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Sleep Expert—an intelligent medical decision support system for sleep disorders

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Abstract. A new type of associative knowledge-based decision support system (Sleep Expert) for the diagnosis and classification of sleep disorders is described. Sleep Expert is based on the International Classification of Sleep Disorders (1990). The programming system used was KnowledgePro (Windows), a high-level language that integrates object-oriented programming, hypertext and expert system technologies. Sleep Expert is an interactive program composed of 288 separate integrated submodules and 264 text files. The program includes eight reasoning questions about symptoms setting the limits for the diagnosis subset. The user obtains a list of possible diagnoses on the screen where he/she can examine their criteria. The program has been written in such a form that the user can freely associate and can move forwards and backwards. Detailed information is included in hypertext.

Keywords: Artificial intelligence; Medical decision-making; Sleep; Classification.

1. Introduction

Sleep disorders medicine has been developed from neuroscience into a clinical field that contains its own specialized clinical symptoms, findings, signs and diagnostic techniques. Despite the fact that electroencephalography forms the basis for the determination of sleep states, neurological practice has been slow to adopt an interest in this rapidly developing subspecialty [1].

Sleep disorders are a problematic clinical area, because they have been treated jointly by experts of different domains. It is difficult for one person to master various domains. The numerous alternative diagnoses are also difficult to keep in mind simultaneously. Therefore it was decided to develop a program to aid in diagnosing sleep disorders.

Many decision support systems or knowledge-based systems have been developed in medicine. Some of the most recent ones are DIABETEX, a decision support system for therapy of type I diabetic patients [2]; DIABLOG, a dialogue computer program for the education of diabetic patients with insulin therapy [3]; NEOANEMIA, an expert system able to recognize disorders causing anemia [4]; and THYROID system for thyroid disorders [5, 6].

An early example system is INTERNIST for internal medicine [7, 8] which later evolved into a new system called QMR, Quick Medical Reference. QMR is able to identify nearly 600 diseases by means of 4200 different symptoms and findings. The program gives the user a list of possible diagnoses and their probabilities [9]. Each diagnosis is a frame in the program. The frames are based on expert knowledge.

A set-covering diagnostic expert system, an implementation of the set-covering model for diagnosing psychiatric disorders, has been developed. In the program 350

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symptoms and signs have been described and distributed among 151 disorders. The Diagnostic and Statistical Manual of Mental disorders (DSM-III-R) of the American Psychiatric Association has been followed in the knowledge base [10].

When decision support systems are being developed, the knowledge base used by the program must be based on current medical knowledge. The knowledge can be obtained and also applied in several ways. One way is to base the expert system on an international classification.

Using this method a decision support system Epilepsy Expert has been previously developed at the University of Tampere. It is based on the ILAE Classification of Epilepsies and Epileptic Syndromes [11]. Experimentation of this program in clinical practice has shown clear improvement in diagnostics.

2. Nature of medical knowledge

In practice the physician uses several knowledge sources in medical decision-making. Every physician has background information of the illnesses/diagnoses and their treatment, i.e. explicit knowledge. The physicians also have recollections of earlier patient cases, i.e. implicit knowledge. In addition to this background information they have the anamnesis and status of the patient, and also information of the possible laboratory and other tests.

To compare the diagnoses and diagnostic criteria between different physicians, hospitals and countries is often difficult. In many countries different diagnostic criteria or classifications are used for diagnostic decision-making. Therefore international classifications and criteria have been created by experts from different countries to make classifications and criteria similar in all countries.

Several international classifications exist for neurologists. For example, the ILAE Classification of Epilepsies and Epileptic Syndromes (1989) [11], the Classification of Sleep Disorders (1990) [12], classification and diagnostic criteria for headache disorders, cranial neuralgias and facial pain (1988) [13] and also a classification of muscular disorders [14].

Even the international classifications differ in principle. For example, in ILAE Classification of Epilepsies and Epileptic Syndromes (1989) several diagnoses are shown in text form, i.e. findings and symptoms connected with the diagnosis and the development of epilepsy in question [11]. This classification does not include lists of diagnostic criteria for different diagnoses, but the user must be familiar with epilepsy in order to be able to apply classification knowledge in clinical practice.

In the Classification of Sleep Disorders (1990), however, all diagnoses have been similarly presented. They are described in the common text part: synonyms and key words; essential features; associated features, course, predisposing factors, prevalence, age of onset, sex ratio, familial pattern, pathology, complications, polysomnographic features, other laboratory test features, differential diagnosis. In addition the diagnostic criteria are described. Minimal criteria, severity criteria and duration criteria are described separately [12].

The classification of sleep disorders is divided into four main groups: (1) dyssomnias, (2) parasomnias, (3) medical/psychiatric sleep disorders, (4) proposed sleep disorders. These are further divided into subgroups [12].

3. Main method of Sleep Expert

Before the programming of Sleep Expert was started, a functioning model for the program was developed by using the International Classification of Sleep

Disorders. The initial objective was to develop a model which could limit a continuously smaller subset from the diagnosis set by using chosen symptoms. After this the user can choose the correct diagnosis by examining the criteria of the remaining diagnoses.

All diagnoses in the classification were defined on separate cards and the symptoms connected with each diagnosis were collected together. Since there were many symptoms, and all the symptoms could not be used as keywords in the program, the symptoms of the same type were classified into one group. About 20 symptoms or symptom groups remained. The diagnoses were then connected back to the symptoms and symptom groups.

The idea of this method is to use the essential symptoms from each patient case. When some symptom, e.g. insomnia, is chosen, the diagnoses connected with excessive sleepiness are removed from the set of all diagnoses. Then a more detailed symptom, e.g. apnoea, is chosen. The program again defines the subset of diagnoses so that the subset contains only the diagnoses connected with insomnia and apnoea. At this stage < 10 diagnoses remain.

In the classification there are some symptoms typical for a certain diagnosis. As a result a separate part that enables the search of a diagnosis by using a certain symptom was added. The essential idea of the model is that, when the user chooses a certain symptom, all remaining symptoms are still possible. In other words, no symptoms have yet been removed, but the user can use all diagnoses and their diagnostic criteria connected with the chosen symptoms. The user can then choose the correct diagnosis himself from the diagnosis subset.

When constructing this model cases connected with diagnoses not included in this classification were problematic. This problem has been partly solved so that the user has the possibility to examine the classification part 'Associated with Other Medical Diseases'. Furthermore, the diagnoses were attached with comments regarding differential diagnostics.

4. Structure of the Sleep Expert system

Sleep Expert has been developed with KnowledgePro (Windows) tool [15]. Windows has the advantage that several windows may be presented simultaneously [16]. This, together with the hypertext properties of the KnowledgePro (Windows), also makes the associative linkage of different modules possible. A totally new principle for developing expert systems can thus be introduced.

The development tool, KnowledgePro (Windows), is a high-level language that integrates object-orientated programming, hypertext and expert system technologies [15]. Hypertext can also contain images, animation videodiscs and tape-recorders together with text. Hypertext is an easy way to traverse quickly a complex information network along user-defined links between any parts of the system. The use of this technique makes it possible to build complex supporting and presentation systems [17]. Sleep Expert runs in a PC/AT personal computer through Windows 3.0. The whole system includes 288 separate integrated submodules and 264 text files.

Some new common requirements have been set for the program. In the first instance the program has been written in such a form that the user freely associating can move forwards and backwards. Furthermore, the user can 'save' the desired program item (window) on the bottom of the screen (i.e. make the window smaller)

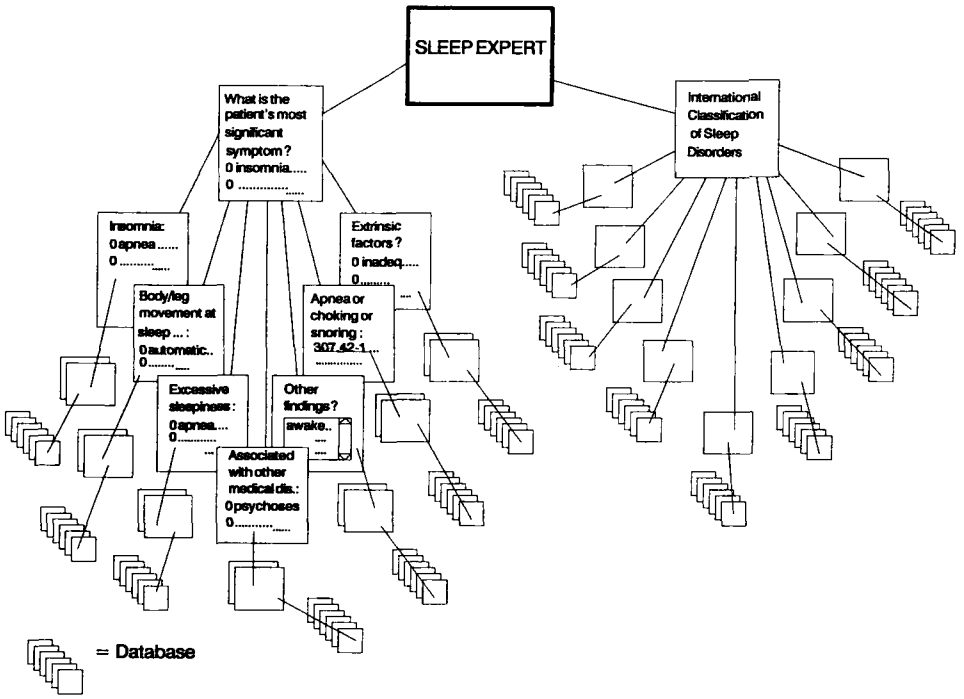

Figure 1. Structure of Sleep Expert. On the right is the summary of the Classification of Sleep Disorders, and on the left the reasoning questions and links to the database.

in order to examine it again later. In the second instance the program had to run quickly so that it could also be used at an office.

The structure of the program can be partitioned into two parts. The first part includes eight reasoning questions aimed at diminishing the diagnosis set. These questions have been programmed into separate frames so they can be opened through different routes and 'saved' on the bottom of the screen when needed. The second part includes hypertexts and their links. The user obtains additional information from hypertexts concerning separate diagnostic criteria. This part does not include reasoning.

Furthermore, an area, which includes the summary for the International Classification of Sleep Disorders, has been programmed. With this the user can come to one diagnosis or to its criteria. The windows of this part can also be 'saved' on the bottom of the screen. Figure 1 presents the structure of Sleep Expert.

All diagnoses in the classification have been programmed into three frames (minimal criteria, criteria, more information). The desired texts are read into these frames from text files.

5. User interface of Sleep Expert

Since Sleep Expert has been developed in Windows 3.0 interface several functions of this program are similar to those in Windows in general. The screen is split into separate windows, generally into two. The user can also change the size of the windows. This characteristic has been utilized in Sleep Expert so that the reasoning questions and a list of possible diagnoses are always opened on the left of the screen, and the minimal criteria of the diagnoses are opened on the right. Therefore the

user can examine different diagnoses on the left and the same list of diagnoses remains on the right. This grouping is aimed at clarifying the operation of the program.

Furthermore, from a certain diagnosis a large window can be opened in the middle of the screen. The window includes either all criteria or additional information. These windows are opened in the middle of the screen since they include a great amount of text and the texts are easier to read in a large window.

When he user starts the system the question 'What do you want to base your diagnosis on?' appears on the screen. If the user chooses the decision analysis, he is given a list of symptoms or symptom groups on the screen. He then chooses some symptoms or symptom groups and gets either a new list of symptoms or a list of possible diagnoses. This is presented on the left side of figure 1. At this stage the user can browse through several possible diagnoses and arrive at one. If the user is not sure of the diagnosis he can go backwards and choose new symptoms to find better alternatives. However, the user can 'save' the found alternatives so that in the end he can compare each alternative and choose the best one.

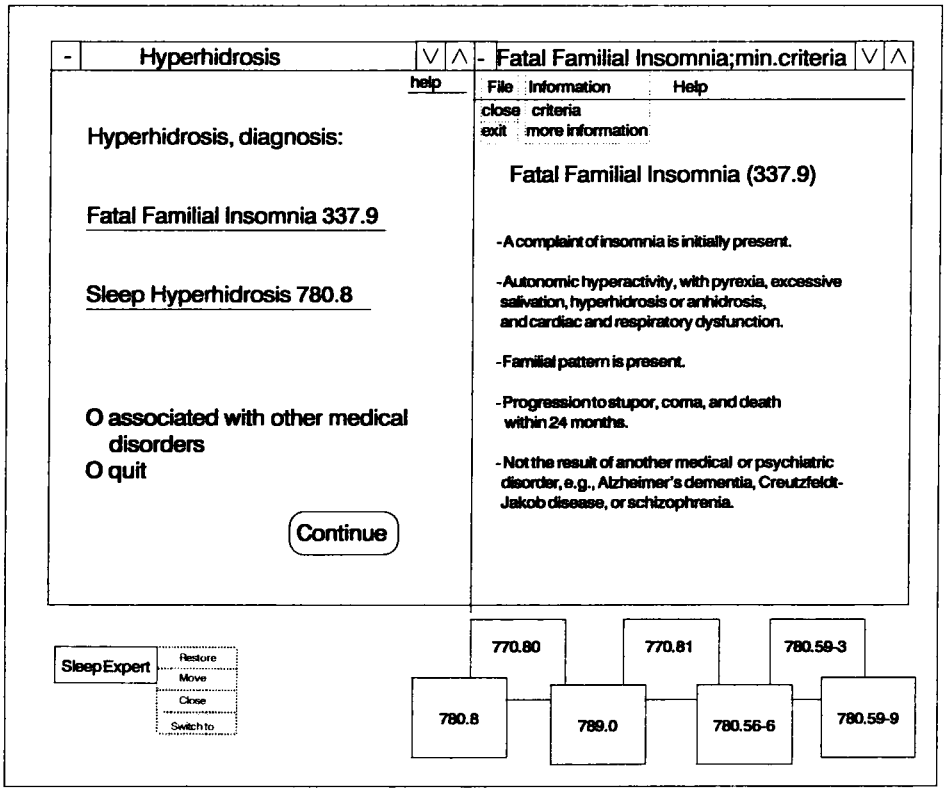

Figure 2. An example of the use of Sleep Expert. The user has chosen hyperhidrosis and has been given two alternative diagnoses. The user has opened the hypertext 'Fatal Familial Insomnia' and its minimal criteria on the right side. On the bottom of the screen there are the reduced windows, i.e. the minimal criteria for some other diagnoses. (The numbers refer to the International Classification of Sleep Disorders.) The marks on the window frames are the same as in Windows 3.0, and the contents of the menus have been written inside dash-line boxes. Underlined words are hypertexts. On the right side there is an additional question, in which the circles are choosing marks and the selection can be verified by choosing 'continue'.

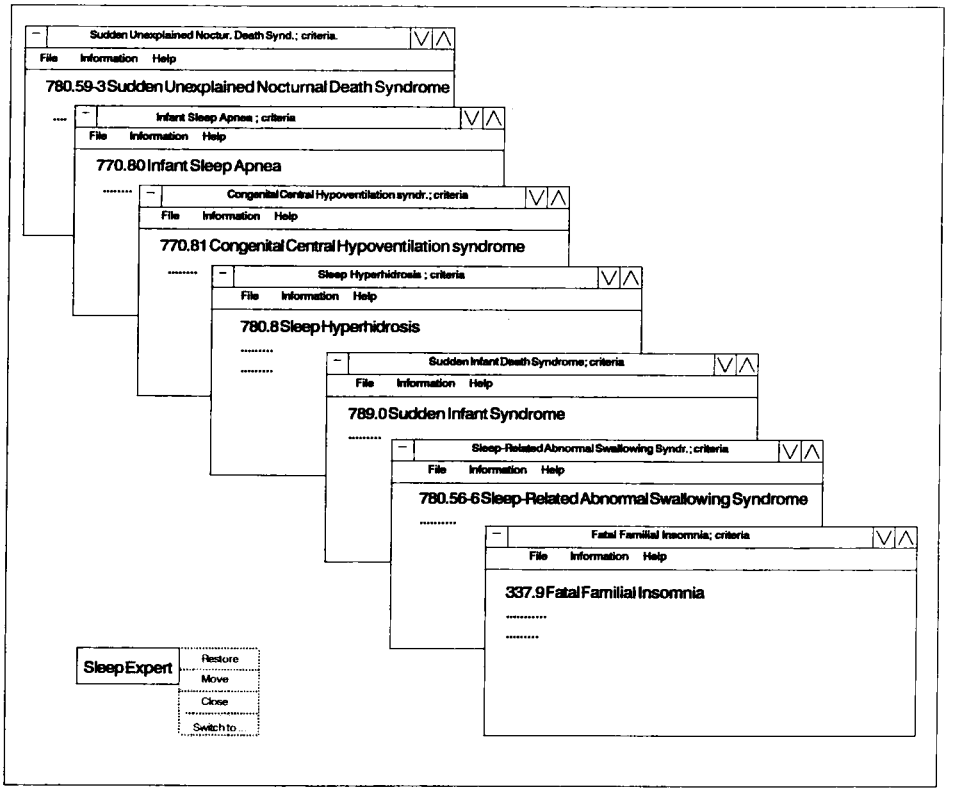

Figure 3. An example of how the user has opened minimal criteria of several diagnoses simultaneously in Windows 3.0 cascade form on the screen.

Figure 2 presents an example in which the user has been given two alternative diagnoses with symptom hyperhidrosis on the left side of the screen. (Furthermore, the user can choose another program item, 'associated with other medical disorders' or 'quit'.) The user has chosen the hypertext (underlining means hypertext) Fatal Familial Insomnia, and then the minimal criteria for this diagnosis have unfolded on the right side of the screen. On the bottom of the screen there are seven squares, which represent those diagnoses that the user has earlier 'saved'.

If the user has examined all possible diagnoses he can open all 'saved' windows again one by one or all together, i.e. in Windows 3.0 cascade form [16]. Thus the user can study them at the same time (figure 3). The user has opened minimal criteria of several diagnoses on the screen simultaneously.

6. Discussion

International classifications offer new possibilities to develop expert systems or decision support systems. They are generally recognized sets of criteria and thus the expert systems based on them can be used in a wider area than the expert systems based on criteria used in only one area.

When Sleep Expert was developed the possibility of changes in international classifications was taken into consideration. All diagnostic criteria and information are read from separate text files, so the files can be modified freely, e.g. with a wordprocessing program. The user can accomplish this by himself. In the same

way, when the user desires, he can include his own comments, e.g. local methods of treatment, in these text files. The program is built of small modules and it is therefore easy to add new modules or modify the old ones.

Sleep Expert is only one example of how international classifications can be utilized when developing medical decision support systems. The same method can be used later when developing other medical decision support systems, e.g. for headache disorders.

The use of the criteria of a certain hospital or country is often problematic. It will be difficult to transfer the developed system to other hospitals or countries because the same criteria are not necessarily in use there. The same problem might occur if only one expert is used, since some other expert might disagree. Using the epidemiological knowledge of a certain population will create problems, because another population does not have the same epidemiological frequency.

For example, the above-mentioned THYROID system for thyroid disorders has been in continuous experimental clinical use since 1987. However, due to the different diagnostic strategies, attempts to transfer it to other hospitals have so far failed. The role of the decision support system must be considered in its clinical context. The system should fulfil a real need while supporting the clinician in a way that fits into the clinical scenario [18].

One of the advantages of Sleep Expert is its user-friendly and flexible interface. The associative properties of Sleep Expert make it a tool to aid medical decision-making also in practice. The user can 'save' the desired program item (window) on the bottom of the screen in order to examine it again later. On the other hand, the user can, freely associating, go forwards and backwards in the program. Two additional advantages are that all diagnoses in the classification have been taken into the program and that the user can modify the text files, such as 'more information' files, by himself.

Patients with borderline diagnoses can prove problematic for Sleep Expert, since the differential diagnosis of a program depends on how the classification takes the differential diagnosis into consideration. At this stage the evaluation of the program is unfinished.

Sleep Expert will be developed so that it will include more knowledge concerning all diagnoses. At present the program contains the criteria of all diagnoses, but more information will be added later. In the future Sleep Expert will be evaluated and, when needed, it will be further developed.

7. Conclusion

Sleep Expert, a decision support system, is based on the International Classification of Sleep Disorders. The system used was KnowledgePro (Windows). Sleep Expert is an example of how international classifications can be utilized when developing medical decision support systems. Other decision support systems can be developed later with the same method. In the future similar programs dealing with other diagnostic problems will also be developed for clinical practice.

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