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Knowledge Encapsulation and the Intermediate Effect

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The present study explored the role of so-called encapsulated knowledge in diagnosing clinical cases outside the expert physicians' domain of expertise. Neurologists and 2nd-year and 6th-year medical students were required to diagnose, recall, and explain the signs and symptoms of two cardiological and two pulmonological clinical case descriptions. Our experiment showed that neurologists diagnosed these clinical cases faster and more accurately than 2nd-year and 6th-year medical students. An inverted U-shaped relationship with levels of expertise was found in recall and pathophysiological protocols: 6th-year medical students remembered more information from the cases and produced more elaborated explanations for the described signs and symptoms than both other groups. The proportion of encapsulating concepts in recall and pathophysiological explanations, on the other hand, increased with levels of expertise. This pattern is similar to that found in previous studies on clinical case representations using only cases within the expert physicians' domain of expertise. Therefore, these results suggest that expert physicians process clinical case descriptions both within and outside their domain of expertise in essentially the same way. © 2000 Academic Press

INTRODUCTION

Chess Masters can recall almost perfectly a chess position that they have seen for just a few seconds (Chase & Simon, 1973; De Groot, 1965; Gobet & Simon, 1996a, 1996b, 1996c). Waiters and waitresses show a superior memory performance for drink and dinner orders (Bennett, 1983; Ericsson & Polson, 1988a, 1988b). Mental calculators can rapidly multiply large numbers in their head and also have exceptional memory for digits (Ericsson, 1985; Jensen, 1990). But also research in other domains such as bridge (Charness, 1979), go (Reitman, 1976), and computer programming (McKeithen, Reitman, Rueter, & Hirtle, 1981) generally demonstrate a superior performance of domain experts. According to Vincente and Wang (1998) there are at least 51 studies in at least 19 different domains dem-

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onstrating the superior memory performance of experts on meaningful stimuli.

However, in the domain of medicine findings have been reported that seem to imply that the relationship between expertise level and recall is not as straightforward as in the aforementioned domains. A consistent finding in clinical case representation studies is the so-called *intermediate effect* (e.g., Boshuizen, 1989; Claessen & Boshuizen, 1985; Patel & Groen, 1986; Patel & Medley-Mark, 1986; Schmidt & Boshuizen, 1993; Schmidt, Boshuizen, & Hobus, 1988). In these studies, participants of different levels of medical expertise were instructed to read a text describing a patient's history, complaint(s), and some additional findings such as physical examination and laboratory data (see Appendix A). After the text was removed, each subject was asked to provide a diagnosis and to write down as much of the text as they could remember. Finally, the subjects were asked to explain in writing the signs and symptoms displayed in the clinical case (the so-called pathophysiological explanation). The outcome typically was that medical students of an *intermediate level* of expertise (i.e., advanced students) remembered more and explained the signs and symptoms of a clinical case in a more elaborated fashion than either expert physicians or novices. So, rather than a monotonically increasing function with increasing levels of expertise, an inverted U-shaped relation was found. This counterintuitive phenomenon of the recall and pathophysiological data is difficult to explain in the light of the aforementioned domains, but also with contemporary theories of text processing. These theories generally assume that prior knowledge facilitates the process of encoding and retrieval of textual information (e.g., Ericsson & Kintsch, 1995; Graesser & Clark, 1985; Kintsch, 1988; Voss & Bisanz, 1985).

Schmidt and Boshuizen (1993) have demonstrated that the occurrence of an intermediate effect is dependent on the amount of time available for processing a clinical case description. In one of their studies, participants of different levels of expertise were subdivided into three groups who studied a clinical case description under different time constraints (3.30 min, 1.15 min, or 30 s). The results showed an increase in diagnostic accuracy with levels of expertise for all study times, but this relationship was not found for the recall data. At the longest and the medium study times, recall data showed a clear intermediate effect (i.e., advanced medical students remembered more of the description than novices and expert physicians). The shortest study time, on the other hand, displayed a clear expert superiority effect in the recall.

Schmidt and Boshuizen (1992, 1993) have provided a possible explanation for the intermediate effect. They suggest that novices, intermediates, and expert physicians apply qualitatively different forms of medical knowledge to deal with their task. According to Schmidt and Boshuizen the novices' medical knowledge is best characterized by little knowledge of biomedicine and even less about the manifestations of a disease in a patient. Intermediates, however, have acquired extensive biomedical knowledge from textbooks and lectures, but, as the novices, they do not have extensive clinical knowledge.[1] Therefore, if advanced students have to diagnose a clinical case, they will employ large amounts of biomedical knowledge to account for the described signs and symptoms. They will consciously relate the signs and symptoms they encounter to concepts in their pathophysiological knowledge base to reason through the case, activating whatever knowledge is available. The expert physicians' knowledge base, however, is different from that of novices and intermediates in that biomedical knowledge only plays a minor and implicit role in normal diagnostic reasoning (Boshuizen & Schmidt, 1992; Gilhooly, 1996; Gilhooly & Simpson, 1992; Simpson & Gilhooly, 1997). As a result of extensive practice and the confrontation with actual patients, the physicians' biomedical knowledge has become linked with, or *encapsulated* under, a limited number of clinically relevant concepts that have the same explanatory power as the elaborate biomedical structure. This restructuring, which takes place in the course of the development from novice to expert physician, leads eventually to abbreviations in lines of reasoning (cf. Koedinger & Anderson, 1990; Elio & Scharf, 1990). It is important to note, that the activation or retrieval of encapsulating concepts is a dynamic process, taking place while the clinical case information is processed. In other words, information about signs and symptoms in a case, point toward, and therefore activate, specific ''prestored'' encapsulating concepts.

For instance, suppose that one would require a cardiologist and an advanced student to study a clinical case description that contains, among other things, the following information: *A 43-year old man with a rapid and weak apex beat; pulse is irregular and weak; tenderness over precordium, percussion is negative, auscultation reveals first sound of heart resembling second heart sound, being high pitched and wanting in muscular quality* (Thomas, 1989). A cardiologist will tend to recall this information as ''Myocarditis'' or ''Inflammation of the myocardium.'' This is an (high-level) inference from the text that summarizes or encapsulates the provided information. An advanced student, on the other hand, will likely reproduce the information as it is written, without high-level inferences as made by a cardiologist.

[1] Clinical knowledge concerns the ways in which a disease can manifest itself in patients. Biomedical knowledge, or basic science knowledge, pertains to the (pathological) processes underlying the manifestations of disease. It incorporates knowledge about domains such as biochemistry, microbiology, and physiology (Patel, Evans, & Groen, 1989; Patel & Kaufman, 1995).

Therefore, the recall performance of advanced students is not really better than that of an expert physician, unless we want to equate more with better (Patel & Groen, 1991b).

Note that knowledge encapsulation explains the above-mentioned disappearance of the intermediate effect if processing time of a clinical case is severely reduced. Under this condition advanced students fail to construct an adequate clinical case representation because their elaborate approach takes considerably more time than the physician's approach of constructing a representation through the application of a small number of encapsulating concepts. Students do not have sufficient time to engage in deeper pathophysiological reasoning and so lost their advantage in terms of text recall (for a more detailed discussion, see Boshuizen & Schmidt, 1992; Gilhooly, 1996; Patel & Groen, 1991b; Schmidt & Boshuizen, 1993; Schmidt, Boshuizen, & Norman, 1992).

Evidence for knowledge encapsulation is not only found in recall data, but also in post hoc pathophysiological explanations (Boshuizen & Schmidt, 1992; Schmidt & Boshuizen, 1992, 1993). Expert physicians who were asked to explain the signs and symptoms in a clinical case description referred primarily to clinically relevant concepts. Advanced students, on the other hand, used primarily biomedical concepts to account for the signs and symptoms. Interestingly, Patel, Arocha, and Groen (1986, 1990) found that subexperts (i.e., expert physicians diagnosing clinical cases outside their specialty) also applied more biomedical concepts as compared to experts diagnosing problems within their domain of expertise. Schmidt and Boshuizen assume that biomedical knowledge, although not used by experts in routine cases, remains easily accessible when the need arises. They have postulated that the different knowledge structures acquired in the course of the development toward expertise are stored into long-term memory and are still accessible when more recently acquired, encapsulated structures fail to produce an adequate representation of a clinical problem (Boshuizen & Schmidt, 1992; Schmidt & Boshuizen, 1993; Schmidt, Boshuizen, & Norman, 1992).

In the present study, neurologists (subexperts in this study) and 2nd-year and 6th-year medical students were required to diagnose, recall, and explain the signs and symptoms of four clinical cases. Two clinical cases were within the domain of pulmonology, the other two were cardiological cases. Based on the assumptions that the development of expertise in a domain is characterized by encapsulation of biomedical knowledge into clinically relevant concepts and that the application of these concepts is confined to the domain of expertise, it is predicted that expert physicians' performance will be comparable to, and not significantly different from, that of students of an intermediate level of expertise. In other words, it is assumed that if expert physicians are confronted with cases outside their domain of expertise they will relapse into the deep or elaborate biomedical processing approach, which is typical for advanced medical students.

METHOD

Participants

The participants were 16 medical students (8 2nd-year and 8 6th-year) of Maastricht University and 8 physicians from three hospitals in the southeastern part of The Netherlands. The 2nd-year medical students (the novice group) had no, or very little, experience in hospitals and their knowledge of disease was therefore principally from textbooks and lectures. The 6th-year medical students (the intermediate group) had completed an in-hospital training under supervision of senior residents and physicians. They had almost completed all of the requirements for obtaining their medical degrees as physicians. The neurologists (the subexpert group) were practitioners with at least an M.D. degree and Board Certification in their specialty and with at least 4 years of experience ($M = 16$). All participants received a financial compensation for their participation.

Material

The materials consisted of four clinical case descriptions presented on a computer screen and two blank response sheets after each case. The clinical cases consisted of two cardiological and two pulmonary cases and were constructed by two domain experts. The cases were based on actual patients treated at the Maastricht University Hospital. Each clinical case description reported some contextual information, the complaint(s), findings from history taking and physical examination, relevant laboratory data, and some additional findings (e.g., X-rays and ECGs). All cases (Aortic Valve Insufficiency, Congestive Heart Failure, Small Cell Lung Cancer, and Legionnaires' Disease) were outside the domain of expertise of the neurologists. The four case descriptions were about one page in length and consisted of 94, 80, 104, and 105 propositions respectively. The translated text of the case of congestive heart failure is provided in Appendix A.

Procedure

The participants were successively presented four written descriptions of clinical cases. They were instructed to read each case description carefully and to provide a diagnosis (students and physicians alike are familiar with written cases because they are often used in medical training and practice). Subsequently, they had to write down everything they could remember about a clinical case description. Finally, they had to explain the described signs and symptoms: the so-called pathophysiological explanation. The participants knew beforehand that a recall task and a pathophysiological explanation would follow each case. All participants were tested individually.

The cases were divided into a number of segments of related information (cf. Joseph & Patel, 1990; Lemieux & Bordage, 1992). The segments were presented successively on a portable Macintosh computer (Powerbook 180). New segments appeared on the screen when the mouse button was pressed. It was impossible to look again at a previous segment. Each participant had to evaluate all cases. Carry-over effects were controlled by randomizing the presentation order of the cases. The participants were free to spend as much time as they needed to complete the different assignments. The time spent reading a case was registered by the computer. To enable the participants to get used to their tasks, the experimental cases were preceded by one sample case.

Analysis

The accuracy and completeness of the provided diagnosis for each case was scored by two expert physicians on a scale ranging from 0 (completely incorrect diagnosis) to 6 (completely correct diagnosis). For example, the complete and accurate diagnosis of one of the pulmonary cases was: Small cell lung cancer with metastases in the mediastinal lymph nodes. If a participant produced a diagnosis containing the term ‘‘Lung cancer’’ (or an equivalent) 3 points were given because it is the most essential part of the correct diagnosis. One point was given for each of the terms ‘‘Small Cell’’ and ‘‘Metastases.’’ Finally, a point could be earned by providing the correct location of the metastases. If the correct diagnosis was part of a differential diagnosis, it was considered correct.

The protocol analysis of recall and pathophysiological data consisted of segmenting the protocols into propositions based on the work of Kintsch (1974, 1978). The essential element in propositional analysis is the segmentation of a clinical case into individual propositions corresponding to discrete idea units in the text (see for a more detailed discussion of propositional analysis, Patel & Groen, 1986). For each proposition in the free recall, it was decided whether it matched any proposition in the text. The identified propositions were divided into three types: literal, paraphrased, and inferred propositions, which have been transformed in some way. Evidence for encapsulation of signs and symptoms was explored by counting the number of high-level inferences in the recall protocols. High-level inferences were included in the analysis to the extent that they could be matched to a combination of propositions in the original text (Coughlin & Patel, 1986). Inferences referring to only one proposition in the text were not considered as encapsulations. To distinguish high-level inferences from inferences based on only one proposition, they will be further referred to as *summaries.* The total recall score was based on the number of literal matching propositions, paraphrased propositions, inferred propositions, and summaries.

From each of the pathophysiological explanations a conceptual network was constructed that formalized the semantic relations underlying the disease. Four measures were used to score the pathophysiological protocols. First, the number of different concepts used in the participants’ explanations was counted. Second, the number of relations or links between these concepts were counted. The two other pathophysiological measures were based on the overlap with a so-called canonical explanation of the signs and symptoms (Patel & Groen, 1986). A canonical explanation constitutes a minimally sufficient explanation for all the signs and symptoms described in a clinical case and it is constructed with the help of domain experts. Canonical explanations are built upon high-level inferences derived from the signs and symptoms in the text (see Appendix B). The number of matching concepts (termed *model concepts*) and links (termed *model links*) are therefore considered to be important indicators for the application of encapsulated knowledge in the pathophysiological explanations.

Interrater agreement for each of these procedures was higher than 95%. The data were analyzed using one-way analysis of variance (significance level was set al .05). In addition, the Student–Newman–Keuls test was used to make pairwise comparisons between the different levels of expertise (significance level was set at .05).

RESULTS

Case Reading Times

Table 1 shows the mean reading times in seconds for the different levels of expertise. Analysis of variance indicated that the time each participant

TABLE 1
Mean Reading Times in Seconds as a Function of Level of Expertise

Levels of expertise	Mean	*SD*
2nd-year students	295.82	91.80
6th-year students	322.38	61.79
Neurologists	211.21	67.88

TABLE 2
Mean Accuracy of Diagnoses as a Function of Levels of Expertise

Levels of expertise	Mean	*SD*
2nd-year students	0.78	0.37
6th-year students	2.34	1.01
Neurologists	3.28	0.47

TABLE 3
Mean Number of Propositions Recalled as a Function of Levels of Expertise

Levels of expertise	Mean	*SD*
2nd-year students	23.38	7.66
6th-year students	36.84	7.34
Neurologists	25.31	14.34

spent reading a case was associated with levels of expertise [$F(2, 21) = 4.80$, $p < .05$]. Newman–Keuls tests indicated that neurologists were faster than both 2nd- and 6th-year medical students. There were no significant differences between 2nd- and 6th-year students.

Diagnostic Accuracy

The accuracy of the provided diagnoses is associated with levels of expertise [$F(2, 21) = 28.28$, $p < .0001$]. The mean accuracy increased with expertise level (see Table 2). Newman–Keuls tests revealed that neurologists provided more accurate diagnoses than 2nd-year students and 6th-year students. Pairwise comparisons between neurologists and 2nd-year and 6th-year medical students indicated a positive linear relationship with levels of expertise. It is important to note that none of the participants provided a completely accurate diagnosis. These results suggest, therefore, that none of the participants perceived the cases as routine problems.

Free Recall

The results for the mean number of correctly recalled propositions are presented in Table 3. Analysis of variance showed that the number of propo-

TABLE 4
Mean Proportion of Summaries as a Function of Levels of Expertise

Levels of expertise	Mean	*SD*
2nd-year students	2.15	1.99
6th-year students	3.66	1.62
Neurologists	7.53	2.02

sitions recalled, as a function of levels of expertise, was significant [$F(2, 21) = 3.99$, $p < .05$]. Newman–Keuls tests showed no significant difference between 2nd-year students and neurologists, but the differences between these groups and 6th-year students were significant. The inverted U-shaped curve, indicating an intermediate effects, seems to provide the best fit for these data.

Further, the presence of summaries in the recall protocols was looked at because they are considered as important indicators of whether encapsulated knowledge had been applied. Table 4 shows the proportion of summaries within the participants' recall protocols. Overall differences between levels of expertise were significant [$F(2, 21) = 17.30$, $p < .001$]. Newman–Keuls tests showed a significant difference between the neurologists and both student groups. So, although their total number of propositions recalled is less than 6th-year students, neurologists introduced more encapsulating concepts in their recall than both 2nd- and 6th-year students.

Pathophysiological Explanations

In order to analyze the pathophysiological explanations four measures were used. First, we looked at the total number of concepts used to explain the signs and symptoms. The mean number of concepts used to explain the signs and symptoms are displayed in Table 5. The analysis of variance showed a significant difference between levels of expertise [$F(2, 21) = 6.44$, $p < .01$].

Second, the number of relations or links between those concepts was analyzed. The mean number of links between the concepts is displayed in Table

TABLE 5
Mean Number of Concepts as a Function of Levels of Expertise

Levels of expertise	Mean	*SD*
2nd-year students	7.19	3.80
6th-year students	14.50	6.02
Neurologists	7.34	3.80

TABLE 6
Mean Number of Links as a Function of Levels of Expertise

Levels of expertise	Mean	*SD*
2nd-year students	5.81	3.43
6th-year students	12.63	5.91
Neurologists	6.19	4.05

TABLE 7
Mean Proportion of Model Concepts as a Function of Levels of Expertise

Levels of expertise	Mean	*SD*
2nd-year students	32.66	10.41
6th-year students	41.53	6.20
Neurologists	56.49	14.36

TABLE 8
Mean Proportion of Model Links as a Function of Levels of Expertise

Levels of expertise	Mean	*SD*
2nd-year students	4.26	6.91
6th-year students	7.09	3.89
Neurologists	20.40	9.94

6. Again, a significant difference with levels of expertise was found [$F(2, 21) = 5.58$, $p < .05$].

Newman–Keuls tests for the total number of concepts and links showed that 6th-year students produced more elaborate (more links and concepts) protocols than neurologists and 2nd-year students.

The last two measures were based on the match of the explanations with the so-called canonical models. Table 7 shows the proportion of concepts used that were identical or equivalent to those in the canonical explanation. The analysis of variance indicated a significant difference between levels of expertise [$F(2, 21) = 9.87$, $p < .001$].

Finally, the proportion of links that were identical with the canonical model was computed. The results for the proportion of identical links are presented in Table 8. There was a significant difference between levels of expertise [$F(2, 21) = 11.02$, $p < .001$].

Newman–Keuls tests for the proportion of model concepts and model links showed that neurologists produced more overlap with the canonical explanations than 2nd- and 6th-year students.

DISCUSSION

The present study investigated the role of encapsulated knowledge in the process of diagnosing clinical cases outside the expert physician's domain of expertise. Previous studies (using cases within the expert physicians' domain of expertise) have shown that although physicians performed better than students on the measure of diagnostic accuracy, the total number of propositions recalled and the elaborateness of the pathophysiological explanations showed a nonlinear relationship with levels of expertise (e.g., Boshuizen, 1989; Boshuizen & Schmidt, 1992; Schmidt & Boshuizen, 1993). Based on the theory of knowledge encapsulation a number of predications were made with regard to the performance of expert physicians and medical students. It was predicted that expert physicians cannot solve a problem outside their specialty in an encapsulated mode, and therefore they would perform at an intermediate level of expertise. This relapse of expert physicians should be expressed in a performance, on all measures, that is not significantly different from that of 6th-year medical students, the intermediates in this study.

The results of the present study clearly demonstrated that expert physicians do not show a performance at an intermediate level of expertise when they are confronted with clinical cases outside their domain of expertise. First, experts were faster and more accurate in evaluating the clinical cases outside their domain of expertise than 2nd- and 6th-year medical students. Second, the recall and pathophysiological data showed intermediate effects analogical to those found in clinical case studies using only cases within the physicians' domain of expertise (e.g., Schmidt & Boshuizen, 1992, 1993).

A fairly straightforward explanation for these findings would be that experts process cases within and outside their domain of expertise in essentially the same way. Qualitative differences (i.e., differences in the number of encapsulating concepts), as found between expert physicians and intermediates solving problems within the physicians' domain of expertise, do also apply comparing these groups under more ''nonroutine conditions.'' Therefore, the presence of an intermediate effect, as it was originally found in recall and pathophysiological data, seems to be relatively insensitive to the nature of the cases used.

Evidence to support this explanation is also found in a recent study of Rikers, Schmidt, and Boshuizen (1997), who compared cardiologists and pulmonologists diagnosing each other's clinical cases. It was predicted, as in this study, that the expert physicians' recall should be more extensive outside their specialty because they cannot rely on their encapsulated knowledge. Nonetheless, their study showed no significant differences in recall data between cardiologists and pulmonologists. In addition, Patel and colleagues also found no differences in recall of relevant and irrelevant propositions between expert physicians (cardiologists) and subexperts (surgeons and psychiatrists). Again, this seems to indicate that expert physician's performance is relatively insensitive for the nature of the cases used (Patel & Groen, 1986; Patel, Groen, & Arocha, 1990). Surely the findings of the present study do not suggest that expert physicians perform outside their domain as well as inside, as is substantiated by the measure of diagnostic accuracy. The diagnostic performance of the neurologists had a mean accuracy of about 50% of the maximum score. This clearly indicates that they did not uncover all crucial components of the correct diagnoses.

It is important to note that based on our data and those of previous studies, some skepticism about the role of encapsulated knowledge as the single cause of the intermediate effect seems to be justified. If we reconsider the recall data of this study, we have to conclude that the proportion of encapsulating concepts within the recall protocols is rather low—albeit significantly different from 2nd- and 6th-year medical students. Neurologists introduced less than 8% of summaries in their recall. So, more than 90% of their recall were literal, paraphrased, and (low-level) inferred propositions. If we take these proportions into consideration, we have to conclude that the recall protocols are not ''characterized'' by encapsulating concepts (cf. Van de Wiel, Schmidt, & Boshuizen, 1998). The pathophysiological explanations, however, seem to supply more support for the pivotal role of encapsulated knowledge. Neurologists introduced in their explanations about 56% model concepts and 20% model links, which is more than either 2nd- or 6th-year medical students. On the other hand, more than 40% of the concepts and about 80% of the links in their explanations did not overlap with the canonical models. Again, but a little less than the recall data, we have to conclude that the neurologists' pathophysiological explanations are not ''dominated'' by encapsulated knowledge. Note that this pattern is similar to that found in previous clinical case studies. For example, Schmidt and Boshuizen (1993) found that expert physicians (internists) introduced about 10% high-level inferences in their recall and about 30% model concepts in their pathophysiological explanations. Therefore, the pathophysiological data, but especially the recall data, seem to indicate that an explanation of the intermediate effect solely based on knowledge encapsulation cannot be the entire story (cf. Patel & Groen, 1991b).

The question, then, is how the intermediate effect must be interpreted, if knowledge encapsulation is not the only cause. Possibly, the inverted U-shaped curve found in the recall and pathophysiological data may also reflect a difference in the way the task is perceived. That is, expert physicians are not as inclined to write down everything (especially case information that is of no significance) they remember of a clinical case description than students do. Evidence to support this hypothesis, however, is primarily anecdotal. Phrases like, ''Must I really write down *everything* I remember?'' or ''Should I explain *all* signs and symptoms?'' were sometimes stated by expert physicians but never by medical students.

Another plausible explanation is provided by Patel and her colleagues (Patel & Groen, 1991a, 1991b; Patel, Groen, & Arocha, 1990). They assume that both expert physicians and subexperts have developed some kind of generic expertise for relevant information in a clinical case. Generic expertise is concerned with the acquisition of adequate case representations and it implies the existence of some schema or macrostructure representation (Van Dijk & Kintsch, 1983). This representation is based on the physicians' experience in practical problems and guarantees the retention of crucial facts in a clinical case within or outside their domain of expertise. Therefore, subexperts are still able to separate the wheat from the chaff and only recall the essential information of a clinical case. Domain experts, on the other hand, have also acquired specific expertise that is essential to achieve a high diagnostic accuracy. They possess the necessary domain knowledge that enables them to link the nonsalient cues or loose ends to the main diagnosis (Patel & Groen, 1991a). However, advanced medical students have more difficulty distinguishing between relevant and irrelevant information than experts and subexperts do (Shanteau, 1992; Vincente & Wang, 1998). Therefore, if recall is scored in terms of relevant and irrelevant information, the intermediate peak disappears: Students process too much irrelevant information, whereas experts and subexperts do not (Patel, 1984; Patel & Groen, 1991b). This seems to indicate that the criterion for expert performance is superior diagnostic accuracy, not the reproduction of irrelevant details of a clinical case (Ericsson & Lehmann, 1996; Groen & Patel, 1988).

In sum, although this study did not support the hypothesis of encapsulation theory that subexperts relapse into an intermediate level of expertise, it did show that the intermediate effect, as it was originally found in recall and pathophysiological data, seems to be independent of the nature of the cases used (i.e., within or outside the expert physician's domain of expertise). Further research is necessary in order to unearth the contribution of encapsulated knowledge and other constituents of the intermediate effect within and outside the physician's domain of expertise.

APPENDIX A

Case of Heart Failure

A 45-year-old woman has complaints of increasing dyspnea and ankle edema for 6 weeks. The patient has always felt a fast heartbeat.

History: Epileptic from the age of 15. Family history: Negative. Social history: She owns a homeopathic shop. Intoxications: She smokes 20 cigarettes a day. Medication: Depakine 3 $\times$ 300 mg.

Physical examination. Physical examination revealed a thin, dyspnoeic woman. Her weight was 50 kg, and her length 1.70 m. Pulse rate was 100/min and regular. Blood pressure was 140/90 mmHg. Carotid artery pulses normal. Distended jugular veins. Thyroid gland was enlarged and elastic on palpation. Heart: Apical impulse was just lateral to the midclavicular line. First and second heart sounds are normal. Left and right ventricular pulsations. There was a 3/6 holosystolic murmur at the apex. Lungs: Normal breath sounds, basal rales and dullness on percussion. Abdomen: The liver was enlarged (four fingers). Extremities: Pronounced bilateral ankle edema.

Laboratory findings. ESR 6 mm/h (normal: <12 mm/h); Hb 9.1 mmol/L (normal: 7.4–9.6 mmol/L); Ht 0.42 L/L (normal: 0.36–0.46 L/L); WBC 6.8 109/L (normal: 3.4–8.9 109/L); platelet count 153 109/L (normal: 150–350 109/L); PTT 31 s (normal: 24–35 s); sodium 140 mmol/L (normal: 132–142 mmol/L); potassium 5.25 mmol/L (normal: 3.6–5.0 mmol/L); calcium 2.27 mmol/L (normal: 2.1–2.6 mmol/L); urea 4.5 mmol/L (normal: 3.0–7.0 mmol/L); creatinine 67 mmol/L (normal: 53–97 mmol/L); alkaline phosphatase 129 U/L (normal: 30–125 U/L); GGT 42 U/L (normal: <50 U/L); ASAT 27 U/L (normal: <35 U/L); ALAT 19 U/L (normal: <35 U/L); CPK 86 U/L (normal: 40–200 U/L); LDH 381 U/L (normal: 200–450 U/L); total protein 68 g/L (normal: 65–79 g/I); albumin 36 g/L (normal: 40–60 g/L); arterial blood gases: pH 7.41 (normal: 7.35–7.45); pCO_2 5.1 kPa (normal: 4.5–5.9 kPa); pO_2 10.5 kPa (normal: 8.7–13.1 kPa); O_2 saturation 94% (normal: 93–98%).

Electrocardiogram. Sinus rhythm, rate 90/min. Left atrial enlargement. Intermediate position of the electrical axis. Poor R wave progression in the left precordial leads. Abnormal ST-T segments.

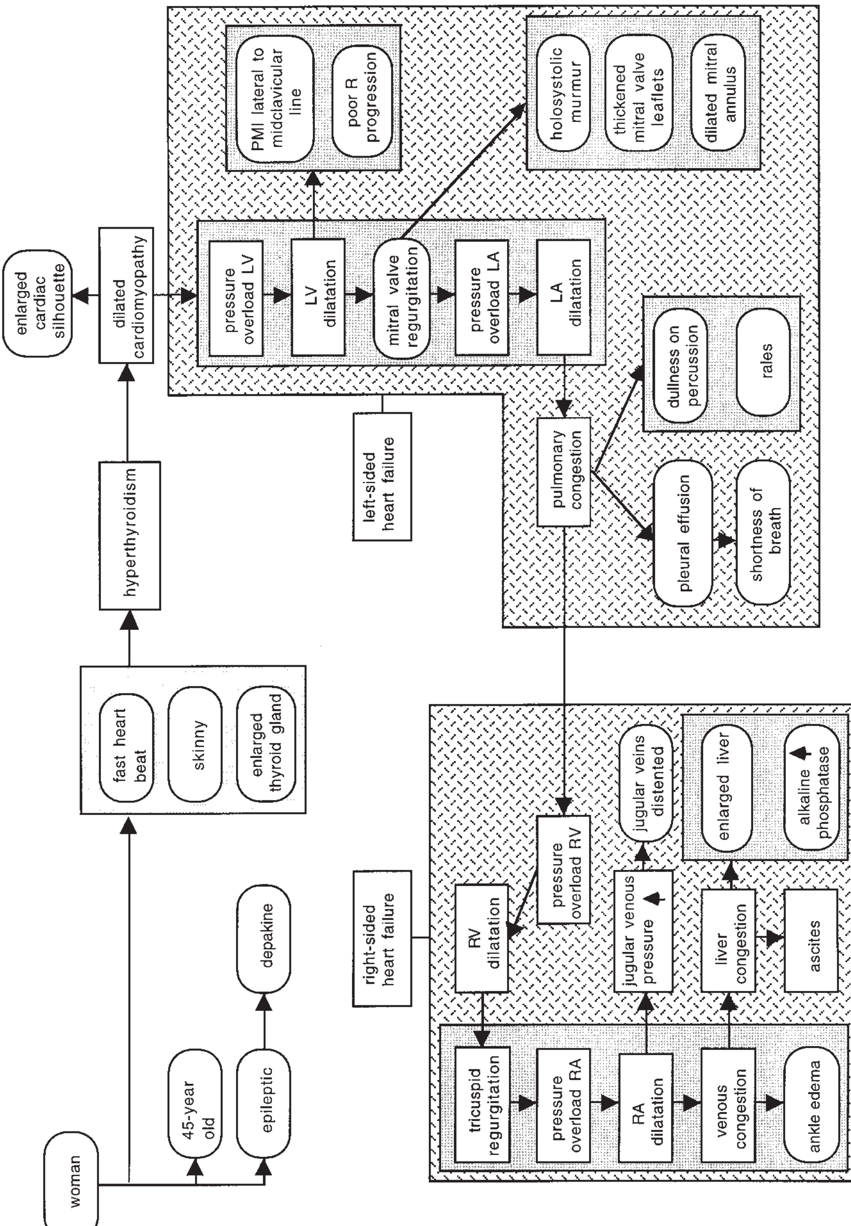
Chest X-ray. Cardiothoracic ratio >0.5. Bilateral pleural effusion (right > left).

Echocardiography/Doppler. Global hypokinesia of the dilated left ventricle and severe mitral insufficiency. Mitral valvular annulus enlarged 4 cm. The mitral valve leaflets are slightly thickened.

APPENDIX B

Canonical Explanation for the Congestive Heart Failure Case

Frames with rounded corners represent signs and symptoms present in the case, and frames with rectangular corners represent concepts that were not present. Most links between concepts in this model indicate a causal relationship (see next page).



woman
45-year old
epileptic
depakine
fast heart beat
skinny
enlarged thyroid gland
hyperthyroidism
dilated cardiomyopathy
enlarged cardiac silhouette
pressure overload LV
LV dilatation
mitral valve regurgitation
pressure overload LA
LA dilatation
PMI lateral to midclavicular line
poor R progression
holosystolic murmur
thickened mitral valve leaflets
dilated mitral annulus
left-sided heart failure
pulmonary congestion
dullness on percussion
rales
pleural effusion
shortness of breath
right-sided heart failure
pressure overload RV
RV dilatation
tricuspid regurgitation
pressure overload RA
RA dilatation
venous congestion
ankle edema
jugular venous pressure
jugular veins distented
liver congestion
ascites
enlarged liver
alkaline phosphatase

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