skupine pučanstva. Rezultati uspoređivanja ocjene radne sposobnosti na temelju ovog računalnog sustava s ocjenom radne sposobnosti medicinskih stručnjaka upućuju na to da je računalna ocjena savršenija i dosljednija te zbog toga i objektivnija. Visokostručni računalni sustav zamišljen je kao računalni program koji će pomoći pri utvrđivanju radne (ne)sposobnosti, no konačna odluka ostaje liječniku stručnjaku.

Ključne riječi:
ocjena radne sposobnosti, opterećenja pri radu, visokostručni računalni sustav

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