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COMPLEX DECISION MAKING IN INTENSIVE CARE: THE ROLE OF MEDICAL EXPERTISE

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ABSTRACT

The study of expertise has led to insight into the nature of expert performance in a variety of problem solving domains. In medicine, considerable study has focused on diagnostic reasoning, however the role of expertise in coping with decision complexity has remained to be more fully explored. In this thesis three groups of subjects, consisting of medical students (novices), residents (intermediates) and intensive care experts were each presented with complex cases of intensive care problems containing varying levels of uncertain and conflicting evidence. The subjects were asked to think-aloud as they worked through the problems and provided a management and treatment plan for each case. The audiotaped protocols were coded for key process variables in decision making and problem solving.

The results indicate that the strategies used by novices, intermediates and experts for dealing with complex cases containing ambiguous information varied considerably. When faced with anomalous evidence, expert physicians were found to disregard the anomalous evidence and focus on the patient's overall clinical condition. In contrast, non-experts used the anomalous evidence to evaluate diagnostic hypotheses and drive the decision making process. Expert physicians were also found to focus on situational aspects of the patient's condition to a greater extent than non-experts, occasionally employing recognitional strategies. Strategies for processing anomalous evidence were shown to relate to level of confidence in decision making.

The research has a number of important theoretical implications for the study of decision making and expertise in general and medical decision making in particular. A theoretical account of the role of expertise in complex decision making is provided which emphasizes the interaction between situation assessment and evaluative reasoning processes in the decision making of experts. In addition, the thesis provides empirical support for aspects of several emerging naturalistic models of decision making, and extends them to include greater consideration of processes involved in evaluation of evidence. Implications for education and design of decision support are discussed.

RESUME

Les études d'expertise ont amélioré la compréhension de la nature de la performance des experts dans la résolution de problèmes dans plusieurs domaines. En médecine, plusieurs études se sont concentrées sur le raisonnement menant à un diagnostique médical, mais il reste à explorer davantage le rôle de l'expertise à faire face à la complexité des décisions. Dans cette thèse, trois groupes de sujets, soit des étudiants en médecine (débutants), des résidents (intermédiaires) et des experts en soins intensifs, se sont fait présenter des cas complexes de problèmes de soins intensifs contenant des niveaux variés d'information incertaine et conflictuelle. On demandait aux sujets de penser à voix haute en travaillant sur les problèmes et de formuler un plan de soins et de traitement pour chaque cas. Les enregistrements audio des protocoles ont été codés pour les variables clés dans le processus de prise de décision et de résolution de problèmes.

Les résultats indiquent que les stratégies utilisées par les débutants, les intermédiaires et les experts, pour travailler sur les cas complexes contenant de l'information ambiguë, variaient considérablement. Lorsque confrontés à des irrégularités dans les informations fournies, on a constaté que les médecins experts mettaient de côté les irrégularités pour se concentrer sur la condition clinique générale du patient. Par contre, les non-experts utilisaient les irrégularités dans la formulation d'hypothèses diagnostiques et le processus de prise de décision. Les médecins experts se concentraient aussi davantage sur les aspects situationnels de la condition du patient que ne le faisaient les non-experts et employaient occasionnellement des stratégies de reconnaissance. On a démontré que les stratégies employées pour traiter les irrégularités dans les informations fournies dépendaient de la confiance des sujets envers leurs décisions.

La recherche comporte plusieurs implications théoriques importantes pour l'étude de la prise de décision et l'expertise en général et pour la prise de décision médicale en particulier. On fournit une explication théorique du rôle de l'expertise dans la prise de décision complexe, qui souligne l'interaction entre l'évaluation de la situation et les processus de raisonnement évaluatifs dans la prise de décision des experts. De plus, la thèse fournit un support empirique pour certains aspects de quelques modèles naturalistes émergeant de prise de décision, et les élargit pour inclure une plus grande considération des processus impliqués dans l'évaluation des informations fournies. On y discute aussi des implications dans le domaine de l'éducation et de la conception de supports décisionnels.

PUBLICATIONS AND PRESENTATIONS

Parts of the work presented in this thesis have been reported in the following:

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CHAPTER I

INTRODUCTION

Decision making in complex domains can be considered to be a function of features of the decision task and the expertise that the decision maker brings to bear on the decision. In general, under conditions of high task complexity, heuristic strategies are likely to be applied by decision makers to simplify the decision problem (Tversky & Kahneman, 1974; Payne, Bettman & Johnson, 1993). As decisions become more complex and the available information leads to potentially ambiguous and contradictory interpretations, simplifying strategies may be required in order to allow the decision maker to act with confidence. For example, high performance decision making in situations such as fire fighting and telephone triage has been found to be closely related to strategies used for interpreting the state of the emergency (Zsambok & Klein, 1997; Leprohon & Patel, 1995). In situations typical of emergency and intensive care medicine, there may be a large number of possible interpretations of patient problems, coupled with a lack of clearly defined "gold standards" for choice of action (Bauman & Deber, 1989). Constraining decision problems under such circumstances may be extremely difficult and strategies selected would be expected to vary according to the expertise of the decision maker.

This thesis examines the effects of complexity of evidence on cognitive processes involved in diagnostic reasoning and therapeutic decision making. Specifically, the study investigates strategies used by subjects of varying levels of expertise in coping with potentially ambiguous medical situations. Ambiguity in medical decision making occurs when there are discrepancies in available evidence or anomalous data appear which contradict the overall patient presentation or the physician's presumed diagnostic hypothesis (Hassebrock & Prietula, 1992). This leads to possibly divergent interpretations of the patient's state. An understanding of the conditions under which different types of strategies are applied by decision makers for coping with such complexity is essential in order to characterize the role of expertise in therapeutic decision making.

1.1 Theoretical Issues

In medicine, the processing of complex data is at the heart of decision making and strategies for dealing with decision complexity have been found to distinguish experts from non-experts (Patel & Groen, 1991a). Research in the study of medical cognition, as well as in other domains, has indicated that: (a) experts have highly organized knowledge structures, (b) they do not process irrelevant information, and (c) they apply specific knowledge-based problem solving strategies in dealing with routine cases (Ericsson & Smith, 1991). Previous work in medicine has shown that the structure of the decision task, including the presence of non-critical cues, affect reasoning patterns of experts, leading for example, to shifts in directionality of reasoning (Patel, Groen, & Arocha, 1990). It has also been found that medical students of differing levels of experience apply different strategies for dealing with contradictory evidence. For example, Arocha, Patel and Patel (1993) found that second-year students ignore or reinterpret anomalous evidence, while more experienced students consider several concurrent hypotheses to account for contradictory evidence. However, the extent to which such differences apply across broad levels of expertise and the effects of anomalous evidence on medical reasoning and decision making have remained to be more fully examined.

How physicians cope with complex decision problems involving uncertain and potentially conflicting evidence is a crucial issue in medicine, since contradictory information is commonly encountered and situations characterized by no ambiguity of features may be uncommon. According to Chinn and Brewer (1993), there are seven ways in which one can respond to anomalous evidence (i.e. data that contradict one's preferred hypothesis or theory, leading to an ambiguous situation). Six of the responses involve discounting the evidence to varying degrees including ignoring the evidence, considering the evidence but rejecting it, temporarily excluding the evidence and reinterpreting it. Alternatively, anomalous evidence may lead to a change in one's theory or hypothesis. In order to integrate conflicting evidence with previous or preferred interpretations, one must decide whether the evidence is believable, whether it can be explained and if one's theories or hypotheses need to be changed in light of the evidence.

A number of factors may lead to different strategies for dealing with anomalous evidence, including the characteristics of the decision maker's prior knowledge (e.g. how entrenched prior theories or hypotheses are), as well as the decision maker's experience. This raises the question of how prior experience and expertise affect use of strategies for coping with conflicting evidence. In the study of medical diagnostic reasoning, previous work has indicated that physicians of varying levels of expertise may assess the validity of evidence quite differently. For example, in the interpretation of radiographic images, Lesgold and colleagues (Lesgold, Rubinson, Feltovich, Glaser, & Wang, 1988) found that experts tended to discount many of the features of radiographic images that residents considered to be good evidence for congestive heart failure. These differences were attributed to the expert's greater technical knowledge of artifacts that can arise as well as better feature perception by experts. In contrast, Lesgold and colleagues (1988), in considering the non-experts studied (i.e. residents) state that:

> Residents interpreted their perceptions very literally: a heart shadow of large size meant an enlarged heart. There appeared to be little decoupling between the manifestations of chest structures and the diagnosticians' internal, mental representations of the chest and its structures. This strategy should serve the diagnostician adequately when the film presents an ideal textbook case example of a disorder. However, when a more complex case arises, there is need for the representation of the patient's medical condition to be decoupled from film features. This decoupling is what enables immediate perception and the representational process to be tuned somewhat independently. (p. 329)

In a study reported by Norman, Brooks, Coblentz and Babcook (1992), novice and expert radiologists were also compared in their ability and strategies in evaluating features in radiographic films. In their study design, a set of films which were radiologically unambiguous were presented with patient histories which were consistent with them. In addition, difficult films were accompanied with normal or abnormal histories. The results indicated that both expert and non-expert subjects did not consider individual features as independent sources of information (i.e. independent of interpretations gained from reading the clinical histories). They contrast their findings to those of Lesgold and colleagues, arguing that unlike the findings from the Lesgold study, both the experts and non-experts applied higher level interpretations (which were influenced by the clinical history) in considering specific radiographic evidence (in contrast to Lesgold's study which indicated that the non-experts tended to treat individual radiographic features more literally than experts). The question therefore remains of how ambiguity of evidence is dealt with by subjects of varying levels of medical expertise and whether or not there are clear differences between physicians of varying levels of expertise in their strategies and interpretation of potentially anomalous evidence.

Similar issues are related to attempts to bring evidence to bear on decision making in clinical medicine. In recent years evidence-based medicine has emerged as a discipline with the objective of bringing "the best evidence from clinical and healthcare research to the bedside, to the surgery or clinic and to the community" (Sackett & Haynes, 1995). This movement has promoted the screening and dissemination of scientific evidence for application by physicians in clinical decision making. With the increasing use of information technology in medicine, evidence-based medicine promises to provide physicians with wide access to recommendations and guidelines for "best practice" in clinical settings. Thus the approach has important ramifications for the field of medical informatics, which endeavors to apply information technology to improve clinical reasoning, decision making and overall medical practice.

Although increased availability of scientific evidence is important in improving quality of health care, it has been argued that the mere availability of that evidence is insufficient to lead to application of the knowledge in actual practice (Allen, Arocha, & Patel, in press). There are a number of factors to be taken into account when considering application of evidence at "the bedside", i.e. use by physicians in dealing with particular patient problems. These include the extent to which specific situational factors (i.e. the patient's particular condition, age, medical history etc.) affect the appropriateness and application of external evidence derived from large-scale epidemiological studies. This includes consideration of the complexity of a patient's circumstances and the presence of uncertain and potentially ambiguous evidence from a number of sources. Thus, an understanding of the integration of "internal evidence" from assessment of a patient's situation, with "external evidence", derived from statistical and epidemiological studies, has remained a challenge (Mehta, Kushniruk, Gauthier, Richard, Deland, Veilleux, & Grant, in press).

Recently McDonald (1996) has argued that "robust scientific conclusions are too sparse to inform fully most of the choices that physicians must make about tests and treatments. Instead, ad hoc rules of thumb, or heuristics, must guide them, and many of these are problematic" (p. 56). McDonald goes on to argue that since not enough randomized trials or epidemiological studies have yet been conducted, evidence from such study cannot be expected to directly guide most medical decisions. In the context of intensive care medicine, these arguments have a number of important implications. If physicians do indeed rely on heuristics to deal with real-life decision complexity, the question arises of how these heuristics or strategies differ for physicians of different levels of expertise. Specifically, the question remains as to what extent physicians of varying levels of expertise rely on global assessments of a patient's clinical state, as opposed to recommendations based on individual test results interpreted in the context of large scale randomized trials. This thesis attempts to consider some of these issues in the context of decision making by subjects of varying levels of expertise, involving medical cases that require the integration of both qualitative and quantitative evidence, where the clinical picture may conflict (to varying extents) with the results and given probabilistic interpretations of evidence from specific test results.

1.2 Methodological Issues

Although conceptually similar, medical problem solving and decision making have traditionally been studied using different research approaches. Over the past several decades, a considerable body of research findings has accumulated in the cognitive study of medical problem solving (Patel & Groen, 1991a). Studies have indicated that physicians use a variety of strategies in dealing with uncertain and ill-structured medical problems (Elstein, Shulman, & Sprafka, 1990; Patel, Arocha, & Kaufman, 1994). For example, in solving diagnostic problems, expert physicians have been shown to be capable of focusing on small sets of related hypotheses and are able to use efficient discrimination strategies for rapidly distinguishing relevant from irrelevant information in diagnostic reasoning (Lesgold et al., 1988; Patel, Evans, & Kaufman, 1989; Kushniruk, Patel, & Marley, 1998). In the study of medical decision making, greater focus has typically been placed on the analysis of decision outcomes, using application of theoretical perspectives which have emerged from decision theory (Elstein, 1988).

The extent to which theoretical frameworks emerging from the study of medical problem solving and reasoning, can be extended to therapeutic decision making remains to be clarified and provides motivation for the present work. Explicating the relation between cognitive processes which have traditionally been considered reasoning and decision processes has remained a challenge. However, a number of researchers have begun to explore the relation between the two areas (Johnson-Laird & Shafir, 1993).

Along these lines, it has been argued that methods applied in the study of medical reasoning can be usefully applied to the study of therapeutic decision making, thereby extending traditional analyses focusing on decision outcomes to include greater consideration of cognitive processes underlying choice (Cooper & Fox, 1997). In the study reported in this thesis, both processes considered to be within the realm of diagnostic reasoning and therapeutic decision making are considered. It is hoped that this approach may lead to a better understanding of how diagnostic reasoning processes relate to treatment and management decisions.

Research has also been conducted in the naturalistic study of decision making in areas ranging from fire fighting to intensive care medicine. Much of this work has employed non-obtrusive observational study (Leprohon & Patel 1995), or use of retrospective reports in the analysis of decision making during critical incidents (Klein & Calderwood, 1991). Some of the results from such studies have challenged findings and conclusions drawn from the larger body of traditional, laboratory-based research in decision making (Zsambok, 1997). For example, it has been argued that a focus of many laboratory studies of decision making on the "decision event" (i.e. a hypothesized point in time when the decision maker chooses among a set of fixed and given alternatives) is not representative of many real-life decision problems which are often ill-structured. Other researchers have recently focused on the need to examine the ecological validity of experimental tasks in studies of decision making and problem solving (Vicente & Wang, 1998). An additional motivation of the present study is to examine the extent to which research findings from controlled laboratory studies (involving in-depth study of cognitive processes of subjects as they perform complex tasks) are consistent with or differ from findings emerging from naturalistic studies, as well as with established theoretical perspectives from the study of decision making and reasoning.

1.3 Research Objectives

The specific research objectives motivating this thesis are the following:

1) To examine the effects of uncertainty and ambiguity of evidence on diagnostic reasoning and therapeutic decision making across levels of expertise

2) To explore the relationship between reasoning and decision making in a cognitively complex domain

3) To consider developmental aspects of expertise in medical decision making by characterizing decision strategies of experts, intermediates and novices

4) To determine the extent to which the results are consistent with existing theories of decision making, problem solving and expertise, including recent perspectives emerging from naturalistic study

5) To consider the implications of the research for medical education and the design of decision support systems

1.4 Thesis Organization

This thesis is organized into the following chapters. Chapter II provides a review of relevant literature in order to situate the research in the context of previous work. Chapter III describes the methodology used in the study, including a complete description of the case materials and the experimental procedure. The coding scheme used for analyzing the data is described and specific research hypotheses are presented along with their theoretical and scientific rationale. In Chapter IV the results of the study are presented, including analyses of decision making and reasoning processes. This is followed by a discussion of decision strategies employed by subjects across levels of expertise. In addition, analysis is presented of subjects' confidence in decision making as well as their representation of uncertainty. The final chapter contains a discussion of the major findings in the context of decision research and implications for the study of medical expertise.

CHAPTER II

LITERATURE REVIEW

This literature review provides an overview of research of particular relevance to this thesis. This includes discussion of recent research trends and models of decision making which focus on cognitive processes underlying reasoning and decision making. Also included is discussion of perspectives on expertise which have emerged from the judgment and decision making literature, as well as from cognitive science. In the final section, research in the study of medical cognition is reviewed in the context of the objectives of the study.

2.1. Introduction

Decision making can be construed as a problem solving process in which the solution is in the form of a decision, typically leading to an action. Consistent with this perspective, important links have been made between research in decision making and related areas of study, including problem solving and reasoning. There has been a growing awareness that decision making and reasoning are highly interrelated. According to Johnson-Laird and Shafir (1993), there are a number of reasons for considering the relation between these two areas. For many purposes it may not be productive to strictly separate the two when considering real-world problems, since in everyday situations reasoning and decision making processes are often highly interwoven (Klein, 1993). Along these lines, Cooper and Fox (1997) have recently argued that research in judgment and decision making needs to address to a great degree the role of situational factors, such as specific task features, as well as cognitive factors, including human memory limitations and specific subject strategies. It is further argued that work is needed to bring methods from areas of cognitive psychology which routinely deal with process and representation, into the mainstream study of judgment and decision making.

In a related direction, researchers have begun to examine the role of experience and expertise in problem solving and decision making in naturalistic environments (Zsambok & Klein, 1997; Patel, Kaufman, & Magder, 1996). This research has been characterized by study of complex domains such as control of nuclear power plants (Rasmussen, 1993), fire fighting (Klein & Calderwood, 1991), intensive care (Patel et al., 1996) and emergency telephone triage (Leprohon & Patel, 1995). A number of researchers have argued that in studying decision making in real-world tasks, the focus should be on decision processes embedded in the larger tasks that the decision makers are trying to accomplish. This is in contrast to a considerable body of previous work in decision making, which has focused on the "decision event", where the decision maker begins with a fixed set of given alternatives and evaluates options in terms of relatively stable and well-defined goals, purposes and values (Orasanu & Connolly, 1993).

Unlike many experimental studies, complex decision making often takes place in the context of incomplete and potentially conflicting information. Furthermore, in domains such as medicine, decision problems are often ill-structured and rarely present themselves with complete information and well-defined choices. Thus, a significant amount of work may have to be carried out by the decision maker in assessing the situation (i.e. clarifying the state of the world) and framing the decision problem. Critical processes include generating hypotheses about what is happening, generating and refining decision options, and recognizing whether a choice or decision is required for a given situation (Orasanu & Connolly, 1993).

2.2 Reasoning and Decision Making Processes

In considering complex decision making, Hammond (1993) has proposed that cognitive processes in decision making can be located along a *cognitive continuum,* which ranges between *intuition* and *analysis.* Hammond and Brehmer (1973) describe the continuum in the following way :

> The analytical end of the continuum is characterized by a form of thinking that is explicit, sequential and recoverable. That is, it consists of a series of steps that transform information according to certain rules which can be reported by the thinker. Intuitive thinking, on the other hand, is implicit, nonsequential and nonrecoverable. Usually, the thinker can report no more than the outcome of the thinking ... Most instances of thinking will have both intuitive and analytic components. (p. 340)

Tasks that require the processing of large amounts of information in a very short time period tend to induce intuitive (i.e., less analytical) processing. On the other hand, tasks that involve quantitative information, presented in a sequential fashion, may induce more analytical processing. Other factors that affect where a decision may fall on this continuum, include the effects of failure (e.g. the decision maker may tend to become more analytical when intuitive judgments fail, or become more intuitive when careful analysis fails), task complexity as well as the experience and expertise of the decision maker. For example, under conditions requiring a rapid response, an expert's decision making may fall more the side of intuition, i.e. based on experience, a decision may be made without extensive conscious deliberation. According to Hammond, it may be possible that cognitive activity in decision making may move along the continuum during complex problem solving, i.e. oscillate between intuition and analysis (e.g. Hammond, 1988; Hamm, 1988). The cognitive continuum provides a useful framework for considering a number of cognitive models (described below) ranging from those focusing on recognitional processes to models that emphasize processes involving explanation and reasoning with evidence.

2.2.1 Recognition-Based Decision Processes

In considering the role of recognition in decision making, Courey, Boulette and Smith (1989) argue that experienced decision makers often apply a strategy whereby they reduce a task to manageable aspects by converting it into a pattern-recognition problem. This cognitive strategy is viewed as being considerably different from models of decision making implied by traditional decision theory where the decision maker is seen as weighing alternatives in terms of utilities and values (Howell, 1993). A perspective on decision making based on recognitional processes is however quite consistent with work from the study of expertise in problem solving and reasoning. For example, work by Chase and Simon (1973) indicates that expert chess players are adept at quickly recognizing arrangements of chess pieces from previous games. In the area of medical diagnosis, Patel, Evans and Kaufman (1989) found that expert physicians are adept at quickly filtering out irrelevant information and focusing on relevant cues in doctor-patient interactions. Other related findings have emerged from the study of cognitive processes involved in expert diagnosis involving radiographic images, where experts were found to develop finely-tuned mental representations of patient anatomy which drive the physicians' perception and allow them to rapidly recognize important features in the images (Lesgold et al., 1988).

The Recognition-Primed Decision Making (RPD) model (Klein, 1993) is a recent cognitive model which focuses on recognitional processes in describing how critical decisions are made by experienced decision makers. The area of research from which the model was developed was the study of the decision making of highly experienced urban fireground commanders (Klein & Calderwood, 1991). In considering analysis of retrospective reports from fireground commanders, Klein and Calderwood (1991) found that experienced decision makers do not work out all possible contingencies but rather develop a workable solution to decision problems (consistent with Simon's (1986) conception of bounded rationality) :

> It was difficult to represent the phenomenological accounts of these decision processes in any meaningful way within the decision tree framework. Indeed, the fireground commanders resisted any attempt to characterize their roles in terms of "making choices", "considering alternatives", or "assessing probabilities". They instead saw themselves as acting and reacting on the basis of prior experience, planning, monitoring, and modifying plans to meet specific constraints. There was no evidence for anything approaching exhaustive option generation... There was no obvious way to apply the concept of optimal choice. Such a term was seen as potentially paralyzing action. Although the commanders could clearly recognize and admit to making mistakes, "workable", "timely", and "cost-effective" were much more meaningful criteria. (p. 1020)

As a consequence of findings from such studies, an emphasis has recently emerged on the relation between decision making processes and aspects of problem solving, in particular the role of problem representation and situation assessment in skilled performance in professional domains (Gaba & Howard, 1995). Situation assessment refers to the identification and clarification, by the decision maker, of the state of the decision problem (Endsley, 1995). This includes identification of goals, the assessment of how critical the problem is, and comparison of the current state of the world to previous experience. Research from a number of domains (Noble, 1993; Kushniruk, Patel & Fleiszer, 1995a; Leprohon & Patel, 1995) has implicated the importance of situation assessment, i.e. "sizing up" a decision problem and understanding a situation in terms of its similarity to previously encountered experiences. Situations that are highly familiar to the decision maker may lead to automatic responses. On the other hand, situations that are unfamiliar, or only moderately familiar to the decision maker, may invoke analogical reasoning, involving the mapping of the conceptual structure of one set of ideas, i.e. from the base domain, to another set of ideas, the target domain (Holyoak & Koh, 1987). Analogical reasoning plays an important role in problem solving (Holyoak, 1985) and is also beginning to be recognized as playing an important role in expert decision making (Klein, 1993). By applying analogical reasoning, the decision maker can invoke new courses of action, by adapting solution methods and other information from reference problems stored in memory as schemata, i.e. prototypical knowledge structures in memory, which are built up as a function of experience with previous situations (Brewer 1987; Hunt, 1989; Glaser, 1984; Rumelhart, 1984).

2.2.2 Explanation-Based Decision Processes

At the analytical end of the cognitive continuum are recent models of decision making emphasizing the role that explanatory processes play in reasoning and decision making (Pennington & Hastie 1993, Groen & Patel, 1988; Chi, Leeuw, Chiu, & LaVancher, 1994). From this perspective, reasoning about evidence is viewed as a central process in complex decision making. Using evidence, in conjunction with stored knowledge about similar events, the decision maker attempts to develop a coherent explanation, using schemata to guide construction of a plausible story and to fill in missing information. For example, from the study of juror decision making (Pennington & Hastie, 1993), it has been found that the juror attempts to develop a plausible argument in order to reach a conclusion regarding innocence or guilt of a defendant. As a further part of the theory, several principles are proposed for determining if a story, or explanation, will be acceptable to the decision maker, including how well the story covers the available evidence, how coherent it is, and whether or not there are alternative explanations.

According to explanation-based models, decision makers construct summary representations of evidence, which are used as a basis of making decisions. These representations are important in facilitating the active process of evidence comprehension, directing inferencing and ultimately reaching a final decision. Pennington and Hastie argue that differences in decision making by individuals of different levels of experience lie largely in the evidence evaluation stage of the decision process. These differences are reflected in the structure of the explanations that they generate. Furthermore, the structure of the causal model that is constructed to explain evidence will be specific to the decision domain. For example, according to Pennington and Hastie (1993), physicians construct an explanation of findings in terms of one or more disease categories. In related work, Patel & Groen (1991a) have found essential differences in the structure of pathophysiological explanations of clinical cases given by subjects of varying levels of medical expertise, with experts producing explanations that are more coherent and that contain less extraneous detail than explanations of non-experts.

2.3 The Role of Expertise in Decision Making and Problem Solving

The study of expertise in decision making has roots in several research traditions. This section reviews perspectives emerging from two areas which have in the past been treated somewhat separately. The first perspective emerged from the traditional judgment and decision making literature. The second perspective has grown out of research on expertise from the study of cognitive processes in problem solving and reasoning.

2.3.1 Perspectives on Expertise from the Judgment and Decision Making Literature

In considering research in expert decision making from the traditional judgment and decision making literature, a variety of limitations of expert decision makers have been reported. For example, psychometric studies of experts' judgment have shown that their judgments often lack reliability (Chan, 1982). Furthermore, in studies that have examined the amount of information that experts use in making decisions, the common finding is that experts demonstrate surprisingly low information use. This has been documented for criminal court judges (Ebbesen & Konecni, 1975), medical pathologists (Einhorn, 1974) and clinical psychologists (Goldberg, 1970). Not only do experts make use of little information, there is also evidence that their judgments can often be described by simple linear models (Dawes &

Corrigan, 1974). Thus, a number of studies from the decision making literature have indicated that expert judgments lack the complexity that might be expected from superior decision makers, and that they rely on heuristic strategies, as non-experts do.

Decision heuristics (i.e. methods or simplifying principles for deciding which among several alternatives is the most effective) represent a compromise between the need to make choice simple, and at the same time the desire to discriminate between good and bad choices (Pearl, 1984). Although application of appropriate heuristics can lead to effective choices over time (Payne, Bettman, & Johnson, 1993), use of heuristics to guide one's action does not guarantee selection of good choices. Indeed, according to Tversky & Kahneman (1974), experts are limited in the same way as non-experts, regarding their need to apply heuristic strategies for simplifying decision making. Tversky and Kahneman (1974) state that "people rely on a limited number of heuristic principles which reduce the complex tasks of assessing probabilities and predicting values to simpler judgmental operations. In general, these heuristics are quite useful, but sometimes they lead to severe and systematic errors" (p.1124). The application of heuristics can lead to a variety of errors of judgment which have been well documented, including insensitivity to prior probabiiities of outcomes, as well as insensitivity to sample size and to predictability when making probability assessments (Tversky and Kahneman, 1974). Other robust types of biases reported in the literature include a tendency for decision makers (including experts) to be overly confident in the accuracy of their judgments (Slovic, Lichtenstein and Fischoff, 1988). In considering the results of a number of studies involving expert decision makers, Kahneman (1991) concludes that, "there is much evidence that experts are not immune to the cognitive illusions that affect other people".

2.3.2 Expert Strategies in Decision Making

Despite the cognitive limitations that experts appear to have in common with non-experts, an identified characteristic of expert decision behavior is use of adaptive strategies in dealing with the complexities of real-world situations. According to Payne, Bettman and Johnson (1993), individuals may use many different strategies in decision making, with the selection of strategies being highly contingent on the demands of the task environment. For example, in choice situations involving uncertain and ambiguous information, or under conditions of time pressure, particular simplifying strategies are likely to be adopted. This selectivity is seen by Payne and colleagues as being highly adaptive and that furthermore "a particular error or bias, as indicated by a deviation between behavior and a normative model, may not really be an error from a long-run, adaptive point of view" and that "flexibility of response (adaptability) is generally viewed as a mark of intelligence" (p.5). For example, the use of noncompensatory strategies in multialternative choice (i.e. choice focusing solely on desirable attributes or solely upon undesirable attributes) may lead to the elimination of potentially good alternatives, but under conditions of high cognitive load or time stress, may be more optimal than other strategies. From this perspective, the selective use of simplifying decision strategies is seen as an adaptive response to the individual's limited capacity for information processing. Furthermore, in the area of medicine, McDonald (1996) argues that heuristics are in effect the "silent adjudicators" of clinical practice and underly decision making in most complex medical decisions, particularly when reliable evidence to guide judgment is sparse.

Review of the decision making literature for findings regarding use of adaptive strategies by expert decision makers sheds light on the understanding of what it is that distinguishes experts from non-experts. Experts have been found to be adept at learning from their mistakes and making appropriate changes in their future decision strategies (Shanteau, 1988). This is in contrast to non-expert decision makers who are more likely to rationalize or defend past decisions. As Brehmer (1980) points out, it is not experience per se that produces expertise, but rather the ability to learn from past experiences. It has also been noted in the decision making literature that although expert decision makers may make small errors, they generally avoid large mistakes. Shanteau (1988) notes that expert decision makers "seem to have discovered that for many decisions coming close is often good enough: the key is not to worry about being exactly right, but to avoid making really bad decisions. Experts often use a dual strategy of first coming up with a rough 'ball park' estimate, perhaps using a simplifying heuristic, and then conducting a more careful analysis" (p. 208).

In addition to being able to quickly extract relevant information, in the area of medicine, experts have been shown to have the ability to simplify complex decision problems (Kuipers, Moskowitz, & Kassirer, 1988). A divide-and-conquer strategy is often used by expert decision makers, where complex decision problems are broken down into smaller, more manageable decision problems (Shanteau, 1988). Confidence in decision making is a further characteristic of experienced decision makers (Shanteau and Phelps, 1977).

2.3.3 Perspectives on Expertise from Cognitive Science

Over the last several decades, a considerable body of findings have accumulated in the cognitive study of expertise (Chi, Glaser & Farr, 1988). Ericsson and Smith (1991) refer to the conceptual framework from which much of this work has grown as the *expertise approach* :

> Two features distinguish the expertise approach from other approaches: first, the insistence that it is necessary to identify or design a collection of representative tasks to capture the relevant aspects of superior performance in a domain and to elicit superior performance under laboratory conditions; second, the proposal that systematic empirical analysis of the processes leading to the superior performance will allow assessment of critical mediating mechanisms. (p. 8)

Ericsson and Smith (1991) go on to state that "one immediately realizes some potential dangers of studying aspects of "real" expert performance with tasks not normally encountered in the normal environments of the experts. If we provide an expert with unfamiliar tasks, we need to consider the possibility that the expert may resort to nonoptimal and unstable strategies" (p. 24). Thus an important aspect of the expertise approach has been the selection of tasks which can capture the essence of the superior performance of experts under laboratory conditions and allow us to assess the underlying differences in processing between experts and non-experts. Typically, these tasks are representative of real tasks in the expert's domain of expertise.

Applying the "expertise approach", studies of expertise have been conducted in a wide range of domains, including chess (deGroot, 1978; Chase & Simon, 1973; Charness, 1989), music (Sloboda, 1991), computer programming (Anderson, 1983; Jeffries, Turner, Polson & Atwood, 1981), physics (Larkin, 1981; Chi, Feltovich & Glaser, 1981) and medical diagnosis

(Patel & Groen, 1986). In their seminal work on chess expertise, Chase and Simon (1973) tested subjects of varying chess skill who were asked to reproduce positions they had viewed on a chess board. It was found that when meaningful positions were presented to subjects, master chess players were able to recall significantly more positions than less experienced players. However, chess masters were no better than novice chess players at recalling positions for chessboards with randomly placed pieces. The finding of superior expert memory for meaningful patterns has since been demonstrated in a variety of other domains, including electronic circuit diagrams (Eagan & Schwartz, 1979), computer programming (McKeithen, Reitman, Rueter & Hirtle, 1981) and the game of Go (Reitman, 1976).

Differences in the cognitive strategies used by experts and novices have also been identified in domains ranging from physics to medicine. For example, physics experts have been shown to solve problems by working forward, from the general data given in the problem to the solution (Simon & Simon, 1978). In contrast, novices were found to work backward, from the goal, for example, starting with the unknown in the problem and then attempting to find an equation to calculate it. This finding has been further elaborated by Larkin, McDermott, Simon, and Simon (1980) and has also been found to be consistent with research in other problem solving domains, including medical diagnosis, where expert problem solving in routine cases is characterized by forward reasoning from data to conclusions (Patel & Groen, 1991a). From this body of research, it is clear that experts have developed specific knowledge-based strategies for solving problems efficiently within their own domain of expertise.

2.4 The Role of Expertise in Medical Reasoning and Decision Making

In medicine, expertise can be considered to exist along a continuum, ranging from novices (i.e. medical students), to medical experts possessing highly specialized medical knowledge (Patel, Arocha, & Kaufman, 1994). Development of medical expertise appears to be marked by transitions which reflect underlying reorganizations of knowledge and increases in mastery of domain tasks (Patel & Groen, 1991b). Although the focus of much of the research on expertise has been on the "expert", with novice performance being used for comparison, a broader perspective encompasses an understanding of the progression from novice to expert. In medical cognition, an important finding relating to the acquisition of skill is that of non-monotonicity in the development of expertise. Rather than performance necessarily improving steadily with training or experience with a task, a non-monotonic learning curve is characterized by a learning curve that is shaped like a U or an inverted U (Strauss & Stavy, 1982). This is known as the intermediate effect. In medicine, this refers to the finding that intermediate level subjects may elicit considerable amounts of extraneous information from a patient and generate more diagnostic hypotheses than either novices or experts (Patel & Groen, 1991b; Schmidt, Norman & Boshuizen, 1990; Patel, Groen, & Patel, 1997). Although intermediates may have acquired an extensive body of knowledge, they may not have reorganized the knowledge in a functional manner for performing various tasks. In contrast, novices lack this extensive knowledge base, while expert knowledge appears to be finely tuned for performing tasks and efficiently filtering out irrelevant information (Patel, Evans, & Kaufman, 1989; Kushniruk, Patel & Marley, 1998). Transitions in problem solving and reasoning may involve shifts over time (when new cognitive skills are developed and tuned), at times resulting in temporary decrements in performance (Lesgold et al., 1988; Patel & Groen, 1991b).

Research in medical cognition has provided support for findings of essential differences in the reasoning strategies and knowledge organization of physicians of varying levels of expertise. For example Feltovich, Johnson, Moller, & Swanson (1984) found that expert physicians possess elaborate and highly structured knowledge bases capable of supporting efficient reasoning. In a series of studies conducted by Patel and colleagues, subjects of differing levels of expertise were presented with short descriptions of medical cases and were asked to provide explanations of the underlying pathophysiology. Applying methods of propositional analysis, Patel and Groen have characterized the reasoning processes and strategies of novices and experts (Patel & Groen, 1991a). From these studies (Patel & Groen, 1986; Patel & Groen, 1991a), it has been found that directionality of reasoning is predictive of diagnostic accuracy, with experts producing correct diagnoses using a forward reasoning strategy (i.e. from data to hypotheses). In contrast, non-experts and experts outside of their domain who produce incorrect diagnoses use predominantly backward reasoning (i.e. from hypotheses back to data).

Although a large body of results have accumulated in the study of medical cognition, the emphasis of the majority of studies has been on diagnostic reasoning (i.e. analyses of cognitive processes occurring prior to treatment choice). Research examining treatment choices and decision making regarding patient management has more typically employed approaches which have emerged from the traditional judgment and decision literature, with a focus on subjective expected utilities and decision outcomes. Cognitive studies of therapeutic decision making (Elstein, 1988) indicate that a process-centered approach to the study of decision making can also provide considerable insight into understanding physicians' decision making strategies. In one cognitive study of therapeutic decision making, Kuipers, Moskowitz and Kassirer (1988) presented three pulmonary physicians with a case description involving a patient with a pulmonary condition. Verbal protocols were collected of the physicians' responses to the cases as they provided treatment decisions. Kuipers and colleagues (1988) found that the process of physician decision making "resembled an incremental, sequential-refinement planning algorithm, where a complex decision is broken into a sequence of choices to be made with a simplified description of the alternatives". Based on protocol analysis, Kuipers and colleagues argue that medical decisions are not made after gathering all the facts, but are instead constructed (through an incremental planning process, allowing complex medical problems to be solved with limited processing resources).

In line with a trend towards studying reasoning and decision making in realistic tasks and real-world contexts (Klein, 1993), research has been conducted involving analysis of decision making by teams of physicians and nurses in critical health care settings, such as the intensive care unit (Patel et al., 1996) and the operating room (Gaba & Howard, 1995). In other naturalistic studies, decision making strategies in emergency telephone triage situations have been examined, focusing on assessing the relationship between decision making strategies and the underlying knowledge of the decision maker. For example, Leprohon and Patel (1995) found that in high urgency situations, nurses use simple rules that often lead to accurate decisions (which however often do not correspond to their retrospective explanations of their actions). In moderate to low urgency conditions, accuracy in the development of plans of action is related to the nurses' ability to assess the overall state of the emergency situation.

2.5 Issues in the Cognitive Study of Complex Medical Decision Making

A number of issues remain as challenges to research in medical decision making. In particular, work is needed in understanding the relationship between results and empirical findings from the study of medical diagnostic reasoning with those from research in therapeutic decision making. The question remains as to what extent findings from the study of medical reasoning processes apply or are different from those that relate to therapeutic decision making processes. Another area that warrants investigation is that of the relation of findings emerging from recent study of decision making in naturalistic settings, typically involving observational methods or retrospective reports (e.g. the work of Klein, 1993 and Patel, Kaufman & Magder, 1996) with results obtained from experimental laboratory-based studies. Some researchers have considered the naturalistic approach to represent a new paradigm in the study of decision making (e.g. Orasanu & Connolly, 1993, and Cannon-Bowers, Salas & Pruitt, 1996) that strongly challenges the results from more traditional psychological and cognitive studies (Klein & Calderwood, 1991). However, as indicated in this review, there may be a number of parallels and consistencies among findings from both naturalistic and experimental studies. The extent to which such parallels hold is an area that requires further study and which has considerable implications for future research directions in the study of decision making and reasoning in general.

Decision making in medicine typically requires the integration of complex evidence from a variety of sources. This evidence may be conflicting or lead to ambiguous interpretation of a patient's state. Differences in approaches to dealing with conflicting and anomalous data have been found in a number of domains, ranging from education and theory formulation in science (Chinn & Brewer, 1993; Dunbar, 1993) to medical diagnosis (Patel, Arocha, & Kaufman, 1994). Understanding how experts, as well as non-experts, deal with medical cases that contain anomalous evidence is of great importance in characterizing the role of expertise in medical decision making. For example, studies have shown that experts may switch from forward reasoning to backward reasoning strategies depending on the complexity of the decision task. It has been found that when "loose ends", i.e. anomalous data not directly related to the main diagnosis, are included in a case, the expert's pattern of forward reasoning may be disrupted (Patel, Groen, & Arocha, 1990). The nature of the decision task, including its difficulty, the extent to which the task is non-routine and the level of ambiguity of evidence, are all factors which have remained to be more fully explored when considering differences in expert and novice decision strategies. Although findings have emerged indicating essential differences in the reasoning and decision making processes of experts and non-experts, work is needed in elucidating the conditions under which such differences appear, particularly the effect of complexity of evidence on decision strategies.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Introduction: The Problem Domain

The necessity to carefully weigh and integrate qualitative and quantitative evidence from various sources is typical of decision making in a variety of health care situations. The characteristics of this type of problem, including incomplete, uncertain and potentially ambiguous information, are also typical of situations faced daily in other real-world domains ranging from economics to aerospace (Kushniruk & Patel, 1995). Decision problems in such domains can be considered to be ill-structured, since initial problem states may be unknown, definite goal states may be unclear, and necessary constraints may not be apparent at the beginning of the problem solving process (Simon, 1973). The study described in this thesis involves the analysis of decision making of physicians in dealing with complex medical problems suggestive of a condition known as pulmonary embolism (PE), which is a respiratory complication encountered in intensive care medicine. Written medical cases, (used as stimulus material) were developed to capture typical, yet complex dilemmas faced by physicians in managing and treating suspected cases of PE. This problem domain is representative of many other areas in medical decision making in that it involves integration of evidence from various sources.

Pulmonary embolism arises from blood clots, originating in the veins of the legs, and eventually leading to the obstruction of the pulmonary arteries, and potentially death (Spence, 1988). Patients who have been immobilized in hospital for lengthy periods are particularly prone to developing this condition. Both the diagnosis and treatment of this condition may be extremely complex from a cognitive point of view, making it ideal for the study of decision making and reasoning.

As described in the medical literature (Spence, 1988), the presence of a number of symptoms (e.g. breathlessness, chest pain and expectoration of blood stained sputum), in conjunction with a past medical history that predisposes a patient to PE (e.g. prolonged bed rest, recent fracture of an extremity etc.) should suggest its possibility. An initial investigative screening procedure is often performed, where the patient is given a lung scan (known as a V/Q lung scan). Weighing the results of the lung scan (which consist of qualitative assessments of the likelihood of PE, typically reported as "low", "intermediate" or "high" probability) with the strength of clinical evidence for PE (which is both qualitative and quantitative in nature), the physician must decide either to proceed with treatment for PE, consider further investigations or rule PE out.

When the clinical evidence for PE is considered to be low and the lung scan probability is also low, the condition is unlikely, and is typically ruled out. On the other hand, a high probability lung scan along with clinical symptoms highly indicative of PE, typically leads to decisions regarding treatment for PE. However, in practice, clinical cases encountered in intensive care often fall in the middle ground - e.g. a lung scan indicating uncertainty regarding the possibility of PE in conjunction with a less than clear clinical picture (Spence, 1988). How physicians of varying levels of expertise deal with such complex situations constitutes an important focus of the research described in this thesis.

3.2 Research Design

3.2.1 Subjects

The subjects consisted of twenty-four volunteers at three levels expertise. Level I consisted of eight third year medical students (novices), level II consisted of eight residents in intensive care medicine (intermediates), and level III consisted of eight intensive care specialists (experts). The subjects were all affiliated with a McGill University teaching hospital. The mean age of the students was 25, the mean age of residents was 27, and the mean age of experts was 43. The students had completed their third year of medical training. The intermediates were physicians in residency training in a surgical intensive care unit. All the experts all had board certifications in areas related to surgical intensive care and averaged 17 years of medical practice since completion of their undergraduate medical degree.

3.2.2 Materials

In developing the task materials (consisting of written medical case descriptions), preliminary examination of the information contained in medical textbooks regarding treatment of pulmonary embolism (as well as discussion with intensive care medical specialists) revealed that the clinical evidence for pulmonary embolism is weighed in conjunction with results of the lung scan (Spence, 1988).

In order to experimentally examine the decision making processes of physicians, written case descriptions were designed to systematically vary the level of evidence regarding the two key factors in diagnosis and treatment of pulmonary embolism: (1) lung scan evidence for PE (three levels corresponding to the probability that appears in actual lung scan reports: low, intermediate, and high), and (2) clinical evidence for PE (two levels: low and high). Six types of cases were developed, corresponding to the following combinations of three levels of lung scan and two levels of clinical evidence:

Case Type	Probability Lung Scan	Clinical Evidence
1	Low	Low
2	Low	High
3	Intermediate	Low
4	Intermediate	High
5	High	Low
6	High	High

Cases of types 1 and 6 represent situations where the clinical evidence is consistent with the lung scan evidence. The other remaining case types represent situations with varying degrees of conflicting lung scan and clinical evidence, leading to potentially ambiguous situations. For each of the six case types, two different cases were developed (leading to development of twelve cases in total). The construction of cases was carried out in conjunction with an expert intensive care physician having considerable expertise in the diagnosis and treatment of pulmonary embolism, and was based on information from real patient cases in intensive care.

In order to validate the cases, the twelve cases were randomly ordered and then presented to three experts in intensive care medicine to classify into the above case types (1-6). Results of this process indicated that all three experts classified the cases as they were intended (i.e. every case designed to be of a particular case type was identified as such by all three experts, who were blind to the details of the study).

As an example, one of the cases is given below (Appendix A contains all the 12 case scenarios used in the study). In this case (case type 6), the V/Q lung scan indicates a high probability of pulmonary embolism, as indicated in the last statement in the case, coupled with high clinical evidence of pulmonary embolism (indicated by evidence such as the presence of blood stained sputum and difficulty encountered breathing):

> A 72 year old lady, previously well, sustained a fractured femur when she fell off a kitchen stool. She was maintained in Buck's traction for six days at which time she underwent a femoral rodding. In the recovery room, difficulty was encountered maintaining her oxygenation and continued mechanical support was required. The nurse noted there were large amounts of blood stained sputum being suctioned from the ET tube. On examination she was unresponsive. Pulse 100; BP 110/70; Temperature 39.1 C. The incision was clean and there was no evidence of bleeding. There were no retinal or sublingual hemorrhage and no petechiae. On auscultation breath sounds were diminished on the left and there was dependent dullness to percussion. EKG showed right axis deviation. HB 8; WBC 18,000. Chest X-ray showed multiple infiltrates on the left and a small effusion. A pleural tap resulted in the aspiration of 400 cc of blood-stained serous fluid. FI 102 100%; PO2 85; PCO2 38; V/Q scan showed multiple areas of mismatch with a high probability of embolus.

3.2.3 Procedure

Experimental sessions lasted approximately one hour per subject. The sessions were conducted individually at a location and at time convenient for the subject (in an office or a quiet room in the hospital). Each subject was presented with the 12 written case descriptions in the same fixed (randomized) order, one case at a time. The sessions were audio recorded in their entirety.

For each of the 12 cases presented, the procedure involved asking subjects to do the following :

(1) read the case and "think aloud" (i.e. verbalize their thoughts) in deciding on a course of action to be taken for that case. The specific instructions were: "Read the clinical case and provide the therapeutic and management plan (include any further investigations and reasons for your choices). Please think aloud in your response".

(2) after providing their treatment choice for the case, the subject was asked the following: "Would you treat with the information given?", and if the response was "no", the subject was asked to indicate what further information he/she would request.

(3) the subject was then instructed to: "Suggest a differential diagnosis for the case, giving any alternative actions (e.g. investigations, treatments) you considered and why".

(4) the subject was then asked "How likely is it that your diagnosis is correct?"

(5) the subject was also asked to indicate how confident he/she was regarding their judgment for the case, indicating on a 7-point scale (i.e. by marking with a pencil), ranging from very unconfident (1) to highly confident (7).

3.2.4 Analysis of Verbal Protocols

The verbal protocols of the subjects were transcribed verbatim, and were then coded for cognitive processes involved in clinical decision making and reasoning. The focus was on analysis of decision making and reasoning processes, and identification of overall approaches to dealing with decision complexity. The first step in the analysis of the transcribed protocols was the determination of meaningful units of analysis. To faciliate coding, the protocols were broken down into short phrases, the boundaries of which were based on syntactic cues such as clauses, sentences and pauses in the verbalizations (Ericsson & Simon, 1993; van Someren, Barnard, & Sandberg, 1994). Groups of phrases, i.e. protocol segments, were then coded for aspects of decision making and problem solving using the coding scheme described in detail below. In general, the construction of coding schemes for think-aloud data is guided by consideration of both the theoretical interests of the investigators and the particular nature of the reasoning tasks selected for study (Hassebrock & Prietula, 1992). The coding scheme which was developed for this thesis includes categories for identifying fundamental aspects of therapeutic decision making. It extends previous coding schemes (Kuipers, Moskowitz, & Kassirer, 1988), which have dealt mainly with selection and comparison of decision alternatives, by incorporating new categories, based on research emerging from the naturalistic study of decision making (Klein & Calderwood, 1991). In addition to coding for decision making, the scheme devised for the study included categories for identifying diagnostic reasoning processes, such as generation and testing of diagnostic hypotheses (Patel, Arocha, & Kaufman, 1994; Hassebrock & Prietula, 1992). Specifically, the subjects' protocols were coded for identifying content using the coding scheme described below:

I. Therapeutic Decision Making Processes

The portion of the coding scheme used for analyzing decision making processes (see Fig. 3.1 for a diagrammatic representation of all coding categories) focuses on identification of choice of investigations and treatments (Kuipers, Moskowitz & Kassirer, 1988), as well as pre-decisional processes, including situation assessment.

1. Situation Assessment: Situation assessment refers to the identification and clarification of the state of the decision problem by the decision maker. According to Endsley (1995), situation assessment is defined as a person's perception of the elements of the environment, the comprehension of their meaning, including comparison to one's previous knowledge and experience. Aspects of situation assessment which were coded for included the following:

> (a) Requests for Situational Information: coded for if the subject indicated that specific situational information (not provided in the case) would be needed in arriving at a decision. (Example: "I would need to know more about the patient's breathing prior to being mechanically ventilated"). This is similar to the category developed by Kushniruk, Kaufman, Patel, Levesque and Lottin (1996) for identifying requests for contextual information by physicians during decision making tasks.

(b) Comparison to Previous Decision Situations: coded for if the subject stated that he/she recalls a previous patient case or clinical encounter that matches, or is analogous to the presented case. (Example: "this case is very similar to a patient I saw last week with respiratory problems"). This is based on Klein and Calderwood's (1991) category "Recognition Match", used to identify analogous matches to prior cases in analysis of protocols of firefighters.

2. Review Data: coded for if the subject reviewed data given in the case (i.e. information from the case description was simply repeated verbatim without interpretation or inference). This category is based on Kuipers, Moskowitz and Kassirer's (1988) category REVIEW.

3. Choice of Action

(a) Choose Investigation: coded for if the subject indicated he/she was considering a choice option for performing an investigation (Example: " I would send the patient for a pulmonary angiogram to get more conclusive evidence"). This category is similar to Kuipers, Moskowitz and Kassirer's (1988) CHOOSE category, extending it to include specification of type of investigation chosen.

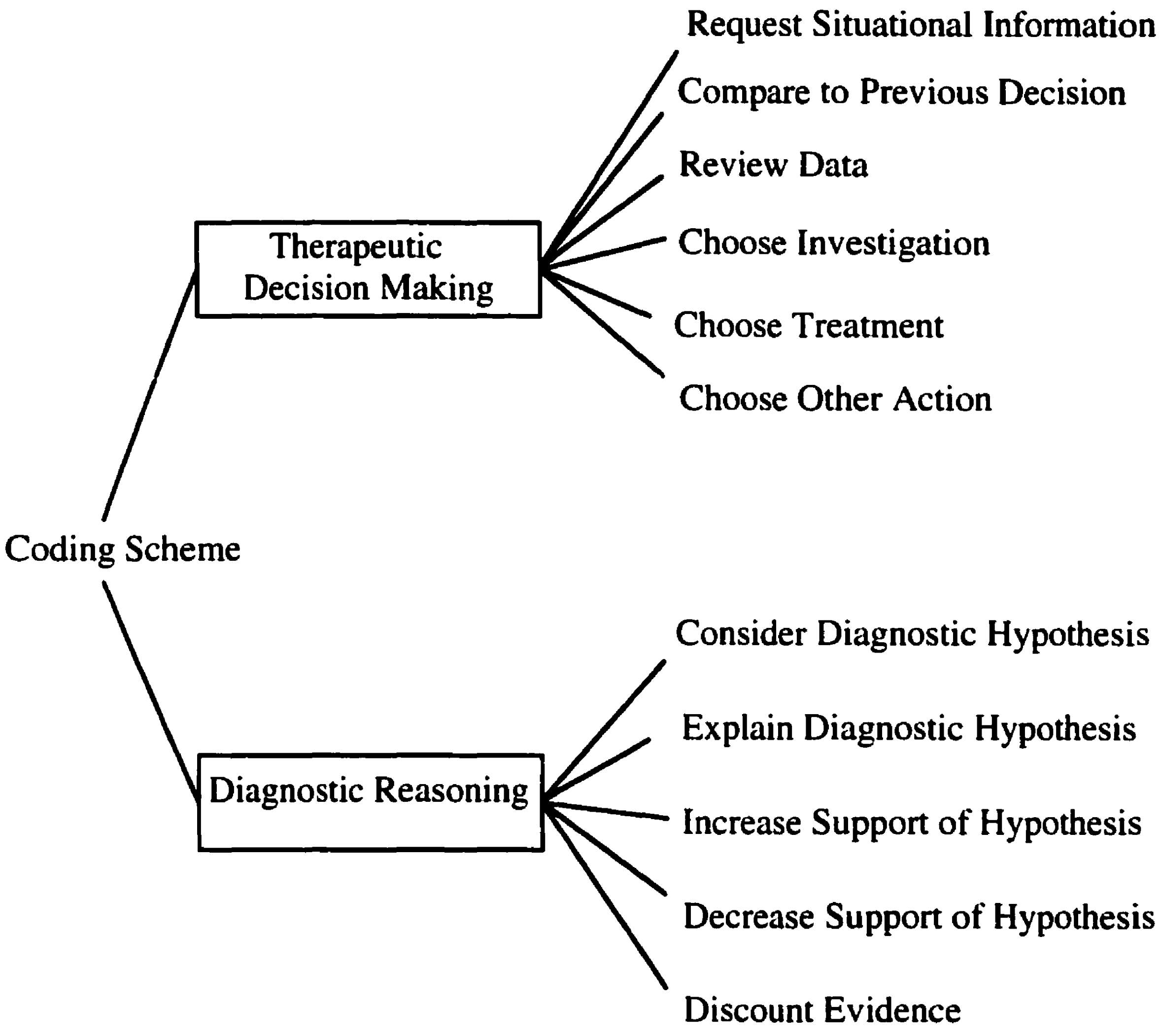

Figure 3.1 Coding categories used in the analysis of think aloud protocols

(b) Choose Treatment: coded for if the subject indicated he/she was considering a choice option for treatment (Example: "I would definitely start the patient on treatment with heparin"). This category is also similar to Kuipers, Moskowitz and Kassirer's (1988) CHOOSE category, extending it to include specification of type of treatment chosen.

(c) Choose Action (Other): coded for if the subject indicated he/she was considering an action other than an investigation or treatment (Example: "I would admit the patient to the hospital and monitor him closely"). This category allowed for identification of choices that ranged in nature from counseling the patient to choosing to send the patient to the intensive care unit.

II. Diagnostic Reasoning Processes

The coding scheme also incorporated categories for the analysis of diagnostic reasoning (see Fig. 3.1), including hypothesis generation and testing (similar to categories used in studies of medical reasoning and problem solving reviewed by Patel & Groen, 1991a and Hassebrock & Prietula, 1992).

1. Generation and Explanation of Diagnostic Hypotheses

(a) Generate Diagnostic Hypothesis: coded for if the subject stated he/she was considering a diagnostic hypothesis (Example: "This patient appears to have pneumonia"). This category was modified from categories used by Patel & Groen (1991a) for identifying generation of diagnostic hypotheses.

(b) Explain Hypothesis: coded for if the subject provided an explanation for a diagnostic hypothesis (i.e. an explanation of underlying pathophysiology). This category was based on Patel & Groen's (1991a) work on causal explanations in medicine, as well as Hastie's (1993) work in examining explanatory processes.

2. Evaluation of Data in Relation to Diagnostic Hypotheses

(a) Increase Support in Hypothesis: coded for if the subject interpreted evidence as supporting or confirming a particular diagnostic hypothesis. This category was included to characterize the use of evidence in providing positive support for hypotheses and is based on Hassebrock and Prietula's (1992) category "confirmation" (coded if evidence is interpreted as being consistent with a hypothesis, thus providing confirmatory value for the hypothesis).

(b) Decrease Support of Hypothesis: coded for if the subject interprets evidence given in the case as disconfirming or decreasing support for a particular hypothesis. This category is based on Hassebrock and Prietula's (1992) category "disconfirmation" (coded if evidence is interpreted as being inconsistent with a hypothesis, thus providing disconfirmatory value for the hypothesis).

(c) Disregard/Discount Evidence: coded for if the subject explicitly stated that he/she was disregarding or discounting evidence. This category was developed to assess how often subjects belonging to different levels of expertise discounted evidence they were presented with (including evidence such as laboratory results, as well as results from investigations and other procedures).

3.2.5 Analysis of Decision Rules

In addition to coding the protocols using the categories described above, the protocols were also analyzed to identify underlying decision rules applied. This involved identifying a decision rule for each case response, in the form of an "If... then ..." statement, with the conditions of the rule consisting of the conditions of the case (in terms of clinical evidence and lung scan probability) and the rule's conclusion consisting of the action taken for the case (e.g. "*If* clinical evidence is high, and lung scan probability is high, *then* treat immediately for PE). In order to identify general, higher order patterns in strategies used by subjects, an approach modified from Elstein, Holzman, Belzer & Ellis (1992) was applied.

3.2.6 Analysis of Use of Anomalous Evidence in Response to Ambiguous Cases

This analysis involved identifying and tabulating the responses made by subjects for complex cases where lung scan evidence conflicted with clinical evidence (i.e. cases of case type 2 and 5). This included identification of subject strategies and approaches to dealing with the anomalous evidence. Possible responses to anomalous evidence include the following (modified from Chinn & Brewer, 1993): (1) applying the evidence in decision making, (2) ignoring the evidence, (3) questioning/rejecting the evidence, and (4) re-interpreting the evidence to fit one's preferred hypothesis. Subjects' responses were coded according to these categories.

3.2.7 Analysis of Subjects' Assessment of Likeliness of Diagnosis and Decision Confidence

In order to analyze subjects' confidence in their decision making, subjects' responses were tabulated regarding their confidence on a 7-point scale.

The transcribed protocols were also coded in terms of how subjects represented and expressed likelihood in their response to the question of how likely it was that their diagnosis was correct. The method used involved an extension of referring phrase analysis (Kuipers, Moskowitz & Kassirer, 1988), where phrases in the transcript that refer to likelihood were coded as the following:

(1) Qualitative descriptions: Likelihood was described in purely qualitative terms (e.g. "I think the likelihood of pulmonary embolism is very high")

(2) Quantitative descriptions: Quantitative descriptions were coded as the following:

(a) Percent - Likelihood was expressed as a percent (e.g. "This patient has a 95 % chance of having heart failure")

(b) Probability - Likelihood was expressed as a probability (e.g. "The probability of my diagnosis being correct is .6")

(c) Scale - Likelihood was expressed on a scale (e.g. "On a scale of 1 to 10, I'd say the probability of the patient having a PE is 9")

(d) Fraction - Likelihood was expressed using a fraction (e.g. "I think one third of the patients with this presentation will have PE")

3.2.8 Statistical Analyses

In order to determine inter-rater reliability in assigning protocol segments to the coding categories, selected protocols were coded independently by the author and a research assistant. The percent agreement was found to be 89.9%, or expressed as Cohen's Kappa .86.

Where possible, statistical analyses were conducted in comparing subjects' reasoning and decision making processes across levels of expertise using Analysis of Variance (ANOVA).

3.3 Research Hypotheses

The overall research objectives motivating this study include the following: (1) characterizing expert-novice differences, specifically the effects of expertise on therapeutic decision making and diagnostic reasoning processes, (2) identifying subject strategies used for dealing with ambiguity of evidence in decision making, (3) examining the relationship between reasoning and decision making in a complex domain, and (4) comparing results obtained from a laboratory-based study of complex decision making, employing the "expertise approach" (Ericsson & Simon, 1991), with recent research results emerging from the naturalistic study of decision making (Klein, 1993).

The specific hypotheses and their rationale are the following:

Hypothesis 1: Decision strategies used by subjects will vary as a function of expertise and ambiguity of evidence. Specifically, differences will exist across levels of expertise in strategies used by subjects to process cases containing anomalous evidence. This hypothesis is based on previous study of students in both science (Chinn & Brewer, 1993) and medicine (Arocha, Patel, & Patel, 1993), indicating that approaches to dealing with anomalous evidence may vary according to one's prior knowledge. In addition, it is based on findings in the area of interpretation of radiographic images which indicates that experts and non-experts may differ in how valid they consider the same evidence (Lesgold et al., 1988).

Hypothesis 2: Experts will focus on processes involved in situational assessment to a greater extent than intermediates (i.e. residents) and novices (i.e. medical students). This prediction is based on results emerging from naturalistic study (involving retrospective interviews with experienced decision makers) which implicate the importance of situation assessment in experienced decision making (Patel, Kaufman, & Magder, 1996; Klein, 1993). It is further expected that significant differences will be found between experts and non-experts regarding key aspects of situation assessment (i.e. number of requests for situational information and comparison to previous decisions).

Hypothesis 3: Experts will apply recognition-based decision strategies more frequently than non-experts. This hypothesis is based on research findings in medical cognition indicating use of forward reasoning processes by experts based on recognition of patterns in the medical data during problem solving

(Patel & Groen, 1991a), and with research in the naturalistic study of decision making indicating the importance of recognitional processes in decision making by experts (Klein, 1993).

<u>Hypothesis 4:</u> An "intermediate effect" will be found for both reasoning and decision making processes. Specifically, it is predicted that:

> (4a) Intermediate level subjects (i.e. residents) will consider a greater number of diagnostic hypotheses than novices and experts.
>
> (4b) Intermediate level subjects will consider a greater number of decision choices for treatment and investigation than novices and experts.

These predictions are based on research in the study of the development of expertise, which has indicated an intermediate effect for diagnostic reasoning (Patel & Groen, 1991b). Given the relatedness of cognitive processes involved in decision making and diagnostic reasoning, it is expected that an intermediate effect will also be found when decision making processes are considered (4b).

<u>Hypothesis 5:</u> Subjective confidence in decision making will increase with increasing levels of expertise. This prediction is based on work indicating that experts demonstrate high levels of confidence in their decisions (Shanteau and Phelps, 1977). For complex cases within levels of expertise, confidence will be lower for cases characterized by ambiguous evidence (e.g. high probability lung scan evidence for PE and low clinical evidence for PE) than for cases where

evidence is consistent (e.g. low probability lung scan for PE and low clinical evidence).

Hypothesis 6: When providing assessments of likelihood in their protocols, subjects of all levels of expertise will use predominantly qualitative descriptors of uncertainty, as opposed to numeric estimates. This is based on work indicating the central role of qualitative reasoning in medical problem solving and representation, as described by Kuipers and colleagues (1988) in the protocol analysis of decision making by pulmonary physicians.

CHAPTER IV

RESULTS AND DISCUSSION

Given the complexity of the results they are presented in several sections, along with discussion of their implications. The hypotheses presented in the previous chapter are considered in light of findings in the following areas: (1) decision making and reasoning processes, (2) strategies for coping with ambiguous and conflicting evidence, (3) confidence in decision making, and (4) description of likelihood and uncertainty by subjects. The first section presents the general results for the coding of the think-aloud protocols for reasoning and decision making processes. Examples and descriptions of a number of excerpts from individual protocols are provided to illustrate differences in the approaches taken by subjects of varying levels of expertise. In the final section, results related to confidence in decision making and subjects' representation of likelihood are discussed. A general discussion of the most important findings is presented in the next chapter, along with the conclusions.

In this chapter, both quantitative and qualitative analyses are presented with respect to coding of the subjects' protocols for cognitive processes involved in decision making and reasoning. This includes statistical analysis of subjects' responses for key process variables collapsed across all cases they were presented with. In addition, in-depth qualitative analysis is provided of individual subjects' responses to particular cases.

4.1 Decision Making Processes

Results from analysis of processes involved in therapeutic decision making, including coding of protocols for choice of investigation and treatment, are presented in this section. This analysis has been extended to include the consideration of decision making processes across levels of expertise, from novices (i.e. medical students) to expert physicians. This section begins with a presentation of the results from coding for cognitive processes which have been considered "pre-decisional" (i.e. cognitive processes essential to decision making which take place prior to actual choice of alternatives).

4.1.1 Situation Assessment

Two important aspects of situation assessment were coded for in subjects' protocols, consisting of requests for situational information and comparison of the decision problem presented to subjects with previously encountered decision situations.

(a) Requests for Situational Information

Table 4.1 presents the total number of requests for situational information by subjects for each of three levels of expertise. For each subject, the table includes the total number of requests for situational information made by that subject in response to the 12 presented cases. Figure 4.1 shows a graph of the mean number of requests for situational information by subjects across the three levels of expertise.

Table 4.1

Frequency of requests for situational information by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	3	21	9
2	11	13	60
3	15	16	30
4	9	1	10
5	9	7	7
6	8	0	21
7	8	8	34
8	1	9	28
Total	64	75	199
Mean	8.00	9.38	24.88

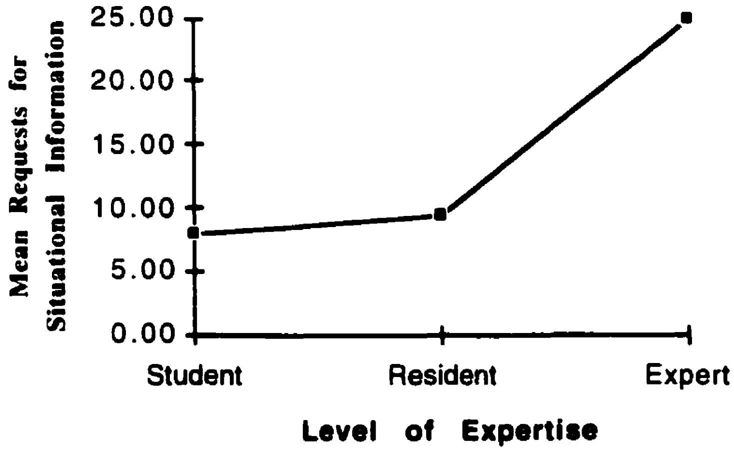

Figure 4.1 Mean number of requests for situational information by level of expertise

Protocols from expert physicians were found to contain significantly more requests for situational information than protocols from either students and residents ($F_{2,21} = 5.562; p < .05$). This is consistent with Hypothesis 2 which states that experts will focus on situational aspects of the cases to a greater extent than non-experts. This finding also provides empirical support for cognitive models of decision making which emphasize pre-decisional processes, such as situation assessment, in the judgment of experienced professionals (Klein & Calderwood, 1991). The results from the present study are also consistent with and extend findings from naturalistic studies (typically involving retrospective reports, e.g. Klein & Calderwood, 1991) to experimental study involving analyses of data from think-aloud protocols. Specifically, the results extend previous work by considering differences across levels of expertise (with significant differences between experts and non-experts), providing support for the claim that emphasis on situational aspects of a decision problem is a characteristic of expert decision making which distinguishes experts from non-experts.

An excerpt from an expert's protocol (subject E2) is provided below (codes are in boldface), illustrating consideration of situational aspects. This case consisted of a description of a patient with a high probability lung scan in conjunction with high clinical evidence for pulmonary embolism (case #4).

> Uh, I'd want further history
> specifically, uhm, starting with the acute event
> **REQUEST SITUATIONAL INFORMATION**
>
> uh, it mentioned that in the recovery room difficulty was encountered maintaining her oxygenation
> **REVIEW DATA**
>
> I'd like to know whether there were any problems intraoperatively
> Uh, specifically with oxygenation

and/or hemodynamics
REQUEST SITUATIONAL INFORMATION

In addition, I'd want to know whether there was any
difficulty intubating the patient
for the operating room itself
REQUEST SITUATIONAL INFORMATION

The expert focuses on consideration of situational factors, specifically the state of the patient upon entering the operating room. Prior to considering a diagnosis and treatment plan, this subject considered a variety of specific situational aspects of the case.

In contrast, the beginning portion of a protocol from an intermediate subject (resident R5) in response to the same case is given below:

So for this 72 year old lady
who is post-orthopedic procedure
She was sitting around for six days
with a femoral fracture
REVIEW DATA

Uhm, my impression is
that she wasn't given any therapeutic subcutaneous heparin
DVT
anything like that
so uhm, she is a high risk case for pulmonary embolus
CONSIDER HYPOTHESIS - Pulmonary Embolism

So I would definitely start uhm, on heparin
because she seems to be very sick
CHOOSE TREATMENT - Heparin

In general, intermediates (i.e. residents) and novices (i.e. students) did not focus on situational information outside of the evidence provided in the case descriptions. They instead typically demonstrated a fixed sequence in dealing with the cases, beginning by briefly reviewing the evidence given for the case, then entertaining diagnostic hypotheses, followed by consideration of treatment options (as shown above in the example of a resident's protocol). In contrast, the experts' protocols were more typically interleaved, with consideration of situation assessment occurring throughout the protocol and consideration of diagnostic hypotheses overlapping with selection of treatment options.

(b) Comparison to Previous Situations

Table 4.2 presents the total number of times subjects compared cases they were given with decision situations they had previously encountered (i.e. when reference was made to previous choice situations the subject had dealt with in the past).

Table 4.2

Frequency of comparisons with previous situations by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	0	0	1
2	0	0	1
3	0	0	3
4	0	0	0
5	0	0	0
6	0	0	1
7	0	0	0
8	0	0	4
Total	0	0	10
Mean	0	0	1.25

As can be seen, expert physicians compared the current decision problem to ones they had previously experienced on average about once per session, while residents and students made no explicit reference to previously encountered situations in arriving at treatment decisions. This provides support for Hypothesis 3, which states that experts will exhibit greater frequency of recognition-based decision processes than non-experts. This is also consistent with models of decision making that focus the experts' ability to recognize similarity between previous situations with current decision situations (Howell, 1993). Analogical mapping of problem representations to similar schemata from one's knowledge base has been recognized as an important strategy in problem solving (Holyoak, 1985; Holyoak & Koh, 1987). In intensive care decision making, comparison of the current situation to prior experience, appears to be a strategy that experts may apply, in particular for complex cases characterized by a high level of ambiguity of evidence, as described below.

The following is an example of an expert's (subject E8) comparison of a presented case (involving a young man experiencing respiratory pain, case #6) to a decision situation she previously encountered in medical practice:

> An 18 year old, what would I do with guy?
> Uhm, I would ask him what he's been smoking
> because I saw a case almost identical to this about 6 months ago
> and you know that both hashish
> and marijuana burn at a much higher temperature than regular tobacco
> so if people smoke
> even if they take a few tokes from the guy next to him
> they have a very irritated, they develop a very uhm irritable response

The expert responded to the presented case with the comparison to a previous case. In the references to previous decision situations, for cases where experts did mention a comparison, it typically occurred early in the protocol (i.e. within the first few segments), with choice of treatment driven to a large extent by the comparison.

In the following example from the same subject (subject E8), the expert (upon reading a case characterized by an intermediate probability lung scan and high clinical evidence for PE, case #7) comments on the portion of the case description which states that the patient says she is going to die:

```
Its always a bad sign when patients say I'm going to die
I've only seen one who wasn't correct
that's very, very disturbing
```

A second expert subject (subject E6), upon reading the same case, responded to the same information with a comparison to previous experience and immediately arrived at a diagnosis:

```
I'd say here that this is a pulmonary embolus.
When people come in and say I'm going to die suddenly,
that's almost, in my experience, always pulmonary embolus
```

Once again, the comparison to previously encountered situations occurred early in the protocol. It was also found that comparison to previous cases by experts occurred mostly in response to the most complex cases, i.e. cases involving potentially conflicting or anomalous data. Of the coded instances of comparison to previous experience, the majority (7) occurred in response to cases where lung scan evidence contradicted the overall clinical picture, 2 occurred in response to a case involving an intermediate probability lung scan, and only 1 occurred in response to a case where lung scan evidence was consistent with the clinical picture.

4.1.2 Review of Data

The total number of coded segments where subjects reviewed data provided (i.e. repeating the information given verbatim without any interpretation or inference) is presented in Table 4.3. The differences between groups were not significant, although there was a slight trend for experts to review data less frequently on average than either students or residents.

Table 4.3

Frequency of review of data by level of expertise

Subject #	*Students*	*Residents*	*Experts*
1	41	22	0
2	0	6	29
3	16	22	9
4	17	1	7
5	1	16	6
6	2	18	1
7	15	1	23
8	16	22	8
Total	108	108	83
Mean	13.5	13.5	10.375

4.1.3 Summary: Pre-decisional Processes

1. Experts generated more requests for situational information than non-experts
2. Experts occasionally employed recognitional strategies, comparing the current case to previously encountered decision situations in response to the most complex cases
3. The protocols of non-experts did not contain instances of comparison to previously encountered decision situations
4. Significant differences were not found across levels of expertise in the frequency of review of data

4.1.3 Choice of Action

Several aspects of choice in medical situations were coded for, including choice of investigations, treatments, as well as actions involving non-standard procedures. The results below include analyses of the subjects' responses (collapsing data from the cases given to each subject) in order to compare choice of action across the three levels of expertise. In addition, qualitative analyses of subjects' responses to individual cases are presented.

(a) Investigations Chosen

In Table 4.4, the total number of investigations (e.g. laboratory tests or special investigations such as pulmonary angiography) chosen by each subjects in response to all 12 medical cases is presented.

Table 4.4

Frequency of investigations chosen by level of expertise

Subject #	*Students*	*Residents*	*Experts*
1	20	20	12
2	16	15	16
3	19	21	26
4	23	44	12
5	3	54	10
6	20	22	14
7	8	16	16
8	17	30	14
Total	126	222	120
Mean	15.75	27.75	15

Figure 4.2 shows the mean number of investigations chosen by subjects of each of the three levels of expertise. Residents chose more investigations than either students or experts ($F_{2,21} = 4.540$; $p < .05$). These results provide support for Hypothesis 4, which states that intermediate level subjects will consider more investigations than either novices or experts.

This finding of an intermediate effect for choice of investigation extends Patel & Groen's (1991b) findings of an intermediate effect from consideration of diagnostic reasoning to decision processes, demonstrating the generality and robustness of the effect, not only for reasoning, but also for what are considered choice processes (i.e. selection of decision alternatives for investigations). This also parallels results recently reported by Patel, Groen, and Patel (1997), where residents were found to order numerous laboratory tests, often not relevant to diagnoses being pursued.

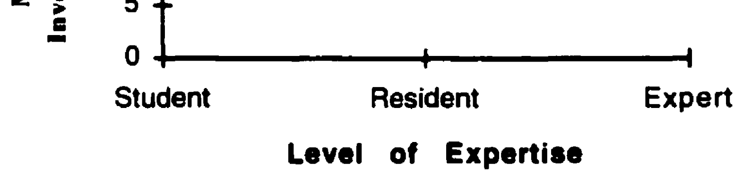

Figure 4.2 **Mean number of investigations chosen by level of expertise**

The range of possible investigations selected were found to be similar across levels of expertise (i.e. the possible type of tests ordered). However, the frequency and pattern of particular investigations varied across levels of expertise. Experts typically applied a structured approach in choosing investigations tailored to the patient's particular situation. For example, experts were hesitant to choose invasive investigations such as pulmonary angiography when the patient's situation might make this difficult (e.g. when it would be problematic to move the patient in order to carry out the procedure involved). Medical students and experts chose considerably fewer investigations than the residents, and in general, students' selection of investigations included fewer invasive tests than either residents or experts.

For complex cases involving a lung scan that contradicted the clinical evidence, residents tended to increase the number and range of investigations chosen. Residents' selection of investigations typically included choice of several investigations in combination, which were often related and sometimes overlapping in terms of the information they might provide (e.g. ordering of both Doppler investigation and an angiogram, the former used to determine if there is a predisposition to pulmonary embolism and the latter used to more definitively determine the existence of pulmonary embolism).

In contrast, the experts tended to order only one key test (e.g. ordering just an angiogram, rather than both a Dopplers and an angiogram), as can been seen in Table 4.5 which shows the investigations and treatments chosen by each subject for a case where the lung scan evidence (characterized by a low probability lung scan for pulmonary embolism, or PE) conflicted with the clinical evidence (high clinical evidence for PE).

Table 4.5

Subjects' choices in response to a case of low probability lung scan for PE combined with high clinical evidence for PE (case #2)

Subjects	Investigations Chosen	Treatments Chosen
Students:		
S1		heparin
S2	ultrasound	oxygen, antibiotics
S3	sputum culture, pulmonary function test, tap effusion	oxygen, antibiotics
S4	leg exam, X-ray	
S5	angiogram	heparin
S6	temperature, Doppler	oxygen, antibiotics, Penicillin
S7		heparin, oxygen, Coumadin
S8	sputum culture	oxygen, Tylenol
Residents:		
R1	IPG, sputum culture	
R2	Doppler, sputum culture	heparin (conditionally)
R3	blood gas, X-ray, sputum culture, Doppler, vitals	oxygen, antibiotics
R4	Doppler, IPG, angiogram	heparin
R5	angiogram, Doppler, IPG, EKG, X-ray	heparin, oxygen
R6	ECG, angiogram	heparin (conditionally)
R7	Doppler, angiogram	heparin (conditionally)
R8	Doppler, angiogram	heparin, oxygen
Experts:		
E1		heparin, oxygen
E2	Doppler	heparin, antibiotics
E3	angiogram	heparin, antibiotics
E4	ultrasound	heparin
E5	ultrasound, Doppler	heparin, antibiotics
E6	angiogram	heparin
E7	angiogram	heparin
E8	angiogram	heparin

In responding to this case, all the experts (with the exception of subject E5) chose only one investigation. Furthermore, none of the experts selected both an angiogram and a Doppler investigation in combination. In contrast, half of the eight residents chose both a Doppler and an angiogram. All of the experts also indicated that they would immediately begin treatment of PE with heparin (an anticoagulant commonly used to treat for PE), despite the lung scan indicating a low probability for PE. Three of the eight residents (subjects R4, R5 and R8) indicated that they would start heparin therapy immediately, while three other residents (subjects R2, R6 and R7) indicated that they would start therapy for PE conditionally (i.e. if the results from investigations ordered came back positive for PE). In contrast, only three of the eight students (subjects S1, S5 and S7) indicated that they would treat for PE at all, despite the high level of clinical evidence for the condition. It appears that the students were more strongly influenced by the lung scan indicating a low probability for PE, while the experts based their decision on the overall clinical evidence.

For cases which were more straightforward (i.e. where the lung scan evidence was consistent with the clinical evidence), these difference were less apparent. For example, Table 4.6 shows the investigations and treatments chosen in response to a case where the lung scan evidence (characterized by a high probability lung scan for PE) was consistent the clinical evidence (characterized by high clinical evidence for PE), making a diagnosis of PE very likely. For this case, every subject chose to treat the patient for PE (by choosing treatment with heparin or thrombolytic therapy). A number of subjects from all three levels of expertise did not choose further investigations, but rather decided to treat based on the information provided in the case description (as indicated by the blank entries for investigations chosen for some of the subjects).

Table 4.6

Subjects' choices in response to a case of high probability lung scan for PE and high clinical evidence for PE (case #11)

Subjects	Investigations Chosen	Treatments Chosen
Students:		
S1		heparin
S2	Doppler, contrast exam, sputum culture	heparin
S3	sputum culture	heparin
S4	sputum culture, blood culture	heparin, bronchodialators, oxygen
S5		heparin
S6	Doppler	heparin
S7	ultrasound of legs	heparin, oxygen
S8		heparin, oxygen, ventillin
Residents:		
R1	Doppler	heparin
R2		heparin, antibiotics
R3		heparin
R4	angiogram, sputum culture	heparin
R5	Doppler, sputum culture, enzymes, EKG	heparin, antibiotics
R6	venous study	heparin
R7		heparin
R8		oxygen, thrombolytic therapy, ventilatory support
Experts:		
E1	bronchoscopy, sputum culture	heparin
E2	angiogram	heparin
E3	sputum culture, angiogram, echogram	heparin, filter, thrombolytic therapy
E4		heparin
E5		heparin
E6		heparin
E7		heparin
E8		heparin

(b) Treatments Chosen

In table 4.7, the total number of treatments considered by subjects of each of the three levels of expertise is presented, with a graph of the mean number of treatments in Figure 4.3. Residents generated more treatment choices than either students or experts, indicative of an intermediate effect, which was predicted. However the differences were not statistically different, which may have been due to the nature of the tasks, where for a number of the cases the evidence was strongly suggestive of pulmonary embolism, leading to treatment options which are typically similar across physicians (i.e. the physician often treats by giving the patient heparin, unless contraindicated). However, for cases where the evidence was less consistent, there was greater variation across groups regarding choice of treatments, as discussed above.

Table 4.7

Frequency of treatments chosen by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	21	9	22
2	14	14	13
3	12	16	26
4	12	20	2
5	4	50	10
6	19	10	16
7	30	22	10
8	20	30	22
Total	132	171	121
Mean	16.5	21.375	15.125

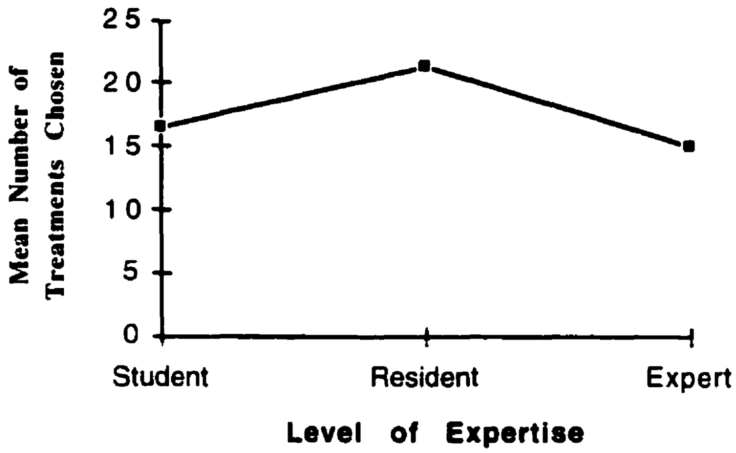

Figure 4.3 Mean number of treatments chosen by level of expertise

(c) Actions Chosen - Other than investigation or treatment

Table 4.8 contains the total number of actions chosen by subjects, which did not consist of investigations or treatments. Included in this category are actions such as admitting a patient, counseling the patient and any other actions that the subject might undertake, excluding standard investigations and treatments. Figure 4.4 shows the mean number of actions of this type chosen by subjects of each level of expertise.

The results indicate that for choice of action other than investigations or treatments, the pattern does not indicate a non-monotonic inverted U-shaped curve indicative of an intermediate effect. Although residents and experts chose slightly more actions of this type than students (as can be seen in Figure 4.4), the differences were not significant.

Table 4.8

Frequency of actions chosen - other than investigation or treatment, by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	0	3	20
2	3	6	2
3	3	6	3
4	6	3	0
5	0	27	4
6	3	4	4
7	12	7	14
8	13	3	14
Total	40	59	61
Mean	5	7.375	7.625

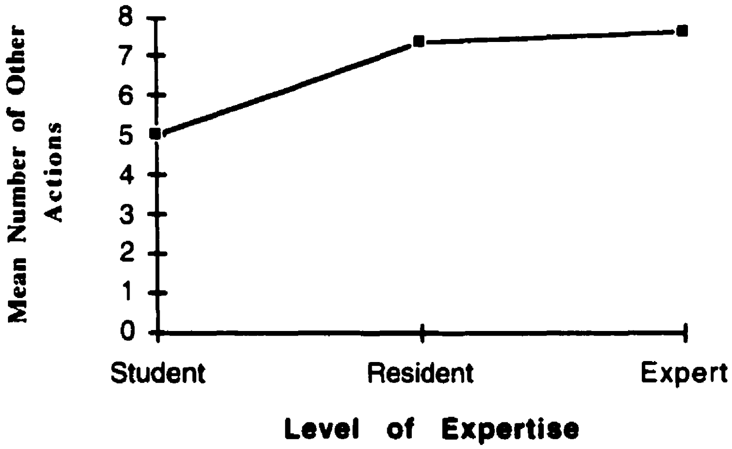

Figure 4.4 **Mean number of choice of actions - other than investigations or treatments**

There were however, qualitative differences in the types of actions, other than specific investigations and treatments, chosen by experts and non-experts. For example, for one case describing a woman dying of pancreatic cancer who was at high risk for also having a pulmonary embolism (case #5), one expert physician (subject E8) chose not to treat for PE, but rather to make the patient as comfortable as possible. She explained that she took this action (based on her previous experience and the patient's specific situation) for the following reasons:

> and you would like me to tell you what I would do with this patient
> I would sit down and would talk to her because
> uh, cancer of the pancreas is not a treatable disease
> and the death from cancer of the pancreas is awful
> the pain is apparently unbearable
> And from the few patients I've seen with that
> that's certainly the case
> my bias, and this is a very personal perspective
> and one that I do not try to impose on patients
> but my view is, if you get a complication in the context of pancreatic cancer
> and you die from it,
> then that's better than dying from the cancer alone
> because of the amount of pain involved
> and how horrendous it is
> So what I would do
> I would sit down and talk to her
> but my bias would be to try to keep her comfortable
> so I would not anti-coagulate her

In contrast, all of the non-experts provided a full treatment and management plan for PE, involving anticoagulating the patient. In general experts tended to focus on aspects of the cases and decisions which were centered around the patient's very specific and particular situation. In this example, the expert is concerned with minimizing the particular patient's pain, specifically in the context of the underlying cancer, and attempts to justify her hesitance to treat based on prior experience with patients suffering from this type of cancer. This type of reasoning about patient specific factors was uncommon in the protocols of either students or residents.

4.1.4 Summary: Choice of Action

1. Residents (i.e. intermediates) chose more investigations than either students or experts, indicating an intermediate effect
2. For complex cases, residents' choices for investigations often contained tests and procedures that would overlap in terms of information provided
3. Experts chose a very limited number of investigations that did not typically overlap in terms of information they would provide
4. Residents chose more treatments than either students or experts, suggestive of an intermediate effect, however, the differences were not statistically significant

4.2 Diagnostic Reasoning Processes

The results for analyses of diagnostic reasoning processes included consideration of generation of diagnostic hypotheses (Patel & Groen, 1991a) and the use of evidence in supporting or refuting diagnostic hypotheses (Hassebrock & Prietula, 1992).

4.2.1 Generation and Explanation of Diagnostic Hypotheses

(a) Diagnostic Hypotheses Generated

The total number of diagnostic hypotheses generated by subjects of each level of expertise is presented in Table 4.9, while Figure 4.5 shows the mean number of diagnostic hypotheses generated.

Table 4.9

Frequency of diagnostic hypotheses generated by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	32	69	37
2	36	34	54
3	36	82	33
4	32	27	17
5	32	48	23
6	24	43	34
7	17	46	39
8	17	55	26
Total	226	404	263
Mean	28.25	50.5	32.875

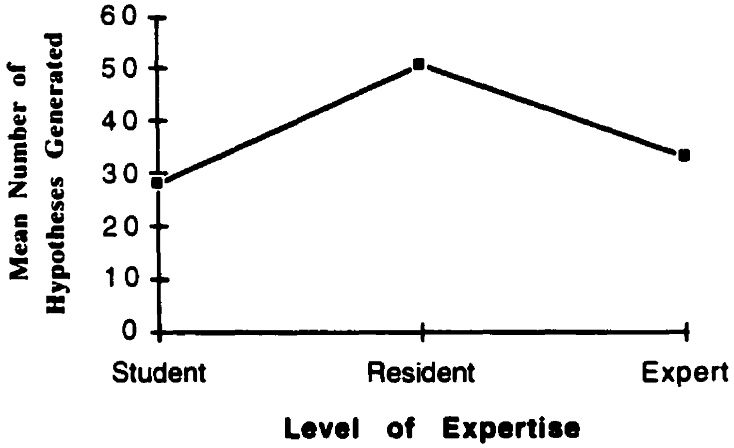

Figure 4.5 Mean number of diagnostic hypotheses generated by level of expertise

It was found that residents generated significantly more diagnostic hypotheses than either students or experts ($F_{2,21} = 6.443$, $p < .01$). This finding provides support for Hypothesis 4, which predicted an intermediate effect for reasoning processes. This result extends to consideration of reasoning involved in therapeutic treatment decisions, findings from previous research focused specifically on diagnostic reasoning (Patel & Groen, 1991a; Schmidt et al. 1990) where residents generated numerous and sometimes superfluous diagnostic hypotheses.

The nature of hypotheses generated in response to the cases varied according to level of expertise, with differential diagnoses of experts more commonly containing small sets of closely related diagnoses (e.g. pulmonary conditions). In contrast, the differential list of students and residents often contained diagnostic hypotheses from less related disease categories, with the residents' differential containing the largest number of diagnoses. This pattern of findings is consistent with work indicating that intermediates (i.e. residents) are unable to constrain the diagnoses they consider to logically related sets that can be easily differentiated (Joseph & Patel, 1990; Kushniruk, Patel, & Marley, 1998). Consistent with research in diagnostic reasoning (Patel & Groen, 1991b, Lesgold et al., 1988) it appears that intermediates are unable to make the fine discriminations among possible diagnoses that would be needed in order to constrain the number and range of hypotheses considered.

Table 4.10 presents subjects' differential diagnoses in response to a case characterized by a lung scan that indicates intermediate probability of PE, coupled with high clinical evidence for PE (involving a cancer patient). The experts focused on pulmonary problems (in addition to the underlying cancer), as indicated by their differentials, while residents and students tended to include both pulmonary (e.g. pneumonia) and cardiac problems (e.g. MI - myocardial infarction), belonging to different disease categories.

Table 4.10

Subjects' differential diagnoses in response to an intermediate probability lung scan for PE and high clinical evidence for PE (case #5)

Subjects	**Differential Diagnosis**
Students:	
S1	PE, pneumonia
S2	PE, pneumonia
S3	PE, metastasis, heart failure
S4	lung metastasis, PE
S5	anxiety, rhonchitis
S6	PE, pleuritis
S7	PE, MI, infectious pneumonia
S8	PE, MI, angina, lung metastasis, pneumonia, heart failure
Residents:	
R1	PE, pneumonia, cancer
R2	pneumonia, PE, cancer
R3	pneumonia, MI, pneumothorax, dissecting aeorta
R4	PE, pneumonia, MI, metastatic pancreatic cancer, congestive heart failure
R5	PE, MI, metastatic cancer, pneumonia
R6	PE, collapsed lung,MI
R7	PE, MI
R8	PE, atelectasis, pneumonia
Experts:	
E1	Pneumonia, PE
E2	PE, aspiration
E3	Metastatic disease, PE
E4	PE, cancer
E5	pneumonia, metastasis, pancreatic tumor, PE
E6	PE, atelectasis
E7	Pneumonia, cardiac ischemia, PE
E8	PE, pneumonia

PE = Pulmonary embolism
MI = Myocardial infarction

(b) Explanation of Diagnostic Hypotheses

Table 4.11 presents the total number of pathophysiological explanations of causes underlying diagnostic hypotheses (i.e. explanations of the pathophysiology leading to the patient's state, coded for as described in the methods section) provided by subjects of each of the three levels of expertise (it should be noted that these explanations were spontaneous in that subjects were not explicitly asked to provide pathophysiological explanations of diagnoses). The mean number of explanations is presented as a graph in Figure 4.6.

Experts' protocols were found to contain fewer explanations of diagnoses than either students or residents ($F_{2,21} = 4.406$, $p < .05$). This is consistent with models of decision making that emphasize experts' reliance on more automatic or recognitional processes, based on matching to prior experience, where experts might be expected to generate fewer diagnostic

Table 4.11

Frequency of explanations of diagnostic hypotheses by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	7	16	7
2	20	9	9
3	9	13	1
4	3	8	1
5	15	8	5
6	8	9	3
7	7	8	8
8	9	8	4
Total	78	79	38
Mean	9.75	9.875	4.75

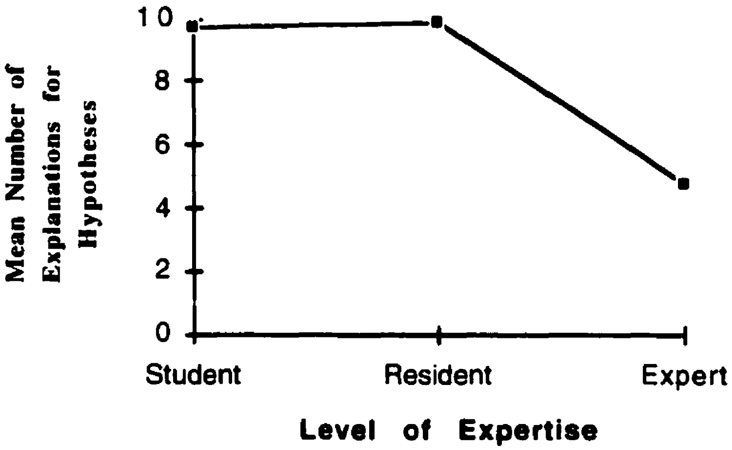

Figure 4.6 **Mean number of explanations of diagnostic hypotheses by level of expertise**

explanations given the more automatic reasoning processing that is associated with expertise and development of high level skill in a domain (Anderson, 1982).

4.2.2 Summary: Hypothesis Generation and Explanation

1. Residents (i.e. intermediates) generated more diagnostic hypotheses than either students or experts, indicating an intermediate effect
2. The differential diagnoses of non-experts often contained diseases belonging to differing disease categories
3. Experts generated fewer spontaneous explanations for diagnostic hypotheses than either students or residents

4.2.3 Evaluation of Evidence in Relation to Diagnostic Hypotheses

Several of the categories in the coding scheme described in Chapter III focus on characterizing the use and interpretation of evidence contained in the cases, including use of evidence by subjects in providing confirmatory and disconfirmatory support for diagnostic hypotheses. The protocols were coded for instances of statements indicating that evidence given in the case was being discounted or disregarded. This relates particularly to lung scan evidence, where several of the cases presented to subjects contained lung scan evidence which contradicted the overall clinical evidence, forcing subjects to deal with conflicting evidence.

(a) Confirmatory Evaluation of Evidence

Table 4.12 presents the total number of segments where subjects interpreted evidence as supporting or confirming a diagnostic hypothesis. Experts more frequently indicated use of evidence for increasing support in diagnostic hypotheses than students ($F_{2,21} = 5.920$, $p < .01$) (although the difference between experts and residents was not significant). An example of use of evidence in increasing support of a diagnostic hypothesis (by an expert, subject E1, in response to a case characterized by an intermediate probability lung scan for PE and high clinical evidence for PE, case #5) is given below:

```
The fact that the patient is febrile
and has a high white count will go along with the uhm
diagnosis of a pneumonia
```

Figure 4.7 presents the mean number of coded instances of confirmatory evaluations of hypotheses by level of subject. From the figure, it can be seen that there is a trend for the number of confirmatory evaluations to increase with increasing level of expertise.

Table 4.12

Frequency of confirmatory evaluations of hypotheses by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	7	4	13
2	7	1	9
3	1	15	6
4	5	3	6
5	8	2	12
6	0	13	15
7	2	11	12
8	1	6	16
Total	31	55	89
Mean	3.875	6.875	11.125

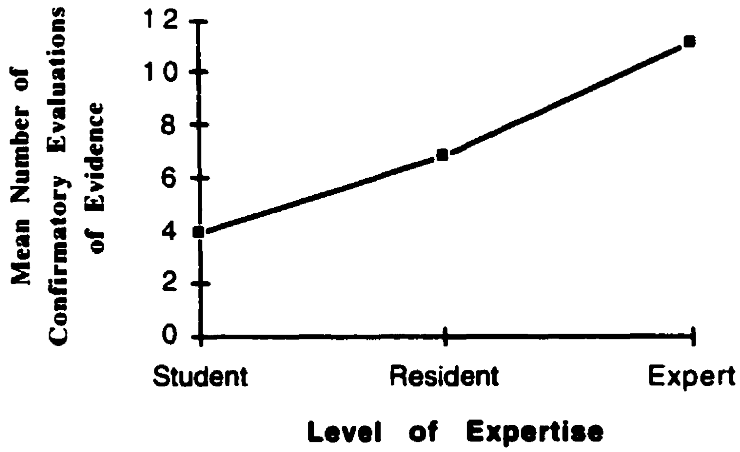

Figure 4.7 Mean number of confirmatory evaluations of hypotheses by level of expertise

(b) Use of Evidence in Disconfirming Diagnostic Hypotheses

Table 4.13 presents the total number of coded segments where subjects interpreted evidence as disconfirming or decreasing support for diagnostic hypotheses. Experts were found to use evidence in disconfirming and decreasing support of hypotheses more frequently than students ($F_{2,21} = 4.535$, $p < .05$). Figure 4.8 presents the mean number of coded instances of this category by level of subject. Although experts also showed more frequent disconfirmatory evaluation of evidence than residents, the differences between these two groups were not statistically significant. Despite this, as can be seen from Figures 4.7 and 4.8, there is a trend towards increased evaluation of evidence in testing diagnostic hypotheses with greater expertise. This could

Table 4.13

Frequency of disconfirmatory evaluations of hypotheses by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	6	6	2
2	6	1	9
3	0	8	14
4	2	0	5
5	5	1	6
6	1	6	3
7	2	4	12
8	0	1	8
Total	22	27	59
Mean	2.75	3.375	7.375

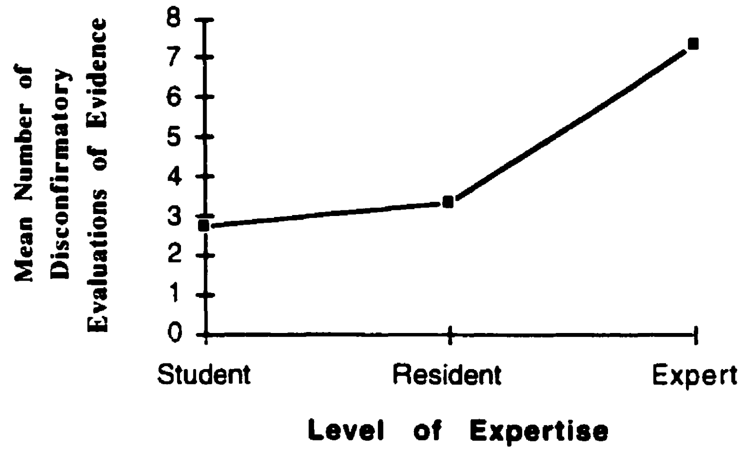

Figure 4.8 **Mean number of disconfirmatory evaluations of hypotheses by level of expertise**

be considered to be consistent with study of experts in analyzing radiographic images (Lesgold et al., 1988) which has indicated that experts do more inferential thinking than non-experts. In this thesis, this has been extended to comparison of processes involved in explicit evaluation of evidence across levels of expertise.

(c) Discounting Evidence

Table 4.14 contains the total number of coded protocol segments containing statements indicating that evidence (e.g. test results or lab data) was being disregarded or discounted. It was found that experts indicated that they were discounting evidence more frequently than residents and students ($F_{2,21}$ = 8.031, $p < .05$). Figure 4.9 depicts the total number of coded instances of this category for each of three levels of subjects.

Table 4.14

Frequency of evaluations where evidence is discounted by level of expertise

	Students	*Residents*	*Experts*
Subject #			
1	2	1	1
2	2	4	5
3	1	4	6
4	1	0	2
5	2	1	10
6	1	1	2
7	0	2	12
8	0	1	11
Total	9	14	49
Mean	1.125	1.75	6.125

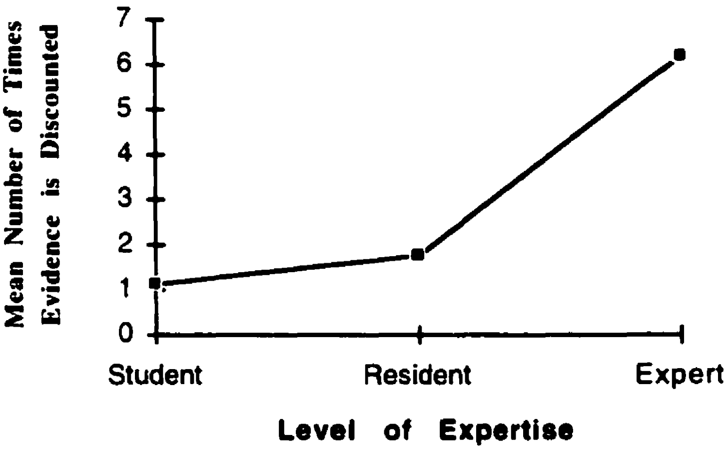

Figure 4.9 Mean number of times subjects discounted evidence by level of expertise

Below is an excerpt from an expert's (subject E8) protocol, where anomalous evidence, i.e. a high probability lung scan for PE, is presented in a case characterized by low clinical evidence for PE (case #8):

> and even though its read as a high probability of an embolus
> I don't think that it has any, uh clinical
> I don't think it has significance in the context of a patient like this

Another expert (subject E3), in dealing with the reverse situation (i.e. a case with a low probability lung scan for PE but high clinical evidence for PE, case #2) states that he will not base his decision on the lung scan evidence, providing the following explanation:

> uhm, uh, in this situation the V/Q scan is normal
> i.e. I gather normal perfusion scan
> the probability of a pulmonary embolism just with normal perfusion scan
> as they say is quite low
> however, I believe that the literature does show
> does come out with several instances of uh
> pulmonary embolism with a normal perfusion scan
> and this clinical situation is like a textbook

In situations involving the presence of anomalous evidence, successful diagnosis and action may depend on the resolution of such discrepancies. One possible strategy in dealing with this type of situation is to discount individual pieces of evidence, which appears to be what experts do more frequently than non-experts. Furthermore, as will be described below, experts appear to be less likely than non-experts to weigh one particular piece of inconsistent evidence (e.g. the results of a test) more heavily than the overall clinical picture, and thus are more likely to discount results of an individual test which is inconsistent with an overall clinical pattern. In contrast to the experts, student and intermediate level subjects (i.e. residents) appear to be more likely to base treatment decisions on individual test results than experts, as described in the next section.

(d) Analysis of Subject Strategies in Response to Anomalous Evidence

Table 4.15 presents an analysis of the approaches taken by subjects of all three levels of expertise in response to a case containing anomalous lung scan evidence. The case was characterized by a low probability lung scan for pulmonary embolism, in conjunction with high clinical evidence for PE. The categories for analyzing the subjects' responses were derived from Chinn and Brewer's (1993) classification of responses to anomalous evidence, ranging from accepting the evidence to ignoring and disregarding it to varying degrees.

From Table 4.15 it can be seen that half of the student subjects (subjects S3, S4, S6 and S8) applied the lung scan evidence (explicitly mentioning that they were using the evidence in arriving at a decision consistent with it) in ruling out PE and consequently not treating for PE (as indicated in the column on the far right of the table). Two of the intermediate subjects (subjects R1 and R3) also applied the anomalous evidence and consequently did not choose to treat for PE.

In contrast to the non-experts, all of the expert subjects chose not to apply the lung scan evidence which contradicted the clinical evidence for PE. Furthermore, all of the experts explicitly questioned and rejected the anomalous evidence, as indicated in the table.

Of the remaining responses, one student and one resident made no mention of the anomalous evidence (and did not make a treatment decision based on the lung scan, which was coded as "Ignore Evidence" in the table). Two of the experts (subjects E2 and E4) stated that they would personally ask to view the lung scan data, rather than relying on the summarized reports

Table 4.15

Strategies used by subjects in response to a case of low probability lung scan for PE and high clinical evidence for PE (case #2)

Strategies for Coping with Anomalous Scan Evidence

Subject #	Apply Scan Evidence	Ignore Scan Evidence	Question /Reject Evidence	Consult Others	Re-interpret Evidence	View Scan	Treat for PE ?
Students							
S1			x				Yes
S2			x				Yes
S3	x						No
S4	x						No
S5			x				Yes
S6	x				x		No
S7		x					Yes
S8	x						No
Residents							
R1	x						No
R2			x				Yes
R3	x						No
R4		x					Yes
R5			x				Yes
R6			x				Yes-cond.
R7			x	x			Yes-cond.
R8			x				Yes
Experts							
E1			x				Yes
E2			x			x	Yes
E3			x		x		Yes
E4			x			x	Yes
E5			x		x		Yes
E6			x		x		Yes
E7			x				Yes
E8			x				Yes-cond.

that physicians normally receive (coded as "View Scan"). One student (subject S6) and three experts (subjects E3, E5 and E6) reinterpreted the anomalous scan evidence in a way that would discount its validity (e.g. that it may be an artifact due to other respiratory problems) and one resident (subject R7) stated that he would consult another physician for interpreting the anomalous lung scan results.

Table 4.16 presents data for subjects' responses to anomalous data for a second case representing the reverse situation – i.e. a high probability lung scan for PE, in conjunction with low clinical evidence for PE. The pattern of responses indicate that four of the eight students (subjects S1, S4, S6, and S8) applied the anomalous lung scan evidence in deciding to treat for PE, despite the low clinical evidence. Three of the intermediate subjects (subjects R3, R4, and R5) did the same. In contrast, six of the eight expert physicians questioned and rejected the evidence, while two did not make explicit reference to the anomalous scan results at all (coded as "Ignore Evidence"). Only one of the experts made a treatment decision consistent with the lung scan results (subject E6). These results also indicate differences in approaches to dealing with anomalous evidence, where experts once again appear to place greater emphasis on the patients' overall clinical picture than students or residents. In contrast, non-experts appear to be more likely to apply the results of an individual investigation to drive the decision making process.

In summarizing the data in Tables 4.15 and 4.16, differences were found in the strategies of subjects of varying levels of expertise in dealing with the inconsistent scan evidence (this is consistent with Hypothesis 1, which states that differences exist across levels of expertise regarding strategies used for dealing with anomalous evidence). Expert physicians questioned and rejected the anomalous data in favor of the overall clinical picture. In contrast, students and residents were more likely to make decisions regarding treatment which were consistent with the anomalous data. This could be viewed as being consistent with the results described earlier, indicating the experts' emphasis on situation assessment, leading to increased consideration

Table 4.16

Strategies used by subjects in response to a case of high probability lung scan for PE and low clinical evidence for PE (case #8)

	Strategies for Coping with Anomalous Scan Evidence						
Subject #	Apply Scan Evidence	Ignore Scan Evidence	Question /Reject Evidence	Consult Others	Re-interpret Evidence	View Scan	Treat for PE ?
Students							
S1	x		x				Yes
S2			x				No
S3			x				No
S4	x						Yes
S5			x				No
S6	x						Yes-cond.
S7		x					No
S8	x						Yes
Residents							
R1			x				No
R2			x				No
R3	x						Yes
R4	x						Yes
R5	x						Yes
R6		x					No
R7			x				No
R8					x		No
Experts							
E1		x					No
E2			x			x	No
E3			x		x		No
E4			x				No
E5			x		x		No
E6		x					Yes
E7			x				No
E8			x		x		No

of the patient's overall state (as opposed to placing greater weight on one particular test or investigation in isolation).

4.2.4 Summary: Evaluation of Evidence in Relation to Diagnostic Hypotheses

1. Experts' protocols contained the largest number of confirmatory evaluations of diagnostic hypotheses
2. Experts' protocols contained the largest number of disconfirmatory evaluations of diagnostic hypotheses
3. Experts discounted evidence more frequently than either residents or students
4. Experts tended to reject anomalous lung scan evidence in favor of decisions consistent with the patient's overall clinical presentation
5. Non-experts were more likely to apply anomalous lung scan evidence in making decisions

4.3 Overall Analysis of Decision Making and Reasoning Processes

A summary of the analysis of coded protocols for cognitive processes involved in decision making and diagnostic reasoning processes is provided in Table 4.17. The total frequency of each coded category is given for each of the three levels of expertise, along with the percentage that number represents out of the total number of coded segments for that level of expertise.

The results are consistent with and summarize a number of the findings described in previous sections of this chapter. The most notable difference between experts and non-experts was in the percentage of requests for situation specific information, with 18.22% of the coded segments in expert protocols dealing with that aspect of situation assessment, as compared to 6.18% for residents and 7.66 for students. Although comparison to previous situations accounted for only 1% of the experts' coded segments, both the

Table 4.17

Frequency and percentage of coded segments from verbal protocols of students, residents and experts

	Level of Expertise					
Coding Category	Students		Residents		Experts	
	Number	Percent	Number	Percent	Number	Percent
I. Decision Processes						
1.Assess Situation:						
1a. Request Information	64	7.66	75	6.18	199	18.22
1b. Compare - Previous Case	0	0	0	0	10	1.00
2. Review Data	108	12.91	108	8.89	83	7.60
3.Choose Investigation	126	15.07	222	18.29	120	10.99
4. Choose Treatment	132	15.79	171	14.09	121	11.08
5. Choose Other Action	40	4.78	59	4.86	61	5.59
II. Diagnostic Processes						
1. Consider Hypothesis	226	27.03	404	33.28	263	24.08
3. Explain Hypothesis	78	9.33	79	6.51	38	3.48
4. Increase Support	31	3.71	55	4.53	89	8.15
5. Decrease Support	22	2.63	27	2.22	59	5.40
6. Disregard Evidence	9	1.08	14	1.15	49	4.49
TOTAL	836	100	1214	100	1092	100

students' and residents' protocols contained no instances of this category. Furthermore, as described earlier in this chapter, when experts did compare the decision problem to previously experienced situations, decision making was largely based on the comparison.

Other differences between groups included a greater percentage of coded segments involving choice of investigation by intermediate level subjects (i.e. residents) than for either students or experts. The tabulated results also indicate a greater percentage of coded segments involving selection of hypotheses by residents, indicative of the interpretation provided earlier in this chapter of an intermediate effect for both choice of investigations and consideration of diagnostic hypotheses.

As described earlier, relative to students and residents, experts' protocols contained fewer coded segments containing explanations of diagnostic hypotheses. The remaining categories in the table, dealing with use of evidence for confirming and disconfirming diagnostic hypotheses, illustrate the greater emphasis on explicit consideration of evidence by experts, as compared to residents and students.

In summary, the results displayed in Table 4.17 highlight a number of findings from this study, including an intermediate effect for both choice of investigation and generation of diagnostic hypotheses. In addition, cognitive processes that appear to distinguish experts from non-experts include greater focus on situation assessment, use of recognitional decision strategies and greater emphasis placed on evaluation of evidence by expert physicians.

4.4 Characterization of Treatments Chosen as Decision Rules

A summary of the final treatment decisions made by subjects of each of the three levels of expertise is presented in Table 4.18. Decision outcomes are expressed as in the table as rules relating the conditions of the six types of cases used in the study to three decision outcomes (identified from the subjects' protocols): (1) do not treat for PE, (2) treat for PE immediately, and (3) treat only if pending investigations are positive.

For cases in Table 4.18 characterized by a low probability lung scan for PE and low clinical evidence for PE, all the subjects chose not to treat for PE. For example, for all 16 responses to this case given by the students (there were two replications of this case type, resulting in a total of 16 presentations of this case) all of the students responses were to not treat for PE (100%). This was the same for the residents and experts, i.e. all subjects' responses to cases of this type consisted of not treating for PE.

For cases characterized by low probability lung scan for PE and high clinical evidence for PE, it can be seen that 56% of the experts' decisions in response to this case type were to treat immediately for PE, while the largest proportion of student responses (44%) consisted of not treating for PE. This is consistent with the finding that students place greater emphasis on results of a lung scan than experts. Conversely, experts appeared to place greater emphasis on the overall clinical evidence for this type of case. The residents in contrast, largely chose to wait for pending results and then treat for PE if they were positive (69% of their responses).

For cases characterized by an intermediate probability lung scan and low clinical evidence, the largest percentage of subjects in each of the three levels of expertise chose to wait for pending investigations before treating for

PE (with the residents' responses again containing the largest percentage of responses of this type - 81%).

Table 4.18

Number and percent of subject responses to cases of varied complexity described as decision rules

		Level of Expertise							
		Students			**Residents**			**Experts**	
		No.	%		No.	%		No.	%
1. If low probability lung scan + low clinical evidence									
a. Do not treat for PE		16	100		16	100		16	100
2. If low probability lung scan + high clinical evidence									
a. Do not treat		7	44		3	19		3	19
b. Treat for PE immediately		6	38		2	13		9	56
c. If pending investigations are positive then treat for PE		3	19		11	69		4	25
3. If intermediate probability lung scan + low clinical evidence									
a. Do not treat for PE		2	13		0	0		4	25
b. Treat for PE immediately		5	31		3	19		4	25
c. If pending investigations are positive then treat for PE		9	56		13	81		8	50
4. If intermediate probability lung scan + high clinical evidence									
a. Do not treat for PE		2	13		3	19		2	13
b. Treat for PE immediately		9	56		6	38		10	63
c. If pending investigations are positive then treat for PE		5	31		7	44		4	25
5. If high probability lung scan + low clinical evidence									
a. Do not treat for PE		9	56		9	56		15	94
b. Treat for PE immediately		3	19		3	19		1	6
c. If pending investigations are positive then treat for PE		4	25		4	25		0	0
6. If high probability lung scan + high clinical evidence									
a. Treat for PE immediately		15	94		14	88		10	63
b. If pending investigations are positive then treat for PE		1	6		2	13		6	38

For the fourth type of case, characterized by an intermediate probability lung scan and high clinical evidence, 63% of the experts' responses consisted of deciding to treat for PE immediately, consistent with greater weight being placed on the clinical evidence by experts. In contrast, for the fifth type of case, characterized by a high probability lung scan for PE and low clinical evidence for PE, 94% of the experts' responses consisted of not treating for PE, indicative of the lack of weight placed by experts on the scan evidence. In response to cases of the sixth and final case type, characterized by a high probability lung scan for PE and high clinical evidence, all of the subjects chose either to treat for PE immediately, or treat for PE if the results of pending investigations were positive.

These results highlight a number of findings:

1. For cases where lung scan evidence was consistent with clinical evidence (e.g. case type 1) there was less variation in responses across levels of expertise (i.e. all subjects would not treat for cases where lung scan and clinical evidence was low, and for cases where both lung scan and clinical evidence was high all subjects chose either to treat immediately or wait for pending results before treating).

2. The majority of decisions made by experts for cases where lung scan evidence did not match clinical evidence, were consistent with the overall clinical picture, implying that under such circumstances experts make decisions based on the overall clinical evidence.

3. The majority of decisions made by students for cases where lung scan evidence did not match clinical evidence, were consistent with the lung scan evidence, implying that the students placed greater emphasis than experts on the lung scan results.

4. For cases where lung scan evidence did not match clinical evidence, the majority of responses from residents consisted of waiting for results of investigations before deciding whether or not to treat for PE.

4.5 Confidence in Decision Making

The mean ratings of subjects' confidence in their treatment decisions (on a 7-point scale ranging from 1 for very unconfident, to 7 for highly confident) are presented in Table 4.19, for each of the six case types used in the study. Overall, there is an increase in confidence with increasing level of expertise, with the experts demonstrating the highest level of confidence for all case types. This is consistent with Hypothesis 5, which predicted that with increasing expertise and experience, confidence levels would be expected to rise. As will be considered in the next chapter, differences in the level of confidence across levels of expertise appear to relate to types of strategies employed by subjects in coping with complex and potentially ambiguous evidence.

The mean confidence rating of experts for the various types of cases was between 6 and 7, indicating a high degree of confidence (with the exception of the mean for cases with a high lung scan and low clinical evidence, where the mean rating of the experts dropped below 6). All of the means for residents fell in the range between 5 and 6, with their overall confidence being intermediate in value between the means for students and experts. Differences in confidence across levels of expertise were found to be statistically significant ($F_{2,270} = 26.491; p < .01$).

Students indicated the lowest confidence for the cases for each case type. For cases involving an intermediate probability lung scan for PE, the means for student confidence were below 5. This might be due to lack of training in dealing with potentially ambiguous lung scan results which are read as an "intermediate probability for PE". Survey of medical texts indicates that discussion and emphasis is more often provided of analysis of results involving more clearly defined lung scans (i.e. low and high probability lung scans). Thus, students might not be expected to have gained knowledge or confidence in interpreting and processing scans of an intermediate probability. However, both residents and experts would likely have had some experience in dealing with these types of cases in medical practice, leading to increased confidence.

Table 4.19

Confidence ratings of students, residents and expert physicians for each of the six case types

Case Type			**Mean Confidence in Judgment**		
Lung Scan	**Clinical Evidence**		**Students**	**Residents**	**Experts**
Low	Low		5.00	5.63	6.00
Low	High		5.19	5.63	6.00
Intermediate	Low		4.69	5.63	6.13
Intermediate	High		4.63	5.44	6.00
High	Low		5.50	5.88	5.88
High	High		5.25	5.88	6.34

Although students' confidence for cases containing intermediate probability lung scans were slightly lower than for other types of cases, statistical differences in mean confidence within groups for cases of varying levels of conflicting evidence were not found. For example, differences in mean confidence ratings between cases characterized by low lung scan evidence and low clinical evidence for PE and cases characterized by low lung scan evidence and high clinical evidence were negligible. However, as indicated in the previous section, there was wide variation in terms of treatments chosen for these two types of cases. Thus, there appears to be dissociation between the complexity of the cases, as indicated by the range of actual responses observed as well as the degree to which evidence conflicted, and subjects' subjective assessment of confidence for the cases.

In summary, confidence in the decisions made by subjects was found to increase as level of expertise increased. However, within level of expertise, significant differences in confidence for different case types were not found.

4.6 Representation of Likelihood

Table 4.20 contains a summary of the results of analyzing subjects' responses regarding their assessment of how likely it was that their diagnosis was correct (in response to being asked for each case how likely they thought their diagnosis was, as described in the methods section). As can be seen from the figure, the majority of student responses expressed diagnostic likelihood using quantitative descriptors (81%), predominantly percentages. In contrast, approximately half of the responses from residents and experts involved a qualitative description of uncertainty (e.g. "The chance of the patient having

PE is very high"). For the remaining quantitative responses, percentages were again the most common response (e.g. "I am 85 percent sure my diagnosis is correct"). It should be noted that none of the subjects expressed likelihood as probabilistic values (i.e. between 0 and 1).

It was hypothesized (Hypothesis 6) that all levels of subjects would use predominantly qualitative descriptors of likelihood (this prediction was based on work by Kuipers, Moskowitz and Kassirer, 1988, who analyzed the protocols of three pulmonary physicians for representation of uncertainty).

Table 4.20

Description of likelihood of correct diagnosis by students, residents and expert physicians

	Students		Residents		Experts	
	Number	Percent	Number	Percent	Number	Percent
1. Qualitative	18	19	53	52	56	49
2. Quantitative						
(a) Percent	76		48		54	
(b) Probability	0		0		0	
(c) Scale	2		1		4	
(d) Fraction	1		0		0	
Sub-Total Quantitative	79	81	49	48	58	51
TOTAL	97	100	102	100	114	100

However, it appears that subjects who lack clinical experience (i.e. medical students) use predominantly quantitative descriptors when asked to provide likelihood for diagnoses, which is consistent with textbook approaches to dealing with uncertainty in medicine. In contrast, for both practicing residents and experts, the use of qualitative descriptors becomes more prominent, accounting for half of the coded responses. This has implications for educational aspects of medicine, with a shift away from quantitative representations by medical students, to a mixed consideration of both qualitative and quantitative representations by practicing physicians.

These results also have implications for cognitive modeling involved in medical decision support. To date, the majority of decision support systems have focussed on reasoning using purely quantitative values for assessment of uncertainty. However, a few researchers have attempted to design decision support models that can allow for integration of both quantitative and qualitative arguments (Cooper & Fox, 1997). Given empirical results indicating approximately equal use of both qualitative and quantitative assessment of likelihood by practicing physicians, but mostly quantitative representation by students, consideration of how physicians of varying levels of expertise represent uncertainty may be important for design of both decision support systems and medical training (Kushniruk & Patel, 1998). The implications of this, as well as other findings from this thesis, will be explored in the General Discussion and Conclusions section.

In summary, students used mostly quantitative descriptions of likelihood, while both residents and experts used both quantitative and qualitative descriptions equally. The results suggest a shift from quantitative representation to mixed representation of likelihood, involving both quantitative and qualitative representation.

CHAPTER V

GENERAL DISCUSSION AND CONCLUSIONS

This chapter concludes the dissertation with a summary of the results and major findings presented in Chapter IV along with the conclusions derived from the findings. The remaining part of the chapter provides a discussion of the research described in this thesis in relation to issues and perspectives from the study of complex decision making and expertise. A theoretical account is developed for explaining the role of expertise in coping with decision complexity and ambiguity. The relation of the findings to emerging models of complex decision making are considered and implications for research in a number of fields are discussed, along with issues to be addressed by future research.

5.1 Summary of the Results

The research described in this thesis has focused on characterizing the decision making and reasoning processes of subjects of varied levels of expertise in coping with decision complexity. In particular, this included analysis of subjects' strategies for dealing with situations containing potentially conflicting and anomalous evidence. By examining both decision making and reasoning processes, this thesis has focused on investigating the role of expertise in dealing with decision complexity and ambiguity of evidence, involving both reasoning and decision making processes. The findings provide support for a theoretical explanation of how expertise affects decision making under conditions of uncertainty and ambiguity of evidence. Based on the analysis of subjects' protocols and analysis of confidence in decision making, the major findings are described below, along with specific conclusions to be tested in future research.

Finding 1: Differences in Strategies for Dealing with Ambiguity of Evidence

From analysis of the results, it was found that expert physicians relied on an assessment of the patient's overall clinical state when faced with ambiguous decision situations containing anomalous evidence. Specifically, experts rejected anomalous evidence in favor of the patient's specific clinical picture based on the overall evidence, leading to treatment decisions which were consistent with the clinical presentation and not the anomalous evidence. In contrast, it was found that non-experts, in particular medical students, tended to base their decisions on the anomalous evidence for cases where the clinical presentation conflicted with anomalous scan evidence. Intermediate subjects (i.e. residents) were more likely to defer their decisions in such cases, although they typically stated they would apply the anomalous data in choosing a treatment if additional confirmatory test results could be obtained. Thus, experts appear to be less likely than both students and residents to apply an individual piece of anomalous evidence in isolation of the patient's global situation. Rather, experts appear to place greater weight on interpretation of the patient's overall clinical presentation when faced with such dilemmas.

For a few of cases containing anomalous evidence, experts were found to employ recognitional strategies, where the presented case was compared to previously encountered situations, leading to decisions regarding diagnosis and treatment based on the comparison. In contrast, instances of comparison to previous decision situations were not found in the protocols of either novices or intermediates. Although the frequency of such comparisons by experts was not high, in cases where it did occur, it was found to drive the decision making process, with decisions made being consistent with the decision applied in the recalled case. Furthermore, such decisions were generally consistent with the patient's overall clinical presentation.

The findings provide support for Hypothesis 1, which stated that decision strategies used by subjects will vary as a function of expertise and ambiguity of evidence. From the analysis described above, this has further been refined from these results to indicate the nature of differences across levels of expertise, as described above. The results support to a lesser extent Hypothesis 3, which stated that experts will apply recognition-based strategies more frequently than non-experts. From the findings, use of such recognitional strategies (involving comparison to previous cases) was shown specifically for decision making by experts involving complex cases containing high degrees of ambiguity.

Conclusion: Strategies for dealing with ambiguous evidence were found to vary across levels of expertise (novices, intermediates and experts). Expert physicians tend to disregard anomalous evidence focusing instead on the patient's overall clinical condition, while non-experts are more likely to apply anomalous evidence to evaluate diagnostic hypotheses and drive the decision making process. For some complex cases, experts use an evaluation strategy where they compare the decision problem to prior knowledge.

Finding 2: Focus of Experts on Patient-Specific Situational Information

Analysis of protocols revealed greater consideration of situational aspects of decision problems by experts than non-experts. This was reflected in the finding of more numerous requests for situational information by experts than students and residents, and greater consideration of evidence by experts, both in confirming and disconfirming diagnostic hypotheses. Furthermore, qualitative analysis of the protocols indicated that experts' selections often included actions tailored to the particular patient, consisting of procedures other than standard investigations or treatments (e.g. counseling a patient regarding their particular risk for a condition). The expert's greater concern for specific aspects of a patient's particular situation is consistent with the above finding of the expert's emphasis on the patient's overall clinical condition.

As will be discussed in a subsequent section, the finding of emphasis by expert physicians on assessment of a patient's situation is consistent with results emerging from the naturalistic study of decision making (Leprohon & Patel, 1995; Klein, 1993). The current thesis is important in that it allowed for comparison of cognitive processes across levels of expertise (for the same decision problems), indicating statistically significant differences between experts and non-experts regarding aspects of situation assessment. In contrast, relevant research from naturalistic study has typically involved analysis of retrospective reports from subjects after decision making has occurred (Klein & Calderwood, 1991), leading to difficulties associated with interpreting such data (including effects of limited memory capacity of subjects for remembering what they actually did retrospectively). In this thesis, the results from controlled experimental study provide a basis for making the claim that in complex intensive care decision making, expert physicians can be distinguished from non-experts by their focus on situational aspects of the decision problem. The results from this thesis further extend findings from naturalistic settings by demonstrating significant differences across levels of expertise in an aspect of medical decision making not previously examined, i.e. requests for situational information, as well as for comparison of the decision problem with previously encountered decision situations (described above under Finding 1). The results therefore provide support for Hypothesis 2 which stated that experts will focus on processes involved in situational assessment to a greater extent than non-experts.

Conclusion: Expert physicians focus to a greater extent than non-experts on situational aspects of a patient's case (including greater consideration of evidence contained in a decision problem) in developing an assessment of the patient's particular circumstances and overall state. The results provide support for theoretical accounts emphasizing the role of situation assessment in decision making by experienced decision makers.

Finding 3: Intermediate Effect for Generation of Diagnostic Hypotheses and Choice of Investigation

It was found that intermediate level subjects (i.e. residents) generated more diagnostic hypotheses and considered more choices for investigations than experts and novices. Furthermore, the diagnoses considered by residents often belonged to differing disease categories. In addition, it was found that the investigations chosen by residents were often extraneous in that they overlapped in terms of the information they could provide. One would generally expect performance to improve with greater training, however, in considering the reasoning patterns shown by the intermediates, this is not necessarily the case. This non-monotonic learning curve, characterized by a developmental pattern shaped either like a U or an inverted U is a phenomena which has been reported for aspects of diagnostic reasoning (Patel & Groen, 1991a; Patel & Groen, 1991b; Schmidt, Norman, & Boshuizen, 1990). In this thesis, this finding of an intermediate effect has been shown to hold for generation of diagnostic hypotheses and has been further extended to consideration of cognitive processes typically considered within the study of decision making, i.e. choice of investigation. Previous research has focused on this effect in diagnostic reasoning processes, while analyses from this thesis have considered the intermediate effect across both reasoning and decision making in determining if parallels exist. From a theoretical perspective, the intermediate effect may be considered a result of stages where one's knowledge may go through phases of re-structuring, where decrements in performance and misconceptions may arise when new bodies of knowledge are first acquired (Patel & Groen, 1991b; Lesgold et al., 1988). In this thesis, the intermediate effect has been shown to be robust in that it has been demonstrated for cognitive processes involved in both diagnostic reasoning and therapeutic decision making. These findings provide support for Hypothesis 4 which stated that an intermediate effect will be found for both reasoning and decision making.

From a particular theoretical perspective, experts can be seen as possessing knowledge structures known as "small worlds", which are hypothesized as consisting of small subsets of closely related disease categories and the critical features which most clearly distinguish among them. By focusing on such small worlds experts may be able to constrain the number of diagnostic hypotheses they consider at any one time and choose a limited number of investigations to distinguish among them (Kushniruk, Patel, & Marley, 1998). In contrast, the hypothesis sets of intermediates are larger, and contain diagnostic hypotheses from categories which are difficult to distinguish among, although they may contain overlapping features. In contrast, students, having less knowledge of disease categories and investigations, consider fewer diagnostic and therapeutic choices than intermediates. However, unlike experts, students lack extensive medical knowledge, which can result in consideration of highly unrelated diagnostic hypotheses and investigations.

Conclusion: Intermediate subjects (i.e. residents) generate more diagnostic hypotheses and choose more investigations than either novices or experts. Thus, the intermediate effect has been shown to hold for critical aspects of both medical reasoning and decision making. The results are also consistent with an explanation of the effects of expertise based on the notion of "small worlds".

Finding 4: Differences in Confidence in Judgment

Subjective ratings of subjects' confidence in their decisions were found to increase with increasing expertise, as was predicted. For example, residents' ratings of mean confidence for the six different types of cases were consistently higher than those of the students. Likewise, the mean ratings of confidence of experts were consistently higher than those of the residents. These results suggest that strategies employed in coping with complex and potentially anomalous evidence may be related to the decision maker's level of confidence, i.e. with the experts' high level of confidence being associated with strategies involving ignoring or rejecting anomalous evidence. In contrast, subjects with the least confidence in their decisions, i.e. students were most likely to immediately apply the anomalous evidence in decision making. Thus, expert strategies involving rejecting anomalous evidence appear to be associated with a high level of confidence. This interpretation is consistent with findings reported by Patel and colleagues that show that for cases within their domain of expertise, expert physicians use data-driven forward reasoning, a strategy that requires a good knowledge of the problem domain and a certain degree of confidence (Patel, Groen, & Arocha, 1990).

As indicated in the previous chapter, differences were generally negligible across different types of cases within groups, i.e. within subjects of the same level of expertise. Thus, predicted differences in confidence for cases containing consistent evidence and cases containing inconsistent evidence were not found. However, for all three levels of expertise, cases characterized by conflicting evidence resulted in more variation in actions chosen than for cases where the evidence was consistent. Thus, even though ambiguous cases resulted in a wider range of decisions, within levels of expertise, subjects' mean confidence for these cases was similar to that of cases where evidence was consistent.

From a theoretical perspective, this appears to be potentially related to an overconfidence bias. For example Baumann, Deber, and Thompson (1991) describe two studies, one in the area of physicians' treatment of breast cancer and a second study of intensive care nurses, where although individual subjects were highly confident they made the right choice (referred to as 'micro-certainty'), there was no consensus across subjects when they were asked what the optimal treatment would be (termed 'macro-uncertainty'). In the context of emergency medicine, it may be necessary that decision makers be confident enough to act rapidly since lack of decisiveness could prove to be extremely dangerous. In the present thesis, it appears that a similar phenomena may apply. There are a few exceptions to this pattern, however, including results indicating that lower confidence levels were observed for student responses to cases involving intermediate probability lung scans, perhaps indicating a lack of exposure to such situations by students. Furthermore, it might be expected that by having only limited experience in the intensive care environment, students might be less susceptible to this type of potential bias. Further research will be needed in order to determine to what extent exposure to the demands and constraints of the intensive care environment may affect confidence in decision making.

Conclusion: As expertise increases, so does confidence in intensive care decision making. Although actions chosen for dealing with ambiguous cases vary considerably, subjects' subjective assessment of confidence for those cases is similar to their confidence for cases where evidence is more consistent. This suggests a possible dissociation between ambiguity of evidence and subjective confidence in decision making. The results further suggest that strategies used for dealing with anomalous evidence are related to level of confidence in decision making.

Finding 5: Differences in Description of Likelihood

The analysis of subjects' responses regarding how likely they considered their diagnoses to be correct revealed differences between medical students and practicing physicians (i.e. residents and experts). The majority of descriptions of likelihood from medical students consisted of quantitative expressions (i.e. with likelihood most often represented as percentages). In contrast, both residents and experts used quantitative (typically percentages) as well as qualitative descriptors of likelihood with approximately equal frequency. This result did not support Hypothesis 6, which stated that all levels of subjects would use predominantly qualitative descriptors of uncertainty, as opposed to numeric estimates. This prediction was based on previous research which argued for the importance of qualitative representations of uncertainty in medical reasoning (Kuipers, Moskowitz and Kassirer, 1988). Kuipers and colleagues had found that the pulmonary physicians they studied considered only symbolic descriptions of uncertainty, with numeric representations not being observed. In contrast, findings from the present study indicate that physicians used both quantitative and qualitative descriptors of uncertainty approximately equally. This difference in findings is perhaps due to the nature of the medical cases used in the present study, which contained both quantitative and qualitative sources of evidence that would be needed to be considered and integrated by the subject into their assessment of diagnostic likelihood. As such, the task conditions in the present study are quite representative of many situations encountered in medical practice, that involve both quantitative test data and qualitative clinical evidence. Another finding emerging from this thesis is the observed difference in description of likelihood across levels of expertise, specifically the finding of increased use of qualitative descriptors by physicians as compared to the students (previous studies on the use of descriptors of likelihood in medical problem solving have not examined differences across these broad levels of expertise).

The empirical findings from this thesis regarding differences in description of likelihood (particularly the use of both qualitative an quantitative descriptors by practicing physicians) provide support for a theoretical proposal put forth by Fox and colleagues (Krause, Fox, & Judson, 1995) who have developed a framework for cognitive modeling which allows for medical reasoning involving both quantitative and qualitative arguments, using a hybrid approach to reasoning under uncertainty. This is in contrast to the majority of models of uncertainty which have focused more exclusively on expression of likelihood involving quantitative values. These results regarding subjects' description of likelihood can also be interpreted in light of findings from studies conducted by Patel and colleagues (Patel & Groen, 1991), which indicate essential differences in expert physician's representation of medical problems as compared to the representations of non-experts. These studies indicate that physicians represent medical problems at a higher level of abstraction (involving predominantly qualitative representations) than students.

Conclusion: Differences exist between medical students and physicians in their description of uncertainty regarding medical diagnoses. Specifically, medical students use predominantly quantitative descriptors, while residents and experts use both qualitative and quantitative descriptors with approximately equal frequency, suggesting a shift from quantitative representations to a more mixed consideration of likelihood involving both quantitative and qualitative representations.

5.2 Relevant Issues and Implications

The study of expertise has led to considerable insight into the nature of expert performance in a variety of domains, providing support for a general theoretical account of expertise (Ericsson & Smith, 1991). This includes findings of fundamental differences in the knowledge-based strategies used by problem solvers of varied levels of expertise, as well as essential differences in problem representation across levels of expertise. General as well as domain-specific aspects of expertise will be considered below in light of the findings from this thesis. The results provide support for a number of aspects of decision making and expertise which have been described in the literature. In addition, research from this thesis has also led to a number of findings which require an extension and refinement of existing theoretical perspectives.

This section begins with an explanation of the findings in the context of the strategies employed by subjects of each of the three levels of expertise. This is followed by consideration of the relation and impact of the results to both general and domain-specific aspects of the study of expertise.

5.2.1 The Role of Expertise in Coping with Anomalous Evidence: A Theoretical Account

An explanation of the findings from this thesis requires consideration of critical aspects of decision making, including situation assessment, as well as aspects of reasoning involving strategies for processing evidence. Consideration of the interrelation between these two processes can provide a basis for understanding the major findings in this thesis. In general, three types of strategies were applied by subjects: 1) focusing on the clinical evidence to the exclusion of anomalous evidence, associated with higher levels of confidence in decision making, 2) considering the anomalous evidence but deferring decision making, and 3) interpreting and applying the anomalous evidence immediately. Specifically, in order to account for the results, the following hypothetical explanation is proposed in terms of strategies applied by subjects of each level of expertise:

1. **Experts:** Through development of a coherent situational assessment of a patient's circumstances and overall clinical presentation, the expert, particularly for familiar cases, would be expected to be less influenced by individual pieces of evidence that contradict the expert's assessments of the patient's clinical condition. By focusing on situational aspects of a case, the expert would be expected to develop a broadly based schema for representing the specific aspects of a patient's problem as a whole. This interpretation is also consistent with the work of Leprohon and Patel (1995), who found that accuracy of decision making by nurses in telephone triage was related to nurses' "holistic" assessment of the medical emergency. In the present study, although experts appear to focus on developing more detailed patient assessments (which would presumably lead to development of an elaborate situational schema, which they could fall back on if difficulties arose) for very complex cases containing high levels of ambiguity, they occasionally employed recognitional strategies (i.e. comparison to a previously encountered decision problems). This result may also be considered to be similar to Leprohon and Patel's (1995) finding that although nurses' understanding of the decision problem was related to accuracy in decision making, recognitional rules may be used by nurses in telephone triage in coping with high levels of urgency. In light of strong evidence in favor of a

preferred hypothesis or interpretation, backed by a more elaborate schema of the patient's particular situation and greater emphasis on evaluation of overall evidence, it would be expected that an expert decision maker will be less likely affected by any single piece of anomalous evidence. From the results of this thesis, this appears to be the case for expert physicians, who place emphasis on understanding the state of the decision problem in terms of the global evidence, integrated with understanding of situational factors. The high degree of confidence displayed by experts in their judgment would likely result from application of this type of strategy, where the expert could be expected to be right for most cases and by "explaining away anomalous evidence" still be left with a coherent explanation. However, as will be discussed, this could potentially lead to specific types of errors in judgment.

2. Residents: Analyses of the protocols indicate that intermediates (i.e. residents) appear more focused than experts on generating diagnostic hypotheses and developing a plan of action. Rather than focusing on initially developing an overall assessment of clinical evidence in conjunction with situation assessment, residents' strategies were quite different. Residents, after briefly reviewing the data given in the problem, immediately focused their attention on consideration of specific investigations, as well as entertaining numerous diagnostic hypotheses, which may overlap (unlike students whose diagnostic hypotheses were fewer and more dissimilar). Given this approach to handling cases, and findings from this thesis indicating less emphasis by residents on overall situation assessment, they would not be expected to develop as comprehensive a schema as experts. Furthermore, they would not be expected to have integrated clinical evidence with situational information to the same degree as experts. As a consequence, they would be more influenced by individual test results in isolation, particularly when faced with ambiguous situations, as was found to be the case. However, consistent with their reliance on further testing, residents often chose to treat on the basis of the anomalous evidence, but only when further test results were obtained, thus considering the evidence but often deferring the decision. In cases involving ambiguity of evidence this "deferral" strategy (for evaluating anomalous evidence more fully at some later date) might prove effective, provided however, that time constraints permit delayed action.

3. **Students:** Of the three groups, the students appeared to be most influenced by anomalous evidence. In cases involving conflicting evidence, the majority of students chose to treat in a manner consistent with the anomalous evidence, involving each piece of evidence being evaluated somewhat independently of the overall clinical context. The students appeared to place the least emphasis on understanding situational aspects of the decision problem. As with residents, it would be unlikely that students would be able to develop as refined a schema of the patient's problem as that of experts. As a consequence, students would be more likely influenced by individual test results in isolation of a global assessment of the patient's problem, particularly when faced with ambiguous situations, as was found to be the case. However, the students, lacking the knowledge of options and diagnostic possibilities possessed by residents, did not order as many investigations or consider as many diagnostic hypotheses as residents.

According to the above account, different types of errors would be expected to occur from use of the different strategies outlined above. For example, experts, by ignoring anomalous evidence might be expected to make errors of omission, i.e. ignoring a key piece of evidence that should lead to changes in diagnostic hypotheses. Regarding this type of error in reasoning, Norman and colleagues (1992) state that, "As in the case of scientific investigations, rationalizing away discrepant findings to make an overall neat picture is a process that needs to be restrained (p. 355)". On the other hand, non-experts (including students and residents), might not be able to screen out irrelevant information and would be expected to be more likely distracted by processing of potentially irrelevant cues (errors of addition), which is consistent with findings reported by Lesgold and colleagues (1988) who found that non-expert physicians interpreted features of a radiographic image quite literally even though they might have been artifacts. These specific predictions, based on the results of this thesis, constitute an area warranting further investigation, as will be described in a subsequent section of this chapter.

In the present thesis, the presence of anomalous evidence has been shown to be related to distinguishable differences in strategies for coping with decision ambiguity. Furthermore, analysis of experts' protocols revealed shifts in strategies of some experts from analytical processes involving explicit evaluation of evidence, to recognitional processes based on comparison of situations. In addition, task conditions characterized by conflicting evidence were associated with differences in strategies for processing anomalous evidence across levels of expertise. From a theoretical perspective, there are a number of possibilities for coping with anomalous evidence ranging from ignoring the evidence to applying it in problem solving and decision making (Chinn & Brewer, 1993). In this thesis, clear differences across levels of expertise were found regarding how anomalous evidence was dealt with.

The results from this thesis extend the findings of Arocha, Patel and Patel (1993) who identified differences in strategies for dealing with anomalous evidence by medical students, with some students re-interpreting evidence to fit their hypotheses, while others generated concurrent hypotheses to account for different sets of data. The finding of differences in strategies for dealing with anomalous evidence has been considerably extended in this thesis to include identification of differences in subjects' strategies across broad levels of expertise, including medical students (novices), residents (intermediates) and expert physicians. The responses of subjects of varied levels of expertise to conflicting evidence can be considered as heuristic approaches for simplifying complex decision problems. In complex decision situations in intensive care, it would be expected that the professional, as well as the student, must adopt particular strategies in order to be able to act, and to do so with confidence. It would also be expected that differences in training and experience would lead to distinguishable differences in strategies across levels of expertise. The results of the present thesis provide support for this and extend theoretical accounts of medical expertise by characterizing the effects of task features including ambiguity of evidence on reasoning and decision making processes.

Based on the results of this thesis, it can be argued that processes involved in experts' evaluation of evidence are closely related to the development of their assessment of the particular patient problem. From the research described in this thesis, it is proposed that understanding of the role of expertise in allowing experienced decision makers to deal with decision complexity, including anomalous evidence, requires consideration of the integration of the following interrelated processes: (a) *global situation assessment*, involving development of a problem representation (or schema) specific to the particular patient and circumstances (which may involve recognitional or analytic strategies), and (b) *evaluation of evidence* (including consideration of anomalous evidence) in the context of the expert's continually evolving schema. These processes could be expected to cycle throughout the problem solving and decision making task, and may be based to varying degrees on comparison to previous cases, depending on factors such as urgency or presence of conflicting evidence. An emphasis on processes involved in evaluating and critiquing evidence in light of the expert's overall situation assessment and problem representation is critical according to this perspective. For non-experts, approaches to coping with ambiguous decision situations appear to be more related to the evaluation of anomalous data as relatively independent sources of evidence, from a probabilistic perspective. In particular, students (and to a lesser extent residents) do not appear to develop a broadly-based understanding of the overall decision problem before attempting to arrive at diagnosis and treatment decisions. Further research will be needed to test and develop a detailed model of decision making proposed in this thesis for explaining expert as well as non-expert approaches to decision making involving complex and potentially ambiguous evidence. However, the work from this thesis provides an important step towards explicating such an understanding.

5.2.2 Relation to Theoretical Perspectives From the Study of Expertise

In the study of expertise, a number of findings have been reported across many domains which have considerable implications for developing general theoretical accounts of skilled performance. The relation of the findings from the present thesis to some of the major aspects of expertise will be considered, as well as a discussion of findings of particular relevance to extending theoretical accounts of medical expertise will be presented.

(a) Relation of Findings from the Current Thesis to General Aspects of Expertise

The findings from this thesis indicating greater focus by experts on the overall decision problem and situation assessment can also be considered to parallel, and extend results which have emerged from the cognitive science literature in the study of expertise in problem solving. Specifically, previous studies have found that experts focus more attention on building up a basic problem representation before attempting to solve a problem (Chi, Glaser, & Farr, 1988). In the context of decision making, the experienced decision makers' emphasis on obtaining refined situational information appears to be consistent with findings indicating greater emphasis on development of a problem representation or schema by expert problem solvers. According to Glaser and Chi (1988): "Protocols show that, at the beginning of a problem-solving episode, experts typically try to "understand" a problem, whereas novices plunge immediately into attempting to apply equations and solve for an unknown". The results from this thesis have extended this understanding to incorporate the more specific concept of situation assessment (emerging from decision analysis) as being a key element of this phenomena in expert reasoning. From the results of this thesis, it is argued that the expert works towards integrating specific situational understanding of the particular decision problem they are facing in conjunction with a global assessment of available evidence in developing an coherent schema of the decision problem.

A classic finding from the general literature on expertise indicates that experts perceive large meaningful patterns in their domain (Ericsson & Smith, 1991). In the context of the current thesis, it appears that expert physicians are able to take a complex decision problem and extract a global picture, based on the overall body of clinical evidence. Experts work towards developing an understanding of the patient problem through consideration of as many aspects of the problem as possible. This is reflected in both the experts' emphasis on developing an understanding of specific details of the patient's situation, as well as by the expert's greater consideration of evidence overall in attempting to confirm, as well as disconfirm diagnostic hypotheses. Thus, the experts clearly attempt to develop an understanding that incorporates a larger number of elements than non-experts - although having done so, they may be more likely to ignore or reject individual pieces of evidence that contradict a large global pattern.

A major finding that extends across a number of domains and provides support for general aspects of expertise is that of characteristic differences in the reasoning strategies of problem solvers of varying levels of expertise. In the area of medicine, one of the most significant findings is that experts employ forward reasoning in routine medical cases, i.e. they reason from data towards conclusions (Patel & Groen, 1991a). In contrast, non-experts have been found to employ backward reasoning, from diagnostic hypotheses back to data. In general, findings of differences in directionality of reasoning have been found in many specific domains (Chi, Glaser, & Farr, 1988). An understanding of the conditions under which differences in expert and novice strategies hold, as well as conditions under which they break down, is of considerable importance in elaborating and advancing theoretical perspectives. For example, research by Patel, Groen and Arocha (1990) has indicated that under conditions of high task complexity, use of forward reasoning by experts may be disrupted. Furthermore, experts may employ backward directed reasoning for complex cases requiring explanation of non-salient cues (i.e. evidence that cannot be linked to the main diagnosis of a case). To some extent, these non-salient cues, or "loose ends" can be viewed as being similar to anomalous evidence (although they may not necessarily contradict preferred hypotheses) in that they result in shifts in cognitive strategies. Furthermore, even though experts may apply pattern-directed forward reasoning, when asked to provide detailed explanation of reasoning, or when faced with complex data, they are able to effectively employ backward reasoning strategies in overcoming impasses and providing explanations that are more coherent and tightly integrated than those of non-experts (Patel & Groen, 1991a). In comparison, explanations given by non-experts of their reasoning are often characterized by disjointed components indicative of lack of overall understanding of the medical problem, in particular indicating a lack of understanding of situational aspects as they relate to underlying pathophysiology.

These findings from the literature on medical expertise have some important parallels to findings emerging from the current work. In this thesis, although experts applied recognitional strategies (which is consistent with studies indicating experts' greater ability to rapidly recognize meaningful patterns - Ericsson & Smith, 1991), they generally focused greater effort than non-experts on developing an understanding of the overall decision problem in the context of the particular patient, prior to actually entertaining diagnostic hypotheses and treatment options. Thus, even though experts may ultimately apply recognitional processes or simple heuristic rules (e.g. regarding processing of anomalous evidence) for complex problems, they generally analyze the decision problem more carefully than non-experts (as reflected by the findings from the present study of more frequent consideration of the overall clinical evidence by experts in conjunction with greater consideration of situational factors). Thus, consistent with the findings described above regarding diagnostic reasoning in medicine (Patel & Groen, 1991a), a greater focus on problem analysis (specifically situation assessment) would allow experts to deal with non-salient cues, anomalous evidence and other perturbations encountered during reasoning and decision making. Furthermore, it can be argued that this pre-decisional processing is reflected in the highly coherent explanations of diagnostic reasoning provided by experts, which has been reported in studies examining reasoning in medical diagnosis (Patel, Groen, & Groen (1997).

(b) Relation to Studies on Expertise in Medical Decision Making and Reasoning

To date, the majority of studies in medical cognition have focused on diagnostic reasoning processes, with fewer studies having examined cognitive processes of varying levels of expertise during therapeutic decision making. Indeed, the explication of cognitive processes (including identification of heuristic strategies for dealing with complex evidence) and the role of expertise in the process of therapeutic decision making constitute research areas that have remained to be more fully explored. Furthermore, the implications for consideration of both diagnosis and treatment together are considerable as many of the medical situations actually encountered in medical practice involve elements of both types of cognitive processes. The present thesis extends the body of research conducted in the analysis of expert-novice differences in diagnostic reasoning to include consideration of both reasoning and therapeutic decision making processes (as derived from both literatures). For example, previous studies examining case ambiguity in medicine (e.g. Patel, Arocha, & Patel, 1993; Lesgold et al., 1988; Norman et al., 1992) have focused on how anomalous evidence affects generation of diagnostic hypotheses. In the present thesis this has been extended to consideration of strategies (across broad levels of expertise) for coping with anomalous evidence for realistic tasks involving both diagnostic reasoning and therapeutic decision making.

Research in medical decision making has typically examined decision making from a different vantage point than research in the area of medical reasoning and problem solving. Indeed, the large majority of studies of medical decision making have involved a decision making and judgment perspective where a subject's decisions are contrasted with a normative model, based on probability theory indicating optimal choices under conditions of uncertainty (Elstein, 1988). In contrast, the problem-solving cognitive approach has focused on describing cognitive process in reasoning tasks, applying protocol-analytic methods and leading to development of cognitive models of performance (Ericsson & Smith, 1991). Thus, although conceptually similar, decision making and problem solving have traditionally been studied using different research paradigms. In the current study of complex decision making, the problem solving nature of the decision makers' approaches were readily apparent. Interspersed throughout consideration of choices regarding aspects of therapy, subjects spent a great deal of effort in considering diagnostic hypotheses and developing explanations of the patient's underlying problem, as evidenced by the considerable percentage of coded segments related to generation and evaluation of diagnostic hypotheses in the context of the decision problem. Furthermore, the nature of the decision problems presented to subjects were ill-defined in that a diagnosis was not provided and treatment options were not already given, as is the case in much decision making in intensive care situations. Under such task conditions, it would seem reasonable that there would be a close relationship between what has traditionally been considered problem solving and decision making. In contrast to the use of experimental tasks where the options are presented to subjects, in the present study, problem solving processes had to be invoked in order to narrow the decision problem space. Thus, cognitive processes involved in hypothesis testing and explanation were found to be closely related to the generation of decision options and selection of alternative actions.

In this thesis, the "expertise approach", involving the use of realistic tasks and experienced subjects, in a controlled laboratory setting, has successfully led to a characterization of different strategies used in coping with complex decisions. Along these lines, important links are being made between research in decision making and work in related areas such as human problem solving and human expertise. A convergence of both methodological approaches and theoretical frameworks shows great promise for increasing understanding of the complexities involved in decision making. An important step has been made in this thesis by applying methods used for the study of reasoning and problem solving in the context of complex intensive care decision making, involving cases of varied complexity. However, further work will be needed in order to more fully characterize the "conditions of applicability" under which findings from the study of decision making and reasoning hold when considering real-world complex problems.

5.2.3 Relation to Cognitive Models Emerging from Naturalistic Study of Decision Making

An objective of the current thesis, as stated in the Introduction, was to consider the results of the thesis in the context of theoretical models which have recently emerged from the study of decision making in complex domains. In considering the relation of findings from the present thesis with perspectives emerging from the naturalistic study of decision making in real-world settings, a number of parallels can be identified. For example, an emphasis on pre-decisional cognitive processes involved in interpreting the state of the decision problem (Endsley, 1995), has been implicated as being an important aspect of decision making in real-world settings (Leprohon & Patel, 1995; Zsambok, 1997). In situations such as fire fighting and intensive care medicine, decision problems are often ill-defined and considerable cognitive effort may need to be invested in analyzing the state of the decision problem (including comparison to previous situations) prior to selection of decision alternatives. It has recently been argued by a number of researchers that traditional laboratory-based analyses of decision making have not typically taken into account aspects of decision making that are of considerable importance when considering real-world contexts (Zsambok, 1997; Cannon-Bowers, Salas, & Pruitt, 1996). For example, it has been argued that since most real-world decision problems are ill-defined and may require considerable analysis of the problem state prior to actual generation and testing of choice alternatives, the emphasis of traditional decision research on the "decision event" (i.e. a hypothesized point in time when the decision maker selects from a given set of alternatives) may be unrepresentative of decision making in many domains.

In the study described in this thesis, an attempt was made to conduct an experimentally controlled study of decision making that took into account both varied levels of expertise of the decision makers (having training and experience in the problem domain), as well as varied task conditions, in terms of complexity of evidence. Furthermore, the tasks were realistic in that subjects were presented with the type of information they would normally receive in medical practice, and were not presented with "given" choice alternatives. Rather, the subjects needed to assess the decision problems in terms of reasoning processes (in generating diagnostic hypotheses) as well selecting a course of action. Thus, an attempt was made to balance the advantages of controlled laboratory study, which allow for experimental examination of varied task conditions (e.g. allowing for study of responses to cases containing systematically varied levels of ambiguous evidence), with use of complex decision problems which have considerable meaning for subjects who are also invested with various levels of prior knowledge and expertise relevant to the task.

Under the experimental conditions in the present thesis, it is significant to note that findings are in a number of important respects consistent with (but also extend, as described in the next section) cognitive models which have emerged from naturalistic studies of decision making. These include findings of an emphasis on situation assessment by experts and use of recognitional strategies, which have been implicated as central aspects of experienced decision making from naturalistic study in domains such as fire fighting and process control (Klein, 1993). In contrast to many models of decision making which have emerged from traditional laboratory study, where decision making has typically been considered in the context of concurrent deliberation and consideration of decision alternatives and attributes (Slovic, Lichtenstein, & Fischhoff, 1988), several recent models have argued that experienced decision makers routinely apply heuristic strategies to simplify decision making (Howell, 1993), which is also consistent with certain findings from the judgment and decision making literature indicating that expert judgments lack the complexity that might be expected from superior decision makers (Shanteau, 1988). Along these lines, the findings from this thesis provide some support for several recent theoretical models of experienced decision making which stress the experts' use of simplifying strategies, recognitional capabilities, as well as emphasis on developing a situational understanding of problems before attempting to solve them.

5.2.4 Proposed Extensions to Existing Cognitive Models of Expert Decision Making

Findings from the present study also emphasize the need to extend and refine emerging cognitive models of expert decision making. For example, according to recognitional models of decision making (Klein, 1993), expert decision makers initially develop an assessment of the decision problems they face and then compare the assessed situation to memory for previously encountered situations (modifying and enacting strategies that worked in the past). Such models may account for decision making based predominantly on prior experience, particularly under conditions of high urgency or high levels of decision complexity, where recognitional processes would be expected to be more frequent (which is consistent with the findings from this thesis regarding experts' comparisons to previous cases). The focus of such models on the experts' consideration of situation assessment is also consistent with findings from the present thesis indicating the experts' emphasis on situational aspects of the particular decision problem and patient they are faced with. However, the results from the present thesis also indicate the importance of cognitive strategies involved in explicit evaluation of evidence and critiquing of possible hypotheses and plans of action. Specifically, the results of the thesis suggest a closer relationship between processes involved in situation assessment and subsequent evaluation of evidence (in coping with ambiguity by experts) than has previously been considered.

In the present study, experts, as well as non-experts were found to demonstrate shifts in strategies for coping with differing levels of complexity. For example, for the most complex cases (i.e. containing contradictory evidence) experts sometimes applied recognitional strategies. However, for other cases characterized by a high level of ambiguity of features (as well as for less complex cases) decision making by experts typically involved explicit consideration of evidence for and against diagnostic hypotheses and treatment plans. Residents also showed shifts in decision strategies as complexity changed, for example resorting to deferring decisions (i.e. stating they would wait for further results before treating) when faced with anomalous evidence. To some extent, shifts in strategies (e.g. experts use of comparison to previous cases when complexity increases) can be accommodated within a theoretical framework which allows for decision processes to move between recognitional processes and analytical processes as the task requirements and cognitive demands change. From this perspective, an essential factor in the development of expertise is the coordination between recognition and inference in coping with problem complexity, particularly in expert decision making.

5.2.5 Implications for Education

The research described in this thesis has implications for professional training and research in education in general. Understanding the role of experience and expertise in complex decision making can provide considerable insight into how physicians make daily decisions. This knowledge can be used to help identify and critique strategies currently being used by decision makers of varied levels of expertise, as well as to help develop better strategies for training both students and practitioners and for updating both their knowledge and practices. Training of physicians could benefit from education in use of more effective strategies, as well as for making decision makers aware of the range of possible approaches that might be taken, along with the potential risks and benefits associated with each type of strategy. Thus, strategies and practices that currently affect complex decision making on a daily basis (in particular approaches to dealing with anomalous evidence) but that are now not known or fully understood, can be explicated in order to lead to open discussion of practices and potential improvement.

In considering developmental aspects of expertise, findings from the current thesis have indicated an intermediate effect for both reasoning and decision making processes, where intermediates choose more investigations and generate more diagnostic hypotheses than either students or experts. The analysis of protocols of intermediate level subjects indicated that they often order superfluous investigations that overlap in terms of information provided, and the diagnostic hypotheses that they consider often belong to widely differing disease categories, making differentiation among diagnoses difficult. These findings suggest that training needs to be targeted at improving the intermediate level physician's discriminatory abilities in selecting among both medical investigations and diagnostic hypotheses. From a theoretical perspective, the present study has extended consideration of the intermediate effect from diagnostic reasoning to processes involved in choice (Patel & Groen, 1991b). It further extends this line of work by describing how specific choices of intermediates differ from novices and experts in terms of informational content and the overlapping of information that makes choice discrimination difficult. Along these lines, training could be targeted at providing students, as well as intermediate level physicians, with education explicitly aimed at promoting effective strategies for selecting among potential investigations in order to obtain the most useful information for discriminating among hypotheses without leading to overlapping or redundant test results.

The results of this thesis indicate that training may also be needed for both students and physicians in coping with ambiguous decision situations, particularly in the interpretation of potentially anomalous evidence from tests (such as lung scans), for which statistical interpretations are often provided independent of the patient's particular situation and for which textbooks typically provide little assistance. Exposure of students as well as physicians in continuing education to a large number of diverse clinical situations, such as those used as stimulus materials in this thesis, could be employed in training for eliciting discussion and explication of possible approaches to dealing with situations that are not classical textbook cases, but which frequently occur in real medical practice. In addition, the present findings have important implications for medical curricula, suggesting that students need to be exposed to cases explicitly containing both consistent as well as conflicting evidence of systematically varying degrees. This could be extended to computer-based training using a case-based approach to presentation of decision situations (Kolodner, 1993), selected from task analyses (Gordon & Gill, 1997) in conjunction with cognitive analyses of decision making such as that described in this thesis.

Integration of evidence from anomalous test results was found to lead to a wide range of responses for the same cases, even by expert physicians. Description of the heuristic strategies used by physicians of varying levels of expertise (as described in this thesis) is an important starting point in making the simplifying heuristics actually used by physicians in dealing with anomalous evidence more explicit, thereby allowing for potential critiquing and improvement. The results suggest the need to provide explicit education for dealing with complex situations, requiring integration of evidence of varying degrees of certainty from different sources (including both qualitative and quantitative data). This is an issue of considerable relevance for a wide range of professional domains characterized by complexity of evidence. Further work along the lines described in this thesis could form a sound basis for understanding the types of problems that may occur for students of varying levels of expertise.

5.2.6 Implications for Design of Computer-Based Decision Support

This research has a number of important implications for the design of computer-based information systems to support human cognitive processing and information needs (Kushniruk, Patel, & Fleiszer, 1995b; Kushniruk & Patel, 1998). Along these lines, it has been argued that a closer relationship should be developed between design of such systems and cognitive research in medical reasoning and decision making. Although improved computer-based support of complex decision making will require a greater understanding of the cognitive processes of potential users of those systems, the identification and extraction of knowledge needed for developing decision support that adequately meets the cognitive needs of users has proven to be a formidable challenge. In this thesis, it is argued that in-depth cognitive analysis of medical decision making in domains targeted for decision support may be necessary where problem complexity makes conventional systems analysis and knowledge acquisition techniques (e.g. interviews) inadequate. For example, in many complex medical domains (including much of intensive care and emergency medicine) physicians are often not consciously aware of how they cope with decision complexity, their strategies for dealing with uncertain and ill-defined problems, and how factors such as experience and expertise affect their decision making processing and those of their co-workers. In such contexts, scientific approaches to analyzing decision strategies and identifying heuristics, using methodological approaches such as that taken in the present thesis, could be used to assess how complex decisions are handled and how knowledge-based decision support systems can be designed to facilitate and enhance the reasoning of users of varying levels of expertise.

The importance of having an improved understanding of cognitive processes in complex domains such as medicine, as well as other complex real-world domains (Kushniruk & Patel, 1995), includes development of a sound basis for strategically targeting computer systems to provide assistance with decision making tasks and processes that humans find difficult or error prone. Furthermore, in order to develop knowledge-based decision support systems that can provide flexible, context-sensitive support for health care workers (of varying levels of expertise and training), methodologies for understanding and characterizing differences in reasoning and decision making, are potentially extremely useful. Specifically, to assist human decision processes, extensions of the approach presented in this thesis, can be applied in characterizing the following attributes of decision making: (a) the skills that decision makers need to bring to bear on the decision-making process (b) the strategies actually used by subjects of varying levels of expertise in coping with complexity and specific constraints in decision making, and (c) the types of problems encountered by subjects of varying levels of expertise – essential for identifying the problem areas that need to be supported and identifying the nature of effective support for cognitive processing (e.g. the range of strategies that might be taken).

In recent years it has become apparent that the design of computer systems in medicine needs to take into greater consideration understanding of how physicians of varying levels of experience process medical information and make difficult decisions (Kushniruk, Patel, & Fleiszer, 1995b). This is especially relevant in the area of designing decision support systems to facilitate and support the higher level decision making processes of users ranging from novices to intermediates and experts. Despite the considerable amount of effort and research that has previously gone into the development of computerized expert systems and knowledge-based medical decision support systems, these systems have yet to penetrate deeply into practical day-to-day medical use (Shortliffe, 1993). It has recently been argued that research in decision support in general has focused on incorporating the latest of information technology while paying little attention to whether these new support systems are compatible with the psychology of decision makers (Hoch & Schkade, 1996). Knowledge of how evidence is used by decision makers of varying levels of evidence may be critical in the development of effective evidence-based decision support tools in providing relevant and up-to-date sources of information for actual application in daily situations. However, an understanding of how physicians of varying levels of expertise apply evidence in decision making will be critical to the success of such technology in actually changing and improving physician clinical practice. From the analysis in this thesis it was found that there are a number of factors to be taken into account when considering how decision makers of varying levels of expertise evaluate evidence in the context of clinical cases. In particular, a greater understanding is needed of the heuristic strategies that affect use of information in complex situations, especially when computer-based support is attempted. An area of work that is currently underway involves the development computer-based advice and guidelines designed to be tailored to particular clinical situations, including customization of information for particular patients and health care providers (Patel, Kushniruk, & Cimino, 1998).

5.3 Summary Statement - Contribution to Knowledge

The research described in this thesis has contributed to general theoretical understanding of the role of expertise in the psychological study of complex decision making and medical cognition. Firstly, this research has identified fundamental differences in the reasoning and decision making strategies of experts and non-experts in processing complex and anomalous evidence. Differences in strategies were shown in the thesis to relate to level of confidence in judgment as well as the approach taken by the decision maker in assessing the decision situation and integrating evidence. Secondly, the research has identified parallels between findings reported in the literature on reasoning and decision making. Thirdly, the research has contributed to understanding of expert-novice differences regarding confidence in decision making as well as representation of likelihood, leading to a proposal regarding a developmental shift in representation of likelihood.

In terms of cognitive research, a theoretical account was proposed as a basis for developing a model for explaining the role of expertise in complex decision making in the presence of anomalous evidence. From a theoretical perspective, this thesis extends previous work by explicating the role of expertise in complex decision making involving situations containing evidence of varying degrees of complexity and ambiguity. Furthermore, the thesis has provided an explanation of these findings in the context of a coherent theoretical account, leading to a number of testable predictions for future research.

The research from this thesis supports cognitive models focusing on recognitional processes involved in expert decision making. Specifically, the present thesis provides experimental evidence showing the importance of the role of situation assessment in complex decision making and reasoning. Based on the results, this thesis has led to a proposal for extending such frameworks to include greater consideration of reasoning processes associated with evaluation of evidence.

From a methodological perspective, the present thesis extends previous research in the study of expertise by examining use of decision strategies by subjects across broad levels of expertise for coping with conditions of varying levels of ambiguity. By examining both decision making as well as reasoning processes this research succeeded in characterizing the role of medical expertise in dealing with ambiguous and complex decision situations. This methodological approach represents an important step towards understanding the relation between decision making and reasoning processes in complex domains such as medicine. In addition, by employing both qualitative and quantitative analyses in a complementary manner, it was found that the nature of results which emerged from statistical analysis could be examined more closely in the context of qualitative analyses of individual subjects' protocols.

In conclusion, this thesis has made a significant scientific contribution to advancing our understanding of the role of expertise in complex decision making involving conditions of ambiguity and uncertainty. It has led to findings not previously reported and has extended general as well as specific theoretical perspectives. In addition, the research has important implications for the domains of medical education and medical informatics by providing a cognitive basis for design of future training and decision support systems. In summary, the research described in this thesis has contributed in a number of original ways to the advancement of scientific knowledge.

5.4 Limitations and Future Research

There are a number of trade-offs involved in selecting an approach to the analysis of complex decision making. By employing an experimental approach, the advantages include being able to experimentally manipulate factors such as ambiguity of evidence. Furthermore, by developing case scenarios based in part on real patient data and employing subjects invested with expertise and training in the domain of the cases, this approach can be considered to have a certain degree of ecological validity. However, as much as one can attempt to develop realistic decision scenarios, differences will exist between decision making in the laboratory and decision making in the real world settings which are characterized by a number of factors that complicate decision making (Orasanu & Conolly, 1993). Thus, future work will need to be conducted to determine the extent to which findings from the current study apply across broad domains of expertise and different types of naturalistic settings. Recently, it has been argued that there is a need for full cycle research, which iterates from laboratory study to naturalistic research, and back, depending on the research questions posed. In line with this approach, research findings from the present thesis are currently driving the design and study of complex decision making in naturalistic settings, ranging from decision making by physicians in actual clinical care (Kushniruk, Patel, Cimino, & Barrows, 1996) to analysis of patient's understanding and decision making for health care situations involving computer-based decision support (Patel, Kushniruk, & Cimino, 1998).

In order to determine the generalizability of results from the study conducted in this thesis, future work will include similar studies in other domains in medicine (such as emergency and clinical medicine), where the domains themselves will be classified according to characteristics including different degrees of complexity and urgency. This will involve initial task analyses of potential domains to determine their salient features (Vicente & Wang, 1998). In addition, it is planned to conduct similar studies in domains outside of medicine, particularly in complex areas such as economic decision making. By focusing on controlled experimental study, the present thesis has highlighted specific aspects of complex decision making, e.g. strategies for processing anomalous evidence. A number of other factors not examined in the present thesis also warrant further investigation. These include the effects of time constraints, and examination of collaborative processes involved in group decision making and evaluation of evidence. Also, future studies could involve the presentation of anomalous evidence in sequence, to assess how experts will compare the clinical picture against anomalous evidence when multiple tests contradict the clinical picture.

The usage of a limited sample size permitted a combination of both in-depth qualitative and quantitative analysis. Future work in these new domains will be conducted along two dimensions: larger scale quantitative analyses focused on examining selected cognitive processes, and further in-depth study of a limited number subjects in further qualitative analysis of decision strategies and heuristics.

A number of specific research questions which have emerged from the present thesis will be considered for further investigation. This includes studies and analyses targeted specifically at investigating the relation between decision making and problem solving processes. The present thesis has indicated that level of confidence of decision makers is related to type of strategies chosen for processing evidence. Future investigations will be required to ascertain the nature of this relationship. In addition, a potential overconfidence bias in intensive care decision making will need to be explored, as will a proposal emerging from this thesis that there is a developmental shift in representation of likelihood (from predominantly quantitative to qualitative representations of uncertainty). Experimental examination of predictions from this thesis regarding the types of problems and errors that may arise from application of different strategies in coping with decision complexity is another area of interest. Finally, work will continue in examining the relationship between the research described in this thesis and the emerging field of medical informatics.

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APPENDIX A

Cases used as stimulus material

As described in Chapter III, 6 types of cases were used as stimulus material, corresponding to the following levels of clinical and lung scan evidence for pulmonary embolism (PE):

Case Type	Probability Lung Scan	Clinical Evidence
1	Low	Low
2	Low	High
3	Intermediate	Low
4	Intermediate	High
5	High	Low
6	High	High

For each case type, two cases were constructed, leading to 12 cases in total, which were presented to each subject. The cases used are given below:

Case #1 (Case Type 3 - Intermediate Probability Lung Scan and Low Clinical Evidence for PE): A 45 year old school teacher complains of substernal chest pain and mild shortness of breath. She takes an antihypertensive and has been on birth control pills for fifteen years. She smokes one package of cigarettes per day and has done so for years and drinks socially. She denies cough or sputum. On examination she is in no distress. She is mildly obese. Her physical examination is unremarkable except for an increase in her pain on deep breathing. Pulse 90; BP 150/90; Respiratory rate 25; Temperature 37.2 C. HB 10.8; WBC 9.6. EKG shows left axis deviation. Chest X-Ray shows mild enlargement of the cardiac silhouette. A V/Q scan shows a moderate mismatch and is read as an intermediate probability of embolus.

Case #2 (Case Type 2 - Low Probability Lung Scan and High Clinical Evidence for PE): A 22 year old male has just returned from Florida. He drove home, alone, in two days. He awoke with difficulty breathing and coughed up some pinkish sputum. On examination he is acutely distressed and very anxious. Pulse 130; BP 115/80; Respiratory rate 30. His breathing is shallow and deep breathing causes him left sided chest pain. There are rhonchi on the left. His right leg is swollen and tender in both the calf and thigh. His HB 15, WBC 18,000; PH 7.46; PO2 82; PCO2 31. His chest X-Ray shows a small effusion in the posterior sulcus on the left. A V/Q scan is read as normal.

Case #3 (Case Type 3 - Intermediate Probability Lung Scan and Low Clinical Evidence for PE): A 53 year old garage mechanic was working in a cramped position for several hours three days ago. He complains of increasing left calf pain. He has a cough productive of thick yellow sputum, present for one week, and he complains of shortness of breath on exertion. He smokes 1.5 packages of cigarettes per day since he was 15. On examination he is in no distress. Pulse 80; BP 135/85; Respiratory rate 24; Temperature 38.2 C. His breath sounds are audible. There are scattered rhonchi throughout both lung fields. Heart sounds are normal. He has a rather tender cord in the left calf and slight pitting edema at the ankle. HB 132; WBC 18.2; Chest X-Ray shows an infiltrate in the left mid-lung zone. V/Q scan shows a moderate probability for embolus

Case #4 (Case Type 6 - High Probability Lung Scan and High Clinical Evidence for PE): A 72 year old lady, previously well, sustained a fractured femur when she fell off a kitchen stool. She was maintained in Buck's traction for six days at which time she underwent a femoral rodding. In the recovery room, difficulty was encountered maintaining her oxygenation and contained mechanical support was required. The nurse noted there were large amounts of blood stained sputum being suctioned from the ET tube. On examination she was unresponsive. Pulse 100; BP 110/70; Temperature 39.1 C. The incision was clean and there was no evidence of bleeding or hematoma. There were no retinal or subungual haemorrhage and no petechiae. On auscultation breath sounds were diminished on the left and there was dependent dullness to percussion. EKG showed right axis deviation. HB 8; WBC 18,000. Chest X-rays showed multiple infiltrates on the left and a small effusion. A pleural tap resulted in the aspiration of 400 cc of blood-stained serous fluid. FI 102 100%; PO2 85; PCO2 38; V/Q scan showed multiple areas of mismatch with a high probability of embolus.

Case #5 (Case Type 4 - Intermediate Probability Lung Scan and High Clinical Evidence for PE): A 57 year old woman is undergoing treatment for cancer of the pancreas. Five minutes after receiving her radiotherapy she develops retrosternal chest pain associated with shortness of breath. On examination she is thin, shows evidence of recent weight loss and appears depressed. Pulse 100; BP 95/70; Respiratory rate 28; Temperature 38.2 C. On auscultation there is a pleural friction rub and some rales in the right upper lung field. There is a large mass easily palpable in the epigastrium. There is no calf tenderness but there is moderate pitting edema bilaterally. Chest X-Ray shows an infiltrate in the right upper lobe and elevation of the right hemi-diaphragm. HB 8; WBC 22,000; PO2 65; PCO2 35; V/Q scan is abnormal and is read as having an intermediate probability of representing embolus.

Case #6 (Case Type 1 - Low Probability Lung Scan and Low Clinical Evidence for PE): An 18 year old male is brought to the emergency room by his friends at 2:30 am. He complains of sudden onset of substernal chest pain associated with shortness of breath. He has had an upper respiratory infection with cough for ten days. Physical examination reveals a muscular young man who is mildly inebriated and rather anxious but is friendly and co-operative. His pulse is 100, BP 130/80, Respiratory rate: 28, Temperature 37.8 C. On deep breathing he coughs violently and produces a small amount of slightly blood tinged sputum. His chest X-Ray is normal and a V/Q scan shows some minor abnormality with a low suspicion for embolism.

Case #7 (Case Type 4 - Intermediate Probability Lung Scan and High Clinical Evidence for PE): An 82 year old pedestrian was struck by a car 6 weeks ago, sustaining an undisplaced fracture of the left hemipelvis. During her physiotherapy she develops a severe bout of non-productive coughing and has trouble catching her breath. Ten minutes later she remains short of breath and keeps repeating "I'm going to die". Medications include digoxin and Aldomet. On examination she is very agitated and appears terrified. Her lips are cyanotic. Pulse 120 and irregular. BP is 160/90. Respiration shallow and labored and there is audible wheezing. She has scattered rales and rhonchi throughout both lung fields with high pitched wheezing. HB 78; WBC 14,000; PO2 65; PCO2 35. Chest X-ray shows cardiomegaly. Both lung fields are clear. EKG reveals atrial fibrillation. (NSR on admission) and right axis deviation. V/Q scan is assessed as "intermediate probability of embolus".

Case #8 (Case Type 5 - High Probability Lung Scan and Low Clinical Evidence for PE): A 57 year old male, known to have severe chronic obstructive lung disease, has been undergoing treatment for pneumonia as an outpatient. He is admitted for increasing shortness of breath and requires oxygen therapy. He has cigarettes on the bed beside him. On examination, he is in respiratory distress, is sitting up, leaning forward and using his accessory muscles. He is very thin. He coughs frequently during the examination and brings up large amounts of thick, yellow sputum. He has rales and rhonchi normal. There is no calf tenderness or ankle swelling. Pulse 90; BP 110/70, Temperature 39.2 C. Chest X-Ray shows marked hyperinflation of both lung fields with a large infiltrate in the left middle lobe PO2 51; PCO2 48; EKG shows mild ST depression in the right and a mild-moderate mismatch on the left and is read as high probability of embolus.

Case #9 (Case Type 1 - Low Probability Lung Scan and Low Clinical Evidence for PR): A 30 year old business executive has been playing squash. She becomes acutely short of breath and feels faint. On examination she is extremely anxious. Pulse 120; BP 135/75; Respiratory rate 32; Temperature 37.4 C. She has occasional rhonchi with mild wheezing in both lungs. HB 11.1; PO2 130; PCO2 28; PH 7.43; Chest X-Ray normal; V/Q scan low probability.

Case #10 (Case Type 5 - High Probability Lung Scan and Low Clinical Evidence for PE): A 70 year old retired Asbestos worker is admitted for increasing shortness of breath. He has been feeling generally unwell for several weeks and recently lost 10 lbs. He has a dry nagging cough. He denies chest pain, hemoptysis, ankle swelling or calf pain. On examination he is thin and wiry. He is mildly short of breath. Pulse 70 regular; BP 160/90; Temperature 37.2 C. On auscultation there are diminished breath sounds on the right with dullness to percussion. Heart sound are normal. HB 10.2; WBC 7.6; PO2 85;

PCO2 42. EKG shows a RBBB and Q waves in the anterior leads. Chest X-ray shows a moderate pleural effusion. V/Q scan shows a marked mismatch on the right, compatible with a high probability of embolus.

Case #11 (Case Type 6 - High Probability Lung Scan and High Clinical Evidence for PE): A 65 year old man developed severe pneumonia of unknown etiology. He required ventilatory support and was paralyzed for four days. He gradually improved when 10 days later he developed severe pain in the left popliteal fossa and marked swelling of his calf. Three days later he suddenly became short of breath and developed a cough productive of small amounts of blood-flecked sputum. On examination he was agitated and cyanotic. Pulse 130 regular; BP 90/70; Respiration 31 (labored and using accessory muscles); Temperature 38.2 C. On auscultation rales were heard on the right, along with a pleural friction rub. The posterior aspect of his thigh and calf were acutely tender and there was moderate pitting edema around the ankle. Homan's sign was positive. HB 13; WBC 20,000; PO2 63; PCO2 28; PH 7.48. Chest X-ray shows multiple infiltrates on the right with a small right pleural effusion. EKG shows a right axis deviation with occasional VPC's. V/Q scan showed a marked mismatch highly suggestive of embolus.

Case #12 (Case Type 2 - Low Probability Lung Scan and High Clinical Evidence for PE): A 68 year old woman with breast cancer has been on bedrest for three weeks following decompression and fixation of a pathological fracture of the L2 vertebra. Thirty minutes after being sat up in a chair, she develops mild shortness of breath and pleuritic chest pain. On examination she is in no distress, but is apprehensive. Pulse 100; BP 140/90; Respiratory rate 26; Temperature 38.5 C. There is dullness to percussion at the right base and diminished breath sounds on the right side. There is no tenderness or swelling on the legs. HB 9.8; WBC 22,000; PH 7.42; PO2 82; PCO2 37. Chest X-Ray shows a small opacification in the right lower peripheral lung field and a small effusion not seen on her admission files. V/Q scan is normal.