A FEASIBILITY STUDY OF THE APPLICATION OF KNOWLEDGE-BASED SYSTEM TECHNOLOGY FOR PHYSIOTHERAPY CLINICAL DECISION MAKING SUPPORT

BY

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A Thesis submitted to
the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements for the Degree of

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FACULTY OF GRADUATE STUDIES
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"A Feasibility Study of the Application of Knowledge-Based System Technology for Physiotherapy Clinical Decision Making Support"

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Abstract

A feasibility study of the application of knowledge-based system technology for physiotherapy clinical decision making support.

The purpose of this study was to investigate the feasibility of applying knowledge-based system applications (KBS) to support clinical decision making in physiotherapy. The goal was to determine if physiotherapy expertise could be encoded into a KBS to support case management of post-poliomyelitis sequelae (PPS). Knowledge extracted from medical journals and interviews with clinicians was represented with rules. The prototype was evaluated with seven real cases. The knowledge base was validated by three physiotherapists. Physiotherapists and physiotherapy students interacted with the prototype to evaluate aspects such as navigation. The KBS treatment recommendations were comparable with those made by the physiotherapists who had managed the real cases. The knowledge base was deemed comprehensive and accurate. The clinicians and students reach relevant knowledge most of the time. Physiotherapy expertise for case management of PPS can be represented in a functional KBS. Research is needed to study deployment issues.

Acknowledgements

This project would likely never have been started had it not been for the suggestion by Glenn Shlachetka to consider research in AI and his confidence that I could easily master AI concepts and techniques.

The project was enriched by the contributions of members of the physiotherapy community. Many thanks especially to Heather Flaig, Monica Kilfoil, Mary-Ann Klus and the 1992 senior year class of physiotherapy students at The School of Physiotherapy at the University of Saskatchewan.

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Without Dr. Evans, the project would never have evolved beyond the initial prototype. I learned a great deal about modern knowledge-based systems and expert systems due to him.

The assistance and patience of my committee are greatly appreciated. In addition to making an inter-disciplinary project go smoothly, they dealt kindly with the unexpected delays.

The secret of joy is resistance.

Alice Walker

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List of Abbreviations

AI	Artificial Intelligence, described on p. 25.
AIM	Artificial Intelligence in Medicine, the application of artificial intelligence techniques to medical problems, described on p. 25.
Dx	Diagnosis
HPI	History of Present Illness
Hx	History
KBS	For this thesis will be used interchangeably for knowledge-based systems and for expert systems, described on p. 2 and pp. 26-31.
PD	Pull-down menus
POMR	Problem Oriented Medical Record, described on p. 121.
PPS	Post-Poliomyelitis Sequelae, described on pp. 20-21.
RB	Radio button
Rec	Recommendation
TB	Text box
T/F	True or False

Definitions

Clinical Specialist	In health informatics, a person with clinical experience who works on the development of computer applications for use in health care.
Descriptive Decision Support	Focus is on determining how decisions are made.
Face Validation	Subjective comparison of the performance of a knowledge-based system against that of a human expert on a given set of test cases (adapted from O'Keefe, Balci & Smith, 1987, p. 86).
Health Informatics	The application of software in health care.
Heuristic	Rule of Thumb.
How	Series of assertions leading to a conclusion.
Prescriptive Decision Support	Focus is to provide solutions or recommendations.
Validation	Evaluation of a knowledge base for consistency, correctness and completeness by domain experts.
Why	Series of assertions leading to a given point in a reasoning path.

Chapter 1: Introduction

1.1 Statement of the Problem

Clinical decision making in physiotherapy is complex. It involves the integration of patient-specific facts with knowledge about anatomy, physiology, modalities and interventions plus clinical experience. The discipline and its practice are as much art as science.

Clinical decision making is difficult because the knowledge and expertise required for decision making can be inconsistent, incomplete or difficult to access. Additionally, there is limited time and money available for clinicians to search for, acquire and analyze knowledge.

Insufficient knowledge can impact adversely on quality of care (Zimny & Tandy, 1989). Cleather (1995), Sim (1995), Zimny and Tandy (1993), Delitto et al. (1989) and others recognize the need for clinical decision making to be augmented with knowledge from published scientific and medical literature. Delitto et al. (1989) also recognize the need for clinicians to access the expertise of others.

Decision support tools have potential to ameliorate this knowledge deficiency. There are a variety of supports available, some of which are computerized. Computerized decision making aids can be designed to perform tasks such as giving advice, reminding clinicians about special circumstances and managing information or making it more accessible. An example of a computer based decision support tool is the Cochrane Collaboration database of systemic reviews. These are available on CD-ROM and can be accessed via the Worldwide Web.

In the physiotherapy literature, there are few articles describing computerized decision support aids (Dennis, 2000). Problem knowledge coupling, a means to link patient specific knowledge with relevant clinical knowledge to "determine the range of possible diagnostic or management options that the clinician should consider" (Zimny & Tandy, 1989, p. 566), has been proposed as a means to efficiently access case specific knowledge from the medical literature. Hypertext was used to create a desktop application for physiotherapists treating geriatric patients (Moran, 1991).

These approaches may address the knowledge requirements of clinicians; however they can be improved upon. For example, the Cochrane Collaboration database is not designed to accept data about patients and then to yield advice. The clinician must analyze each systematic review for each particular case. Problem knowledge couplers can accept data about patients, but have not been designed to incorporate domain expertise (Zimny & Tandy, 1989).

Knowledge-based systems incorporate human expertise. This knowledge is applied to patient specific data to yield treatment recommendations (Durkin, 1994).

Knowledge-based system technology is a branch of artificial intelligence (AI). AI is an interdisciplinary field that includes computer science and is concerned with designing intelligent computer systems (Durkin, 1994). A knowledge-based system is comprised of a knowledge base and an inference engine. Through a process known as knowledge acquisition, knowledge is extracted from experts and reference materials in a particular field as part of the process of creating a knowledge base. Knowledge acquisition can be lengthy, whether the knowledge is derived from experts (Robertson, 1993), literature (Zimny & Tandy, 1989) or other sources.

During the knowledge representation process, this knowledge is converted into a format that the inference engine can manipulate. There are a number of different representation methods, one of which is rules. Rules consist of If-Then statements that express the relationship between elements (Waterman, 1986).

Knowledge-based systems can be used for many types of problem solving. One problem solving task for which knowledge-based systems have shown success is that of prescription (Durkin, 1994). Knowledge-based systems designed for this purpose help to identify faults or malfunctions and suggest methods to remedy them. For example, a knowledge-based system for auto mechanics might ask a series of questions about possible causes (e.g. dead battery, corroded wires) of a car not starting before suggesting a specific solution (e.g. recharge or replace battery). MYCIN (Shortliffe et al., 1973) suggests anti-biotic interventions. In a blind trial, this knowledge-based system performed better than physicians.

Knowledge-based systems can provide decision support even when knowledge is incomplete and uncertain, as is often the case in physiotherapy decision making. They can be designed to show the path of reasoning taken to reach a recommendation, enhancing understanding and confidence by the clinician. They can increase access to expertise and support standardization of care, both of which have potential to improve quality of care (Durkin, 1994).

A knowledge-based system specifically for clinical decision making support in physiotherapy has not yet been reported. Delitto and colleagues (1989) created a knowledge base for clinical decision making for treatment of low back pain, but did not implement it into a knowledge-based system.

Two computer aided instructional systems, one designed to teach students how to use modalities and the other what questions to ask during patient assessments, have been created. The authors (Stone & Parry, 1991; Dennis, 2000) of both projects speculated that these systems could also be used for clinical decision making support, but did not test them in this capacity for fiscal reasons.

There would be overlap in the knowledge bases of a computer assisted instructional system and a clinical decision making system which both dealt with the same condition. However, the design of each would be distinct. The former system would emphasize student decision correction while the latter would be focused on patient condition correction. Additionally, aspects of a computer aided instructional system that made it suitable for students might render it inefficient for use in a clinical setting. For example, the system described by Dennis (2000, p. 6) "offers no guidance regarding a preferred path through the problem." This design helps students to learn efficient and efficacious clinical decision making through trial and error. In contrast, clinicians need efficient access to recommendations. Additionally, a system for students may need to be more highly granular than for clinicians (who would not require explanation of basic steps).

Post-Poliomyelitis Sequelae (PPS) case management is used as a model to explore the feasibility of the application of knowledge-based systems in physiotherapy, specifically in the provision of clinical decision making support.

1.2 Research Overview

To demonstrate that a clinical decision making support tool could be created using a knowledge-based system approach, rapid prototyping was undertaken. Development was limited to proof of concept and preliminary evaluation of the resultant system.

Physiotherapy case management of Post-Poliomyelitis Sequelae (PPS) cases was selected for the prototype. It was deemed to involve clinical decision making that is sufficiently complex to justify decision support (Holtzman, 1989), while simultaneously being a suitable size in terms of development time and difficultly for a Master's thesis project.

Case management of Post-Poliomyelitis Sequelae is complicated, especially because the pathophysiology of the disorder is unknown. As well, there are not many long term studies on interventions (Dean, 1991a). Post-Poliomyelitis Sequelae can affect all major systems (musculoskeletal, neurological and cardiorespiratory) treated by physiotherapists. Case management could also be delimited to exclude severe respiratory and dysphagic cases without significantly reducing the utility of the knowledge-based system.

Knowledge was acquired by the author from medical literature and a clinician with neurological case management experience. This clinician also had been diagnosed as having Post-Poliomyelitis Sequelae. The author augmented the knowledge base with expertise and materials (e.g. course notes) from the academic and clinical physiotherapists who evaluated the initial knowledge base.

The author represented the knowledge with rules. The prototype was evaluated in three ways. Interactive sessions were held with licensed physiotherapists and physiotherapy students to determine which aspects of the knowledge base and user interface required modification. Secondly, the knowledge base was examined for completeness and consistency by three physiotherapists. Finally, the recommendations of the system for real cases were compared with those of the clinicians managing them. The knowledge-based system prototype performed well on the real cases.

Analysis of the evaluations of the first prototype suggested that the knowledge base and recommendations were adequate but that the interface needed more development.

For the second iteration prototype, the author teamed with computer scientists to explore different development methods. The author combined the best aspects of the first and second iteration prototypes to conceptualize a third iteration demonstration prototype that had potential to address the needs identified by end users.

The result of prototyping was demonstration that a knowledge-based system can be created to support for clinical decision making in physiotherapy for case management of a condition whose pathophysiology is unknown and which can affect several systems simultaneously.

The thesis research focused on development. Research into deployment issues is required to determine if clinical decision making support systems will be adopted by physiotherapists.

1.3 Organization of the Thesis

Chapter 2 describes the domain of physiotherapy. The challenges to clinical decision making faced by clinicians in general and specifically in regards to case management of Post-Poliomyelitis Sequelae are discussed. A brief overview of Post-

Poliomyelitis Sequelae and poliomyelitis is given for those unfamiliar with the disease and the condition.

Chapter 3 provides a discussion of the variety of computerized clinical decision making aids available. The review of related literature that follows highlights the paucity of knowledge-based systems for physiotherapy for either teaching or clinical decision making and the need for further research.

The type of questions usually investigated in physiotherapy research utilize methodologies significantly different from those used in artificial intelligence (AI), the field to which knowledge-based systems belong. In preparation of the discussion of the prototype development described in Chapters 5 and 6, Chapter 4 gives an overview of knowledge-based systems development.

Analysis is integral to knowledge-based systems development, and therefore is included in Chapters 5 and 6. Where this analysis speaks to the thesis problem as well as the project evolution, it is included and elaborated upon in Chapter 7.

Chapter 7 includes an analysis of the prototypes developed with respect to the feasibility of developing knowledge-based systems in physiotherapy. Additionally, research questions arising from the thesis research (e.g. what is an ideal interface for clinicians?) and that could extend it (e.g. what deployment issues must be addressed prior to acceptance of knowledge-based systems practitioners?) are presented.

For those interested in more specific details of the development of the prototypes, the appendices include materials used in the development stages. A bibliography of materials that can be easily accessed that were used in creation of the thesis knowledge base can be found in Appendix A.7.

Chapter 2: Clinical Decision Making in Physiotherapy

2.1 Introduction

This chapter explores the domain of physiotherapy, what is entailed in case management and the challenges involved with clinical decision making in this field. Knowledge-based system software is suggested as a means of providing computerized decision making support. The problem from the domain selected to test this approach, Post-Poliomyelitis Sequelae case management is presented.

2.2 The Domain of Physiotherapy

Physiotherapy (physical therapy) is the health care profession devoted to maintenance or maximal restoration of function and independence for those whose physical health has been or is at risk of being compromised secondary to illness or injury (Rose, 1989; Cleather, 1995). Physiotherapy can be indicated for patients with cardiovascular, pulmonary, neurological and musculoskeletal conditions. Physiotherapy is administered to patients with acute and chronic problems, in hospitals, clinics, schools, chronic care facilities, industries, athletic events. Practitioners are referred to as physical therapists or physiotherapists.

Physiotherapists in Canada must have a Bachelor's degree or equivalent (e.g. diploma plus degree completion). By 2010, a Master's degree will be required to practice. Physiotherapists study first principles from disciplines such as anatomy and physiology. Physiotherapy is both an art and a science (Cleather, 1995). Graduates from different institutions have varying amounts of practical experience. Most graduates write a national exam to be licensed. Physiotherapists work in diverse environments, from large teaching hospitals to small clinics. As well, they may work with several colleagues or as sole charge practitioners.

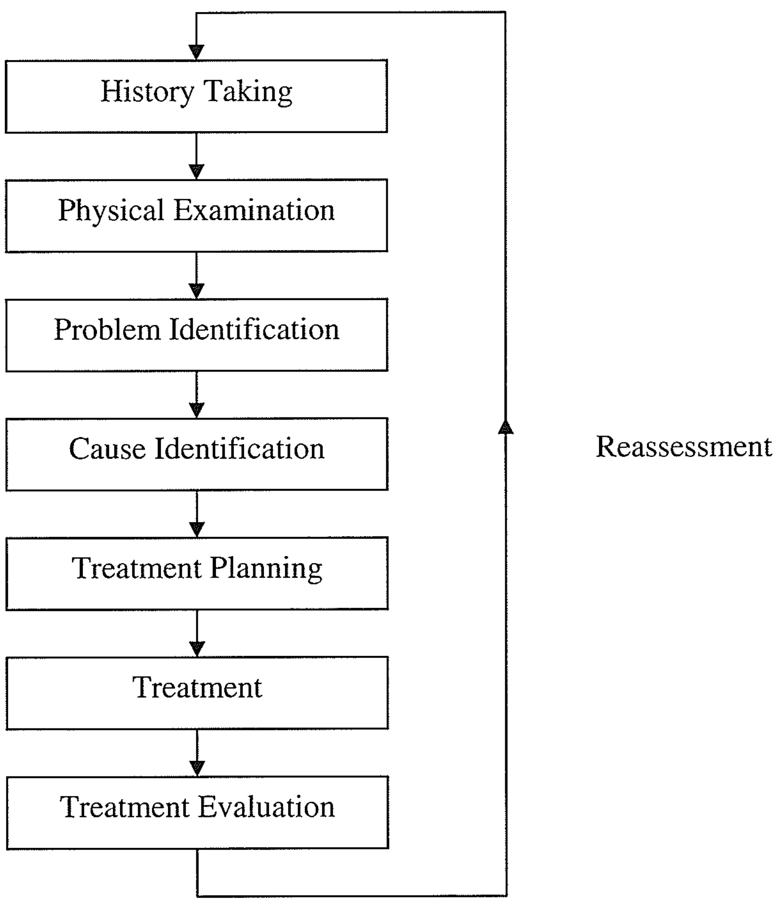
2.3 Physiotherapy Case Management

Case management components include history taking, physical assessment (e.g. strength of the biceps muscle), identification of problems, analysis to determine attendant causes, establishment of short term and long term treatment goals, treatment (e.g. exercises to increase strength, electrical stimulation, mobilizations), evaluation of treatment efficacy, documentation (e.g. chart notes, legal letters), education and interdisciplinary correspondence.

History taking is the process of gathering information about the patient that may assist in determination of problems and appropriate treatments. Data about the patient's present and past illnesses or injuries, medications, social and work responsibilities, recreation or avocational activities, family medical history, and test results are all important. An assessment is essential to collect quantitative and qualitative information about the physical status of the patient (Delitto & Snyder-Mackler, 1995). Anatomical and physiological evidence is elicited from observation, palpation, and testing. Physical examination examples include evaluation of passive, active and accessory joint range of motion, graded strength testing, auscultation, and pulse or respiration rate monitoring.

The physiotherapist analyzes the signs and symptoms elicited from the history and physical examination to identify problems and associated causes (Cleather, 1995). Treatment goals for those problems that are amenable to physiotherapy intervention are recorded. The therapist prescribes treatments that will facilitate goal attainment. Reassessment of the patient's status, treatment goals and treatment efficacy may be repeated several times before the patient is discharged from therapy (Delitto & Snyder-Mackler, 1995), as shown in Figure 2-1: Physiotherapy Case Management Process.

Figure 2-1: Physiotherapy Case Management Process



2.4 Clinical Decision Making in Physiotherapy

Problem solving in physiotherapy involves complex clinical decision making (Watts, 1989) as well as the application of treatment techniques, such as ultrasound or of prevention measures, like bracing. Some patients have conditions that are common, like back strains or knee sprains; others present with relatively rare disorders, such as giant cell arthritis.

It is difficult to be an expert in all areas, although some clinicians specialize in a sub-specialty such as pediatrics, burns, geriatrics, palliative care, or work hardening. Clinicians are constantly taking courses to increase their knowledge and expand their repertoire of skills. In the past, hospitals were able to finance these courses. However increasing costs to send clinicians to courses and to provide substitute coverage while they are away or to bring a qualified expert into the facility, combined with decreasing budgets, have minimized this support. Patients with some conditions (e.g. some pediatric cases in small towns) may have to leave their home for an extended period in order to receive optimal treatment.

Clinical decision making is similar in physiotherapy, other rehabilitation professions such as occupational therapy and speech therapy, and in medicine; there is much overlap in the knowledge (Robertson, 1995) and reasoning strategies used. Problems associated with the collection, analysis and application of information and knowledge can complicate medical decision making, which has been studied by various researchers (Elson & Connelly, 1995; Miller, R.A., 1994; Weed, 1989).

Collecting relevant information and knowledge is not a trivial task: "medical information is complex and extensive" (Friedman & Wyatt, 1996, p.6). There is a large body of scientific literature (Delitto, Shulman & Rose, 1989; Miller, P.L., 1988; Stone & Parry, 1991) and clinical knowledge to search (Miller, P.L., 1986; Miller, P.L., 1988; Gorry, 1984; Shortliffe, 1987). This knowledge base changes continually, sometimes resulting in re-examination of old assumptions (Dennis, 2000). Portions of the knowledge base may be difficult to access because it is presented in a format which does not allow for efficient extraction of clinically applicable knowledge (Elson & Connelly, 1995; Miller, P.L., 1986), has never been explicitly articulated (Stone & Parry, 1991), is shared with only a limited number of people, is expensive to acquire or is physically distant (Elson & Connelly, 1995). Another obstacle relates to the practitioner's experience base; bias (Elson & Connelly, 1995; Coiera, 1997) may constrain his ability to recognize what knowledge he needs to solve the problem (Elson & Connelly, 1995; Miller, R.A., 1994).

The knowledge that has been gathered may not be useful because it is incomplete (Miller, P.L., 1988; Miller, R. A., 1994), inaccurate (Miller, R A., 1994), uncertain (Miller, P.L., 1988; Shortliffe, 1987; Stone & Parry, 1991; Szolovits, 1982), anecdotal, or irrelevant (Elson & Connelly, 1995). In physiotherapy, the "scientific basis for practice is incomplete" (Watts, 1989, p. 569). Dennis (2000, p.3) points out that physiotherapists "do not have an extensive research base on which to base clinical decisions…" and that "[in] spite of an impressive amount of recent research, the sources of probability data are still limited." Models of human systems in healthy and diseased states may be no more than gross approximations of reality (Coiera, 1997). The identity, etiology, or pathogenesis of a disease process is not always known or fully understood (Miller, P.L., 1988). There is often great variability in the presentation of a disease, and more than one disease process may be present simultaneously (Miller, R.A., 1994). The effects of some treatments alone or in combination are unpredictable because they have not been studied and there can be significant variation in the application of techniques and in patient response (Miller, P.L., 1986). Evaluating the quality of the information and knowledge amassed may require more time than is available or acceptable. Because physiotherapy relies greatly on literature from other disciplines (Robertson, 1995), more time may be required to identify salient points for application to case management in physiotherapy.

Applying knowledge and information to a particular case is not always a straight-forward process (Stone & Parry, 1991). As practitioners gain experience in their domain, they may develop heuristics (rules of thumb) that simplify decision making. Due to the large amount of knowledge to which a practitioner is exposed, it may be difficult to retrieve these heuristics from memory when needed (Weed, 1989). As well, many factors, such as patient compliance, the unpredictability of patient response to treatment due to variations in patient characteristics (Watts, 1989) or clinic resources will differ from the known or ideal, necessitating customization for each case.

Other factors such as insufficient funding can negatively impact on clinical decision making and problem solving (Elson & Connelly, 1995; Miller, P.L., 1988; Zimny & Tandy, 1989). Health care budgets may be so limited that support to research databases, to acquire reference materials, to analyze the material located, to contact distant colleagues or to take courses is minimal. As Coiera (1997, pp. 290-291) notes, "while patients may be motivated to seek out the most recent literature for their condition, and can invest considerable effort in that search, most clinicians cannot." Staff reductions can result in decreased diversity of skills and knowledge of a physiotherapy department, and less time for activities other than direct patient care.

The goal of this thesis is to further examine the **tractability** of developing knowledge base system applications, specifically as clinical decision making aids for physiotherapists. The author selected Post-Poliomyelitis Sequelae (PPS) case management, exclusive of rarer complaints (Einarsson, 1991a; Halstead, 1991) such as dysphasia, swallowing impairments which are commonly treated by a speech language therapist, and new breathing problems as the problem for which clinical decision making support would be developed. She developed a prototype that validated the expert system approach and confirmed the "choice of the knowledge representation technique and control strategies" (Durkin, 1994, p. 634), thus demonstrating the **tractability** of this method for clinical decision making support in physiotherapy.

A brief discussion of physiotherapy case management of Post-Poliomyelitis Sequelae, poliomyelitis and PPS is given in the following sections to illustrate the complexity of the decision making associated with this problem.

2.5 Physiotherapy Case Management of PPS

Clinical decision making in the management of PPS cases is challenging (Dean, 1991a). In the absence of complete understanding of the pathophysiology of the Sequelae, physiotherapy management of patients with Post-Poliomyelitis Sequelae must be focused on symptom alleviation (Jubelt & Cashman, 1987), and treatment may be controversial. Patients may present with symptoms in all three major areas of physiotherapy intervention, including weakness, generalized fatigue and decreased cardiovascular fitness. Treatments may include manual therapy or modalities such as transcutaneous nerve stimulation to relieve pain, or education about energy conservation and exercise among other interventions.

Delitto and Snyder-Mackler (1995) note that "physical therapists .... identify clusters of signs, symptoms, symptom-related behavior, and other data from patient history and other testing" to formulate "classifications or diagnoses" that can be used to guide case management. Identification of dysfunctions and their underlying causes is important due to the impact on treatment choices and outcomes. In the management of PPS cases, this process is complicated by a number of factors.

Many therapists are unfamiliar with PPS cases, and therefore have not developed specific expertise for managing them (Dean, 1991b). Some tests, either of historical or current origin are of questionable validity or utility. For example, assessment of strength by manual muscle testing can be inaccurate in this patient population (Agre et al., 1989; Einarsson, 1991a; Perry et al., 1989). As well, some EMG abnormalities and muscle biopsy results are present in both symptomatic and asymptomatic individuals (Einarsson, 1991a; Grimby et al. 1989) who have a history of poliomyelitis infection.

The long term outcomes of some treatments (e.g. Dr. Feldman's exercise protocol) and treatment combinations are not known, are anecdotal (e.g. low level electrical stimulation protocols established by Dr. Pape in Toronto) or inaccurate. Indeed, in some instances (e.g. Dr. Feldman's and Dr. Pape's protocols), there is little or no published rigorous research studies to support efficacy. Additionally, this population can respond to medical, surgical, pharmaceutical and rehabilitation interventions in different ways from the general population (Smith, 1990). Dean (1991a, p.758) states that there is a "scant number of published controlled treatment outcome studies" concerning PPS.

Some authors feel that there may be potential risks of harm to patients as a consequence of some treatments (Dean, 1991b; Einarsson, 1991a; Jubelt & Cashman, 1987; Perry et al., 1985). The optimal treatment may remain unknown until the cause is understood. A given symptom such as pain may be due to one or more causes. Sometimes physiotherapy treatment will be the same regardless of the cause of a symptom (e.g. inflammation in a joint due to rheumatoid arthritis or due to an acute sprain). Sometimes treatment is tailored to directly affect the cause of a symptom (e.g. a heel raise to lengthen a shorter limb when knee pain has arisen due to a leg length discrepancy).

Regardless, physiotherapy intervention has potential to improve or maintain function and quality of life (Dean, 1991a; Dean & Ross, 1988; Einarsson, 1991a; Einarsson & Grimby, 1987; Feldman & Soskolne, 1987). Short term studies have shown improvements in strength (Einarsson & Grimby, 1987; Feldman, 1985; Fillyaw et al., 1991), endurance (Dean & Ross, 1988, 1991; Jones et al., 1989; Kriz et al., 1992), function (Dean & Ross, 1991) and experience of pain (Waring, 1989) as a result of physiotherapy treatments and patient education.

In summation, clinical decision making in the case management of PPS is difficult. Physiotherapists cannot completely rely upon reasoning from first principles, because the pathophysiology of the syndrome and the natural history of it are not known or fully understood. They cannot completely rely upon experience, because they may not have treated these patients nor have ready access to those with expertise. As well, some clinical observations may not be valid. Finally, physiotherapists cannot rely upon clinical literature, because a database of treatment outcomes over the long term does not exist. However, access to the knowledge that is available in the medical literature and from experienced physiotherapists in a form that is readily applicable in the clinical setting could potentially enhance clinical decision making for these cases. A review of poliomyelistis and Post-Poliomyelitis Sequelae follows for those unfamiliar with the disease and the sequelae.

2.5.1 Poliomyelitis

Poliomyelitis is a picornavirus (enterovirus) with three immunologically distinct strains (Einarsson, 1991a). Infection occurs through the upper respiratory or gastrointestinal tracts (Einarsson, 1991a). In ninety to ninety-five percent of cases, infection is mild and the individual fully recovers (Agre & Rodriquez, 1991; Dalakas, Bartfeld & Kurland, 1995; Einarsson, 1991a; Westbrook, 1991). Symptoms are non-specific and can be similar to those of the flu, including fever, fatigue, sore throat and diarrhea. Three to ten percent of cases are systemic (Agre & Rodriquez, 1991; Dalakas et al., 1995; Einarsson, 1991a). Symptoms, such as high fever and neck and back pain, are more severe but do not result in paralysis (Dalakas et al, 1995). Less than one to two percent of cases result in the most severe forms of the disease, paralytic and encephalitic poliomyelitis (Agre & Rodriquez, 1991; Dalakas et al., 1995; Einarsson, 1991a; Westbrook, 1991).

Presentations of paralysis include: 1) spinal poliomyelitis (infection of anterior horn cells in the lumbosacral and cervical regions of the spinal cord); 2) bulbar poliomyelitis (infection of the brainstem, especially the reticular formation of the medulla, pons and mid-brain); and 3) bulbo-spinal poliomyelitis (infection of both the brainstem and spinal cord) (Dalakas et al., 1995; Einarsson, 1991a).

Paralysis may have a patchy presentation, affecting limbs asymmetrically and different heads within the same muscle group differentially (Einarsson, 1991a) The most common pattern of motor involvement is for the lower extremities to be affected more so than the upper extremities (Dean, 1991a; Einarsson, 1991a). Physiological recovery from paralytic poliomyelitis may require three to twenty-four months (Dalakas et al., 1995). It is achieved by: 1) recovery of partially affected anterior horn cells; and, 2) reinnervation of denervated muscle cells via collateral sprouting of terminal axons by recovered and unaffected anterior horn cells (Dalakas et al., 1995). Strengthening exercise regimes were commonly used to stimulate the second mechanism of recovery (Einarsson, 1991a; Perry, et al. 1988). About fifty percent (Dean, 1991a) of those experiencing paralysis have residual deficits in motor function and may require orthotics, surgery, and mobility aids such as canes or wheelchairs. Additionally, they may adopt 'trick' movements (i.e. adaptation of function) (Smith, L.K., 1990) to perform activities of daily living such as dressing or walking, significantly altering normal body mechanics (Waring et al., 1989).

Annual epidemics of poliomyelitis were common in temperate zones of the developed countries from the mid-1880s when the virus was first reported in the medical literature (Jubelt & Cashman, 1987) until the mid-1950s (Dean, 1991a; Einarsson, 1991a) when vaccines were developed and distributed (Jubelt and Cashman, 1987; Dalakas et al, 1995). Acute infections are still a problem in the tropics and sub-tropics (Westbrook, 1991). Soares (2005, p. 18) reported that poliomyelitis was endemic only in Afghanistan, India, Pakistan, Egypt, Nigeria and Niger prior to 2003. However, since then it has spread. Resistance in Nigeria to immunization resulted in cases appearing in several bordering countries previously free of it (Soares, 2000). Infection secondary to immunization with live attenuated virus is also possible and resulted in an epidemic in India (Soares, 2000).

2.5.2 Post-Poliomyelitis Sequelae

In the late 1970s (Perry, Barnes & Gonely, 1988), some survivors of the last large polio epidemic (mid-1950s) in the developed countries began to experience new fatigue, pain and weakness after decades of stable functioning (Bruno, 1985; Cosgrove et al., 1987, Dalakas et al. 1986; Dalakas et al, 1995; Dean, 1991a; Dean, 1991b; Einarsson, 1991a; Einarsson & Grimby, 1987; Halstead & Weichers, 1987; Jubelt and Cashman, 1987). Early diagnoses included chronic fatigue syndrome, a rare form of ALS (Lou Gehrig's Disease), psychological problems (e.g. depression, hypochondria), recurrent polio infection and other ailments (Einarsson, 1991a; Dalakas et al., 1995).

Post-polio, post-poliomyelitis syndrome, post-poliomyelitis sequelae, post-polio progressive muscular atrophy and other terms (Agre, Rodriquez & Tafel, 1991; Einarsson, 1991a; Halstead, 1991; Jubelt & Cashman, 1987) have been used in the medical literature to refer to a variety of new problems that may be the result of the late effects of poliomyelitis (Laurie et al., 1984).

The etiology of PPS is not known (Jubelt & Cashman, 1987) and there is no sign or test that is pathognomic for the syndrome (Dean, 1991b; Halstead, 1988). The diagnosis of PPS is one of exclusion, that is all other potential causes must be ruled out (Dalakas et al., 1995; Halstead, 1991). To be diagnosed as having PPS, a patient must have: 1) a history of acute paralytic poliomyelitis confirmed by medical tests and records; 2) partial (i.e. some residual dysfunction) or complete neurological recovery following the acute infection; 3) maintained a level of functional stability for a minimum of fifteen years; and 4) experienced an abrupt or gradual onset of new neurogenic weakness in muscles affected or unaffected by poliomyelitis, with or without accompanying deterioration of function, excessive or unaccustomed fatigue, cold intolerance, atrophy or muscular or joint pain unexplained by other medical diagnosis. (Dalakas et al., 1995; Einarsson, 1991a; Halstead, 1991).

Some early theories to explain the three main symptoms associated with PPS have been discounted (Einarsson, 1991a; Halstead, 1991; Laurie et al.; Perry et al., 1987; Young, 1988). A popular theory (Cashman et al., 1987; Einarsson, 1991a; Weichers & Hubbel, 1981; Perry et al., 1988) is that the body of the paralytic poliomyelitis survivor has suffered long-term overuse while satisfying what would be considered normal demands by a healthy, intact body. It is speculated that neural cell ability to meet metabolic needs via terminal sprouting may have limits, which when exceeded lead to cell death (Einarsson, 1991a; Dalakas et al., 1995). Remaining motor neurons would consequently be further taxed as they attempted to reinnervate newly orphaned muscle cells (Einarsson, 1991a).

The incidence and prevalence of the Sequelae in the general population is unknown (Jubelt & Cashman, 1987). Many researchers believe that approximately 25% of those who survive acute poliomyelitis infections will develop PPS (Agre et al., 1991; Berlly et al. 1991; Dalakas et al., 1995; Halstead, 1988).

2.6 Summary

Clinical decision making in physiotherapy case management can be complicated, for several reasons. Historically, a variety of clinical decision making aids have been used to support clinical decision making. Computers and software, now readily available to the clinician, have not been fully exploited in the creation of clinical decision making aids (Dennis, 2000). Delitto and colleagues (1989), Stone and Parry (1991) and Dennis (2000) all speculate that knowledge-based systems could be helpful in the support of clinical decision making in physiotherapy. The goal of the thesis is to study the feasibility of creating these applications in physiotherapy by developing a prototype to support clinical decision making in PPS case management. Post-Poliomyelitis Sequelae (PPS) case management, exclusive of rare complaints (Einarsson, 1991a; Halstead 1991) such as dysphasia, swallowing impairments which are commonly treated by a speech language therapist, and new breathing problems was selected as the problem for which clinical decision making support would be developed.

An overview of the types of computerized decision support solutions that have been used in health care is given in Chapter 3. The role of knowledge-based systems in medicine and particularly in physiotherapy is examined. A review of reported knowledge-based systems in physiotherapy demonstrates the need for further research.

Chapter 3: Computerized Clinical Decision Making Support

3.1 Chapter Introduction

One approach to address the difficulties associated with clinical decision making has been the development of various aids. Nomograms, formulae and protocols and other methods have been used to increase access to pertinent information, guide practitioners in the application of knowledge, decrease errors or simplify procedures. Computer hardware and software offer calculation, storage, and memory retrieval capabilities that can augment those of a person and exceed those of the traditional aids (Reggia & Tuhrim, 1985; Stafford, 1996; Szolovits, 1982).

Computerized decision making aids have been developed for use in health care. Consultation applications are one such aid. There are many ways to create decision support systems. An approach from the field of Artificial Intelligence is knowledge-based system technology. This chapter discusses how clinical decision making in physiotherapy can be augmented with a clinical decision making system created using knowledge-based system technology.

3.2 Computer Applications as Clinical Decision Making Aids

Shortliffe (1987) lists three ways in which computer applications have been used to support decision making in health care. **Information management** applications, such as EMBASE (a database of rehabilitation journals) or MEDLINE (a database of medical journals) assist the practitioner by accessing patient data or bibliographic references (Shortliffe, 1987). **Reminder and alert** applications notify the practitioner about abnormal test results, potentially harmful therapy interactions, contraindications to therapies given a particular case history, and optimal times to schedule diagnostic tests, appointments or treatments (Shortliffe, 1987; Rauch-Hindin, 1988; Coiera, 1997, p. 299). **Consultation applications** "[customize] assessments or advice" on the basis of "patient-specific data" (Shortliffe, 1987, pp. 61-62). The majority of these applications operate by collecting information about a case from electronic databases or the end user and analyzing it according to the contents of its knowledge base to make suggestions about a probable diagnosis or optimal treatment (Shortliffe, 1987). Others interact using a critiquing approach; characteristics of a patient and a proposed treatment plan are compared with those of patients and protocols described in the medical literature or stored in a database of cases (Shortliffe, 1987; Rennels & Shortliffe, 1987). Similarities and differences are noted and appropriate treatment plan modifications suggested.

3.3 Medical Advice Systems

Consultation applications also referred to as medical advice systems support clinical decision making by making accessible knowledge and clinical expertise (Reggia & Tuhrim, 1985; Shortliffe, 1987). Conventional programming and artificial intelligence (AI) are two computer science paradigms that can be used to develop consultation applications.

Conventional programs use algorithms (pre-programmed instructions) to repetitively and effectively manipulate large databases to reach quantifiable or mathematically provable solutions (Turban, 1988; Jackson, 1990). Billing clients or insurance groups, keeping an inventory of clinic supplies and statistical analysis of survival rates relative to gender, age or treatment are tasks to which conventional programming software is usually applied (Turban, 1988; Durkin, 1994). However, some conventional programs that use statistical or probabilistic methods have been designed to assist with clinical decision making (Coiera, 1997).

Artificial intelligence is "concerned with the computational understanding of" "intelligent behavior, and with the creation of artifacts that exhibit such behavior" (Shapiro, 1992, p.54; see also Jackson, 1990; Miller, P.L., 1988; Turban, 1988). AI encompasses several areas including image understanding, robotics, natural language understanding, neural networks and knowledge-based systems (Jackson, 1990; Shapiro, 1992). In contrast to conventional programs, AI programs use heuristics (rules of thumb) to manipulate symbolic knowledge (Coiera, 1997; Shortliffe, 1987; Waterman, 1986). (See Chapter 3 for an example of a heuristic space). The processes to infer solutions are not predefined (Turban, 1988). AI programs do not always yield a correct or the best result (Turban, 1988; Jackson, 1990), but can provide acceptable solutions to problems (Turban, 1988; Jackson, 1990) that are difficult or awkward to address with conventional programming (Turban, 1988).

3.4 Artificial Intelligence in Medicine (AIM)

Artificial intelligence methods have been used to create applications for medical imaging processing, medical instrumentation and biotechnology, as well as decision making support (Galper, Shortliffe, Rennels & Patil, 1992). "AIM systems are

....intended to support health care workers in the normal course of their duties, assisting with tasks that rely on manipulation of data and knowledge" (Coiera, 1997, p. 297). Coiera (1997), believes that the primary concern of medical artificial intelligence is the construction of AI programs that perform diagnosis and make therapy recommendations, however.

Knowledge-based systems and expert systems are AI methods that have been used successfully to create decision making support applications (e.g. XCON, Turban, 1988). According to Coiera (1997, p. 298), "[e]xpert or knowledge-based system are the commonest type of AIM system in routine clinical use." Both contain "medical knowledge...and are able to reason with data from individual patients to come up with reasoned conclusions" (Coiera, 1997, p. 298).

Coiera (1997, p. 299) notes that in health care, these systems have been used to: 1) generate alerts; 2) assist with diagnosis; 3) critique therapy plans by comparing them with accepted guidelines; 4) intelligently retrieve information from databases or the World Wide Web; 5) recognize and interpret images.

The terms expert systems and knowledge-based systems are sometimes used interchangeably (Jackson, 1990; Miller, P.L., 1988; Turban, 1988), however distinctions between the two have been noted (Jackson, 1990; Turban, 1988). Any system that manipulates symbolically represented knowledge is knowledge based (Jackson, 1990). A KBS application provides knowledge about a topic that can be applied by a user when making decisions. Knowledge base system applications in general may contain a degree of domain expertise, however they address knowledge deficiencies rather than expertise deficiencies per se (Turban, 1988). KBS applications that specifically yield expert level conclusions within a domain are referred to as expert systems (Jackson, 1990). Beyond being a source of knowledge, an expert system uses expert level rules of thumb to provide expert level advice (Turban, 1988).

For example, a medical knowledge-based system application could offer knowledge about immunizations for travelers. A medical expert system application could predict which travelers were more likely to become ill if not vaccinated or to give prognoses for ill travelers based upon their specific characteristics, such as age or prior health status.

Regardless of these differences, the development process for both types of systems is essentially the same. Throughout this thesis, the terms knowledge-based systems and expert systems are used interchangeably, and abbreviated to KBS. Distinctions are noted when significant to a particular discussion.

3.5 Knowledge-based systems

Knowledge-based systems can explicitly and symbolically encode knowledge and the reasoning processes of experts (Hayes-Roth, 1992; Coiera, 1997). The strength of these systems lies in the knowledge they contain (Miller, P.L., 1988; Waterman, 1986; Durkin, 1994). The knowledge may be facts, beliefs, rules of thumb (heuristics), or judgments (Durkin, 1994). Knowledge-based systems are particularly useful when applied to problems whose solution requires complex decision making with incomplete and uncertain knowledge (Turban, 1988).

A basic KBS consists of a knowledge base, an inference engine and an interface. The knowledge base stores the knowledge and heuristics needed to solve a given problem. To infer a recommendation or arrive at a diagnosis, the inference engine compares the knowledge in the knowledge base with information entered by a user about a particular case (Coiera, 1997). The inference process involves searching rather than execution of a procedural algorithm. The interface allows the user to interact with the application, by accepting user inputs and displaying advice.

Knowledge-based systems applications have been applied in many fields. An illustrative list includes chemistry, computer science, engineering, geology, nursing, social work, mathematics, medicine, psychology, and finance (Durkin, 1994). Applications in these and other fields have been used to assist humans with many problem solving tasks, as illustrated in Table 3-1. For example, MYCIN was developed to assist physicians in the identification of bacterial agents causing infection and in the prescription of antibiotics (Buchanan & Shortliffe, 1984).

There is some overlap between these categories; a prescription of exercise requires the design of a program tailored to the needs and characteristics of each specific patient. In other words, if a system was designed to improve fitness and strength in the elderly, exercise would most likely be recommended, but to be useful specific details about the type, level, frequency and duration of activity would have to be provided, too. The former task is one of prescription and the latter task involves design. Additionally, KBS applications may incorporate more than one problem solving task (Durkin, 1994).

Table 3-1: Problem Solving Tasks Incorporated into KBS Applications

Paradigm	Description	Health care example (actual system)
controlling	• manage overall system behavior	• maintain respirator or treadmill settings to meet specifications • (VM; Fagan, 1978)
debugging/ prescribing	• prescribe solution to system malfunctions	• prescribe antibiotics or strengthening exercises • (MYCIN; Shortliffe et al., 1973)
designing	• configure objects under constraint	• clinic where microwave diathermy and feedback devices used simultaneously; orthotic for diabetic foot / quadriplegic hand
diagnosing	• infer system malfunctions	• determine cause of shoulder pain and weakness, determine cause of acid-base imbalance • (Abel; Patil et al.,1981)

Paradigm	Description	Health care example (actual system)
instructing	• diagnose + debug + repair student behavior	• teach novice physiotherapists how to manage back pain cases; instruct medical students in effective treatment of bacterial infections • (Guidon; Clancey, W.J., 1979)
interpreting	• analyze data to infer situation/status	• determine lung disease from interpretation of pulmonary function tests • (PUFF; Aikins et al., 1983)
monitoring	• detect differences from expected outcomes, especially for vulnerable factors	• compare pulmonary function test results to normal values • (VM; Fagan, 1978)
planning	• devising a series of actions to achieve a goal	• treatment protocols/care plans
predicting	• infer probable consequences of given actions/factor combinations	• estimate rehabilitation time for given treatment protocol, diet, passive techniques, age, and gender

Paradigm	Description	Health care example (actual system)
repairing	• execute plans to accomplish prescribed solutions	• change respirator or treadmill settings • (VM; Fagan, 1978)
selecting	• rank list of possible options and choose best	• rank list of possible diagnoses and choose most probable for presenting signs and symptoms
simulating	• model interactions between agents/factors	• examine interaction of ROM and strength and effect on risk of injury

Note. Adapted from Waterman (1986) and Durkin (1994).

3.5.1 Knowledge-based system Applications for Clinical Decision Making

As previously stated, "expert or knowledge-based systems are the commonest type of AIM systems in routine clinical use," (Coiera, 1997, p. 298). Medical advice systems constructed using knowledge-based system techniques can facilitate clinical decision making by helping to retrieve, interpret and apply knowledge (Coiera, 1997; Rennels & Shortliffe, 1987). The knowledge base contents can be comprehensive, and contain expertise that may not be available elsewhere. Additionally, the knowledge can be analyzed and assessed. Knowledge bases in applications destined for commercial release are validated, in some cases according to standards dictated by agencies such as the U.S. Federal Drug Administration. These applications can be designed for convenient retrieval of knowledge that is relevant and in a clinically applicable format

(Stone & Parry, 1991; Coiera, 1997). Heuristics gleaned from experts can be used to cue those unaware of their complete information needs to salient points (Miller, P. L., 1988), to explain rationales or concepts to novices, and to provide guidance with respect to reasoning with uncertain, incomplete and inaccurate knowledge.

Knowledge-based system applications have several advantages over other clinical decision making aids available to physiotherapists (see Table 3-2).

Table 3-2: Comparison of Traditional and Newer Methods with KBS Decision Making Aids

Traditional Methods	Advantage with KBS
Formulae	• automatic calculation with an explanation feature
Nomograms, charts	• quick retrieval of related information
Hard copy texts and manual	• video display • intelligent, automatic and quick search of large databases • provide explanations (in greater detail than is typically found in manuals) • electronic distribution (quicker and more convenient than hard copy distribution)
Colleague	• consulting time unrestricted • advice consistent
Research and review articles	• efficient access to clinically relevant knowledge

Newer Methods	Advantage with KBS
World Wide Web (e.g. WebCT, online journals)	• direct access • provide guidance • modem and Internet service provider not necessarily required • Internet security issues not necessarily applicable • efficient access to relevant knowledge, vs. searching for it through countless web sites
Electronic Text (e.g. The Cochrane Database) and Conventional Programming Software	• reasoning techniques and knowledge made explicit (Coiera, 1997; Hayes-Roth, 1992) as explanations • interactive rather than passive (Coiera, 1997; Hayes-Roth, 1992) • case relevant material readily provided • less sensitive to imprecise or missing data • "based on symbolic models of disease…and relationship to patient factors…." (Coiera, 1997, p.296)

A medical advice system created with KBS methods can provide obvious benefits such as dissemination of expertise (Szovolits, 1982), formalizing and archiving of expertise for posterity (Szolovits, 1982), and improvements in efficiency or efficacy of decision making. Indirect benefits such as enhanced institutional image or status (Durkin, 1994), improved perception of a profession's integrity (Zimny & Tandy, 1989), training or instructional alternatives for novices (Stone & Parry, 1991; Coiera, 1997), improved job satisfaction, and improved quality of care (Zimny & Tandy, 1989) may also be realized.

3.5.2 Knowledge-based systems and Health Care - A Brief Historical Perspective

For over 30 years, knowledge-based system techniques have been applied to health care problems (Miller, P.L., 1988). The earliest systems were often created by AI researchers to study or develop KBS techniques. As KBS techniques matured and it became evident that knowledge-based systems incorporating the knowledge and expertise of physicians could make beneficial recommendations, applications were developed for clinical use (Miller, P.L., 1988; Coiera, 1997).

Four early experimental systems are notable both for advancing AI techniques and for demonstrating that applications to address health care needs for decision support were feasible (Rennels & Shortliffe, 1987; Szolovits, 1982; Coiera, 1997). The purpose and contributions of each of these systems are briefly noted in Table 3-3.

Table 3-3: Historically Significant Experimental KBS

Name	Purpose	Contributions
CASNET (Szolovits & Pauker, 1978)	• diagnosis and treatment of glaucoma/related eye diseases	• representation of and reasoning with causal representations of medical concepts possible
PIP (Present Illness Program) (Pauker, S.G. et al., 1976)	• diagnosis and treatment of renal diseases	• representation of and reasoning with underlying physiological processes
INTERNIST (Pople & Myers, 1982)	• diagnosis of internal medicine conditions	• >1 condition can be reasoned about simultaneously
MYCIN (Shortliffe et al., 1973)	• diagnosis and treatment of bacterial infections	• 'certainty factors' addressed the uncertainty associated with decisions regarding diagnosis and prescription; explanation of reasoning used to achieve recommendations or to request information from the user

Note. Adapted from Waterman (1986).

In 1986, the majority of all expert systems surveyed by Waterman had been created for the medical domain (Waterman, 1986). In 1992, Durkin surveyed 2500 applications created since knowledge-based system technology had been developed (Durkin, 1992). He found that 12% of these had been developed for the medical domain, resulting in a ranking of third highest number of applications among all domains. If Durkin's estimation that his survey represented only about twenty percent of all systems ever developed is correct, approximately 1500 medical systems had been created up to 1992.

The author found hundreds of knowledge-based systems constructed to support clinical decision making cited in MEDLINE from 1991 to 1995 inclusive. For a variety of reasons most of these systems are not available commercially (Miller, P.L., 1988; Coiera, 1997). In August, 2005 on his home page at http://www.coiera.com/ailist/list.html, Enrico Coiera listed thirty eight knowledge-based systems currently in routine clinical use. Four examples (see Table 3-4) found both at his Web page (http://www.coiera.com/ailist/list-idx.htm) and in his text (Coiera, 1997) illustrate the variety and utility of these applications.

Table 3-4: Examples of KBS Applications Currently in Routine Clinical Use

Name	Function	Comments
Puff	• interprets pulmonary function test data collected automatically from peripheral devices to diagnose pulmonary pathologies	• built in 1977 • routinely in use since 1978 • several hundred copies of a commercialized version have been sold
PERFEX	• interprets cardiac function test data automatically collected from a peripheral device to assist in the diagnosis of coronary artery diseases	• commercial version is undergoing beta testing in hospitals as part of the FDA approval process
Dxplain	• generates a ranked differential diagnosis list from its bank of over 2000 diagnoses by considering a patient's signs, symptoms and laboratory results	• routinely used for both clinical consultation and education

Name	Function	Comments
NéoGanesh	• interprets clinical data and controls mechanical ventilation in intensive care units	• clinical evaluation demonstrated that its use resulted in an improvement in "the quality of the patient's ventilation and the prediction of weaning from mechanical ventilation respiratory support", (Coiera, 1997).

Note. Adapted from Coiera (1997).

An examination by the author of abstracts listed on MEDLINE for the years 1991-2000 inclusive revealed a number of trends for knowledge-based system applications reported in the journals indexed by this database. The majority of medical knowledge-based systems have been developed as consultation applications rather than for other purposes (e.g. warning or reminder systems, instructional aids). Most of these support diagnosis exclusively or in combination with prescription, were designed for use by physicians, and utilize a consultation interaction style. Fewer systems have been developed for use by nurses or other health care practitioners, for prescription or management exclusively, or with a critiquing interaction style. These trends reflect the patterns evidenced in the medical applications listed by Waterman (1986). That diagnosis is the most common problem solving paradigm is not surprising given that this strategy is easier to encode than others such as planning (Durkin, 1994).

3.5.3 Knowledge-based systems in Physiotherapy

A search of MEDLINE and Embase from 1985 to 2005 yielded three articles concerning physiotherapy knowledge based or expert system applications. Other applications may not have been located because: 1) MEDLINE omits "many relevant publications in the engineering and computer science literature" in which knowledge-based system applications might be reported (Miller, R.A., 1994, p. 8); 2) they are not developed sufficiently or have not been selected for publication; and, 3) commercial applications may not be reported in the scientific literature.

Delitto and colleagues (1989) were commissioned by the National Institute for Occupational and Safety and Health (NIOSH) to standardize low back syndrome examination procedures and to develop algorithms for diagnostic classifications of patients based on normative data (Delitto et al., 1989). Additionally, they wanted to identify the factors that influence an individual physiotherapist expert's reasoning and those that affect groups of experts attempting to achieve consensus (Delitto et al., 1989). Delitto and colleagues used heuristics from “approximately a dozen different practitioners including physical therapists, chiropractors, and physicians” (Delitto et al. 1989, p. 557) to develop algorithms. The NIOSH Low Back Atlas was intended for use by health care practitioners preventing or managing cases of low back syndrome (Delitto et al. 1989, p. 557). At time of publishing, the system was being further refined. The authors of the Low Back Atlas noted that the process of developing knowledge-based system for decision support facilitates: 1) formalization of “the process by which …experts make clinical decisions,” (Delitto et al., 1989, p. 557) including clarification of the biases effecting them and different rationales; 2) integration of experts’ opinions into a knowledge base that can be validated independently; 3) identification of clinical diagnostic categories (Delitto et al, 1989, p. 558).

Dr. Nelson (personal communication, 1997), who coordinated the NIOSH Low Back Atlas project reported that the heuristics gleaned from expert clinicians were not encoded into an expert system because: 1) the group was unable to obtain funding for this purpose; 2) after consultation with a knowledge engineer, they surmised that the weighting of factors used in the decision making process were too variable to represent in an expert system.

Stone and Parry (1991) were interested in using expert system techniques as a means to archive, formalize and disseminate physiotherapy expertise. Stone, a physiotherapist used a shell to create the ELEXSYS. It was intended as a learning aid, also referred to as a computer aided instructional tool (CAI), for physiotherapy students and newly qualified practitioners. The ELEXSYS "emulate[s] decision-making" about the safe use of interferential therapy" (Stone & Parry, 1991, p. 224). Stone derived the rules for the ELEXSYS from knowledge and expertise gleaned from instructional materials, medical literature and interviews with clinicians and instructors (Stone & Parry, 1991). Parry reported (personal communication, 1994) that the ELEXSYS had been informally tested as an instructional aid by physiotherapy students taking an undergraduate course in the United Kingdom. Funding restrictions limited development of the ELEXSYS to a "simple prototype" (Stone & Parry, 1991, p. 224) that provides decision support for the use of only one rather than a variety of modalities. Stone and Parry concluded however, that despite some implementation problems the ELEXSYS demonstrated that development of an "expert system for electrotherapy is feasible"

(Stone & Parry, 1991, p. 226) for training purposes. Unfortunately, according to John Cleak (personal communication, July 2005), a physiotherapy professor at Sheffield-Hallam University, the ELEXSYS is not currently being used as a teaching aid. The system was not adapted for clinical use.

Dennis (2000) created an expert system to help physiotherapy students learn clinical decision making techniques. Cases in "critical care, neurology, pediatrics, and pulmonary care" (Dennis, 2000, p. 5) were created by faculty of the Medical College of Georgia for the knowledge base. Dennis (2000) used authoring software to create a menu driven program from which students could select modules of information concerning test results or patient histories.

This allowed the students to practice doing assessments with real cases but without interacting with patients. The goal was for the students to identify which information was pertinent to gather for given cases. The process of decision making was the focus rather than the outcome of it. After students interacted with the software, academic staff could review their choices in information gathering and suggest more efficient clinical decision making as needed.

Dennis noted that her computer based patient management problem (PMP) application was descriptive, that is concerned with determining "how individuals make decisions" (Dennis, 2000, p. 4). She expressed concern that prescriptive knowledge-based systems applications, that is ones designed for clinical decision making support might not be worth the cost (Dennis, 2000, p. 8).

Charlotte Chatto (personal communication, July 2005), a physiotherapy faculty member in the Medical College of Georgia, stated that prior to retirement from her academic post, Dennis transferred the cases in the knowledge base to web pages. The primary reasons for abandonment of the expert system were the inability of the application to be accessed via the Internet and loss of support for Authorware, the authoring toolkit used to create the expert system. The system was not adapted for clinical decision making support.

A brief description of selected aspects of the development of the ELEXSYS, the NIOSH Low Back Atlas and the PMP is provided in Table 3-5.

Table 3-5: Characteristics of the ELEXSYS, NIOSH Low Back Atlas and PMP KBS Projects

Contribution	ELEXSYS Prototype	NIOSH Low Back Atlas Project	PMP Prototype
Development Team	• physiotherapist sole developer	• physiotherapists part of development team	• physiotherapist sole developer
Knowledge Source	• knowledge elicited from texts, articles and interviews with clinicians and instructors	• knowledge elicited from a dozen practitioners including physiotherapists, chiropractors and physicians	• knowledge elicited from case studies created by faculty
Knowledge Acquisition Techniques **Representation**	• interviews, review of printed materials • Rules	• three 'expert physiotherapists" analyzed input from the practitioners to separate out information that was necessary from that which was optional and to propose three diagnostic classifications based on treatments that are most efficacious	• physiotherapist collected case studies • Rules

Contribution	ELEXSYS Prototype	NIOSH Low Back Atlas Project	PMP Prototype
Knowledge Type Formalized	• knowledge concerning modality application	• knowledge concerning orthopaedic case management	• knowledge concerning clinical decision making
Prototype Function	• **CAI** (computer assisted instruction) for students and novice licensed physiotherapists	• **clinical decision making** knowledge base for practitioners managing low back syndrome cases; classification of patients into physiotherapy **diagnostic** categories	• **CAI** for students
Evaluation Type	• field tested (with physiotherapy students)		• field tested (with physiotherapy students)
Status	• never tested for clinical decision making • not in use for instruction	• Never implemented into a knowledge-based system	• never tested for clinical decision making • not in use as a knowledge-based system but content is available via WebCT

Note. Derived from Delitto et al. (1989), Stone and Parry (1991) and Dennis (2000).

Zimny and Tandy (1989) suggest using a problem knowledge coupler (PKC) as a "philosophical and practical alternative to…expert decision-support systems" (p.155). They state that a PKC can "provide clinicians with easy access to information in the literature" (Zimny, 1992, p.110) without as expert systems may do, replicating "the frailties inherent in human experts and probability-based systems" (Zimny & Tandy, 1989, p. 159).

3.6 Summary

Variations between sub-domains in medicine have resulted in different "computational implications" (Miller, P.L., 1988, p. 4). The requirements and feasibility of developing KBS applications in physiotherapy may differ from those in other health care domains and may vary according to the idiosyncrasies of each of its own sub-domains.

The **ELEXSYS** system is consistent with the notion that some types of knowledge and reasoning required to solve some problems in the domain of physiotherapy can be elicited and formalized for representation in and reasoning by a knowledge-based system used for computer aided instruction. Dennis (2000) also demonstrated that physiotherapy knowledge can be acquired and represented in an expert system designed for instruction.

At the conceptualization stage, Dr. Nelson (personal communication, 1997) and colleagues speculated that the heuristics required for expert level decision making in the diagnosis of low back dysfunction cannot be represented in an expert system (see Delitto et al., 1989). However, this belief has neither been confirmed nor disputed by construction and feasibility of development is difficult to ascertain without prototyping (Jackson, 1990; Durkin, 1994; Waterman, 1986).

Dennis (2000, p. 2) noted that computers in general "have not been used extensively to support and enhance decision-making in physical therapy". The goal of this thesis is to further examine the feasibility of developing prescriptive knowledge base system applications, specifically as clinical decision making aids for physiotherapists. The work is limited to the study of development exclusively. Deployment issues are discussed, especially as they impact on development but they are not investigated. Three prototypes created for the thesis enable evaluation and comparison of the use of different main sources of knowledge, development tools, and interface designs. The prototypes are developed for demonstration rather than for other purposes such as production of a commercially viable application or basic AI research.

Chapter 4 summarizes the process of knowledge-based system development that is used to create the thesis prototypes.

Chapter 4: Knowledge-based system Development

4.1 Introduction

There are several processes involved in the creation of a knowledge-based system. Development consists of several tasks, such as acquiring and representing the domain knowledge, and implementing it into computer code to construct an application that solves a problem in a domain.

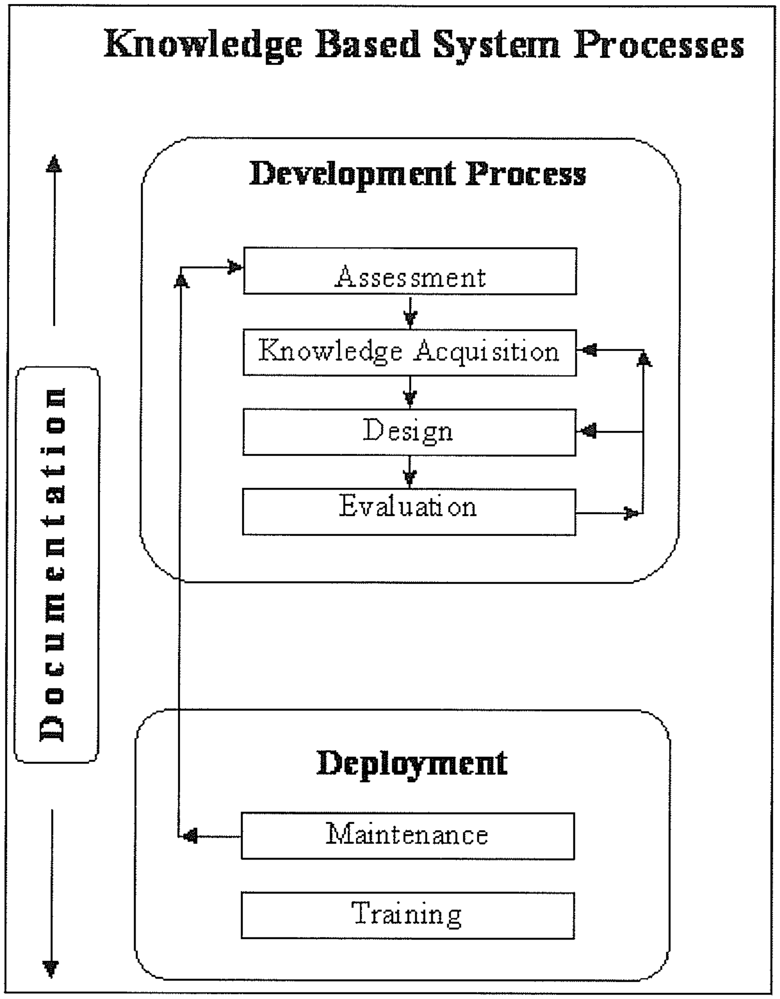
Documentation involves creating and maintaining a record of all materials pertinent for development of the system, including the knowledge gleaned from the expert and the suite of test cases used to evaluate the system (Durkin, 1994).

Deployment entails installing the system into the area in which it will be used. This can include training users on how the system operates and changing procedures to incorporate its use (Durkin, 1994).

Figure 4-1 shows the components of and the relationships between the processes of development, deployment and documentation.

A brief discussion of the basic concepts and of the processes commonly involved in a knowledge-based system project, especially as they apply to the thesis project, is presented in this chapter.

Figure 4-1: Relationship Between Knowledge Based System Development, Deployment and Documentation Processes



4.2 Knowledge-based system Development

4.2.1 Development

Knowledge-based system application development is an iterative process (Luger & Stubblefield, 1998; Stafford, 1996; Durkin, 1994; Waterman, 1986) (See Figure 4-1). The tasks to produce an application are repeated until an adequate level of performance has been achieved (Durkin, 1994). Many of the tasks will have impact on more than one process, therefore the output of a task may necessitate repetition of other tasks associated with other processes (Hart, 1989). Consequently, the processes are performed non-sequentially and repetitively until the application is evaluated as functioning to specification.

For example, if after initial evaluation it is determined that a system does not provide a sufficient suite of recommendations, more knowledge may need to be acquired, then represented and finally the behaviour of the revised system re-evaluated.

Different researchers (Durkin, 1994; Jackson, 1986; Turban, 1988; Waterman, 1986; Weitzel & Kerschberg, 1991) use different task category designations, however the processes of assessment, knowledge acquisition, design and testing are common components. Assessment procedures help the development team to determine whether a project is justified and practicable. Knowledge acquisition, considered by many to be the most difficult and time consuming task, is the process of eliciting relevant domain knowledge from experts (Durkin, 1994, Luger & Stubblefield, 1998; Frenzel, 1987; Forsyth, 1984; Hart, 1989). During the design stage, the application is conceptualized, the knowledge and problem solving methods required are formalized and code implemented. Testing incorporates evaluation of user acceptance and validation. User acceptance is measured to determine the extent to which the application meets the needs of the end users. Validation to establish that the system performs with an acceptable level of accuracy is done to ensure that the knowledge base is accurate, complete and consistent for the narrow range of problems it will be used to solve.

4.2.2 Development Team

Knowledge-based system development is usually a collaboration between knowledge engineers, software engineers, end users, and domain experts or specialists (Durkin, 1994; Waterman, 1986; Jackson, 1999). Knowledge engineers are usually computer scientists who specialize in knowledge-based system development, particularly assessment, knowledge acquisition, design, implementation and testing (Durkin, 1994; Waterman, 1986; Jackson, 1999). However, as in this project, the roles of domain expert and knowledge engineer were assumed by the author (Parsaye & Chignell, 1988; Elson & Connelly, 1995; Luger & Stubblefield, 1998). Software engineers are computer scientists who may be consulted if conventional programming or interaction with other software is required (Durkin, 1989).

End users (users) are the individuals who will ultimately be using the application (Jackson, 1999). They may be novices or experts (Durkin, 1994; Waterman, 1986) who need assistance with "routine task[s] to improve productivity," "difficult task[s] to effectively manage the complexities," or accessing and analyzing pertinent knowledge to make informed decisions (Durkin, 1994, p.11). During the design process, end users can help to identify interface requirements (Durkin, 1994; Waterman, 1986), such as the appearance, contents and organization of screens and the depth of explanations provided (Shortliffe, 1987; Jackson, 1999). Their feedback during field testing can improve the utility of the released system. In turn, this can increase the likelihood that the application will be accepted and used in the target environment (Durkin, 1989).

Domain experts are individuals who have expertise in the field and preferably are able and willing to communicate that expertise (McGraw & Harbison-Briggs, 1989). Domain experts are considered to be highly competent (Delitto et al, 1989; Durkin, 1994;

Waterman, 1986). As a result of their clinical experience, or exceptional problem solving abilities, they are a source of rules of thumb that can be applied to solve complex problems at an expert level.

In the domain of physiotherapy Shirley Sahrmann would be considered a domain expert (with respect to muscle imbalances). It has been noted (Delitto et al., 1989) that in the field of physiotherapy, a practitioner is considered an expert mainly on a subjective basis. If he makes the same case management choices as other experts, he too is considered an expert (Delitto et al., 1989). In physiotherapy, there are few official certifications to designate expertise. Practitioners can expand their skills by taking post graduate courses, but these alone do not signify expertise.

Domain experts contribute knowledge and expertise to the knowledge base (Jackson, 1999). They also evaluate the reasoning and recommendations offered by the knowledge-based system application, specifically for correctness and completeness. Historically, many applications were expert systems; their knowledge bases were comprised of knowledge elicited from practitioners informally or formally recognized as domain experts (Delitto et al., 1989; Durkin, 1994; Waterman, 1986).

4.3 Assessment

4.3.1 Assessment Process

The two main purposes of assessment are to ascertain the merit and feasibility of a project (Waterman, 1986; Hart, 1989), in other words to answer the questions "should it be done?" and "can it be done?" To do so, the development team needs to define the purpose, goals, and scope of the project (Waterman, 1986).

A knowledge-based system project may be undertaken with the intention of exploring or enhancing expert system methods; solving a specific problem within a domain; demonstrating the capacities and value of knowledge-based system applications; or some other intention. The objectives and scope of a project vary according to which of these or other project goals is primary (Durkin, 1989; Coiera, 1997). Durkin (1989) and Coeira (1997) divide projects into those that are problem driven and those that are solution driven. In the former, a knowledge-based system is developed to resolve a particular problem (Coiera, 1997, p.75). In the latter, new techniques may be applied to determine which problems that method can address (Coiera, 1997, p.75).

As previously stated, the goal of this thesis is to demonstrate that a knowledge-based system technology can be developed to support clinical decision making in physiotherapy. More specifically, the goal is to determine whether the domain-specific knowledge and expertise required to make decisions to assess and treat patients can be acquired and represented in a system that can yield recommendations on these aspects of case management. For demonstration projects (Waterman, 1986) or proof of concept projects, a potential goal is to establish that the knowledge and reasoning required to solve problems in the domain can be acquired and represented in a knowledge-based system. Another goal would be to investigate whether a knowledge-based system could be constructed in such a way as to satisfy end user requirements, such as ease of use and adaptability into the environment in which the end user would be problem solving. A potential benefit of meeting these two goals might be the acceptance or adoption of the technology in the domain. Durkin (1994) recommends selecting a problem that is considered of importance in the domain, is moderately complex but manageable due to its narrow scope and is solvable. These characteristics help to avoid perceptions of either triviality or poor performance, both of which could undermine the acceptance of the knowledge-based system applications.

Knowledge-based system applications are not suitable for problems that are exhaustive in breadth (Waterman, 1986; Coiera, 1997). Applications with a broad focus can be difficult to validate and to verify. In the domain of physiotherapy, it would be reasonable to construct an application to assist physiotherapists treating pressure sores in paraplegics, but not for the solution of all physiotherapy management problems related to neurological conditions.

Although in 1985 Reggia and Tuhrim expressed doubt that some of the limitations of KBS technology could be overcome, it should be noted that AI research continues to examine methods to improve KBS technology (Reggia & Tuhrim, 1985; Waterman, 1986; Hayes-Roth, 1992). The AIM electronic mail (ai-medicine@med.stanford.edu) list for people interested in Artificial Intelligence in Medicine regularly posts conferences exclusively on such topics as temporal representation, spatial representation, automated knowledge acquisition, and many other aspects of KBS technology.

4.3.2 Project Justification

The purpose of a project partially determines which factors are significant in determining justification for it. Research (e.g. in psychology or computer science) and demonstration projects (e.g. the prototypes for this thesis) can be justified by consideration of potential benefits that may be intangible or abstract, such as discovery of a new technique. The potential benefits of developing a knowledge-based system application for demonstration could be adoption of the technology within a domain (Durkin, 1994) or an increased understanding of knowledge-based systems or of the domain.

Justification of a project motivated by the need to solve a particular problem requires consideration of different and possibly more stringent criteria. For example, determining whether decision support is essential and KBS technology practical and optimal would be necessary if the primary motivation was creation of an application that would be relied upon in the domain to solve real problems (Durkin, 1994; Turban, 1988; Waterman, 1986). Coiera (1997) believes that development of health care systems should be problem driven to ensure that the best method to solve problems is found. Dennis (2000, p.3) opines that creation of a decision support system is justified solely to "promote a clearer understanding" of the process itself.

4.3.2.1 Evaluating the Need for Decision Support

Allocation of resources for clinical decision making support of any kind will be difficult to justify when problem solving does not rely on expertise, decision making knowledge is easy to obtain, an adequate supply of domain experts exists, or a condition or problem is relatively rare (Durkin, 1994; Waterman, 1986). For example, it may be more efficient to transfer a patient to a facility that has the required resources than to arrange to have these provided locally.

In the health care domain, investment in decision support may be more readily justifiable when a condition is complex to diagnose, treat or manage; expertise or knowledge is scarce or highly localized rather than dispersed; or excellence in the provision of quality care is perceived to be associated with decision support applications (Durkin, 1994; Turban, 1988; Waterman, 1986; Luger & Stubblefield, 1998). Other reasons, such as greater consistency, improved accuracy, increased efficiency and consideration of human issues are other possible justifications for supporting decision making (Dennis, 2000).

When determining the value of a solution in health care, efficiency measured in terms of expenditure or frequency of decision support access alone may not be a sufficient criterion (Taylor, 1980; Dennis, 2000). The human costs associated with alternatives to providing decision support may have equal importance to monetary considerations in this evaluation (Taylor, 1980).

4.3.2.2 Evaluating the Optimality of a KBS Decision Support Application

<u>Advantages and Disadvantages of Knowledge-based systems</u>

The benefits and costs of developing a KBS application can be appraised and compared to alternative solutions to justify selection of this approach (Clancey & Shortliffe, 1984; Luger & Stubblefield, 1998). Whether or not annual seminars to train staff, Internet (E-mail, WWW, news groups) access, conventional programs, electronic textbooks, or databases (e.g. MEDLINE, Embase) can address some problems more efficiently or with less risk than a KBS application can be investigated for each project.

KBS applications have the capacity to provide decision support for complex problems that require expertise to solve (Durkin, 1994; Reggia & Tuhrim, 1985). Applications developed for the health care domain can potentially improve access to health care expertise over space and time, increase the speed at which salient information can be gathered and applied, reduce redundancy and potentially error in decision making, reduce the cost of a given level of care, improve the quality of care, improve the image of the health care facility or institution and provide training for health care professionals or students (Durkin, 1994; Waterman, 1986).

KBS applications have several advantages over other many traditional clinical decision making supports. KBS applications can store and retrieve large amounts of knowledge and increase the speed at which it is accessed (Durkin, 1994; Reggia & Tuhrim, 1985; Stafford, 1996; Szolovits, 1982). KBS applications can automatically calculate solutions to formulae, store more information conveniently than hard copy nomograms or charts, display video unlike texts or manuals, intelligently and automatically search large databases quickly like some electronic texts, and provide explanations in greater detail and more efficiently than is typical for manuals. They can be updated and disseminated more quickly than printed materials (Waterman, 1986), and are likely to be more accessible over greater periods of time than people, who are unavailable due to vacations, illness or busy schedules or than hard copy sources of information stored in libraries, hospitals and other areas with restricted access.

KBS applications have advantages compared with other computer technologies. Algorithmic programs are efficient means of finding deterministic solutions (e.g. calculating body fat percentage from skin fold measurements) and have been "useful in selected areas" of medicine (Reggia & Tuhrim, 1985, p. 10), such as chemotherapy case management. However, this method of knowledge representation is simplistic and difficult to modify because the knowledge and inference methods are intertwined (Coiera, 1997). As well, many health care problems lack "precise quantitative formulas (sic)" that can be encoded using conventional algorithms (Reggia & Tuhrim, 1985a, p. 10). KBS applications separate the knowledge and reasoning used to solve problems, have a variety of methods to represent knowledge, and can address health care problems that do not have deterministic solutions.

Statistical programs have yielded applications that are "impressive in their performance" (Reggia & Tuhrim, 1985, p. 103). However, the conclusions at which they arrive are based on several assumptions that are often violated in reality. Two such assumptions are that patients have only one disease at any given time and that all information that is significant can be and is collected to apply in the calculations (Reggia & Tuhrim, 1985). KBS applications can be sufficiently robust to handle uncertainty and incomplete knowledge (Turban, 1988).

Databases are programs that can store information about different cases to which a specific case can be compared. Reggia and Tuhrim (1985) noted that databases have been used to aid in both diagnosis and prognosis. Databases implicitly encode knowledge. Their value is dependent upon the size and quality of the data they contain; the larger and more accurate the data, the better the result (Reggia & Tuhrim, 1985). These characteristics are not always fulfilled in the real world, because the information is not currently known or is too costly to attain. Reggia and Tuhrim believe that "a fundamental limitation of this approach has been reliance on the user to specify which patient features to use" (Reggia & Tuhrim, 1985, p.16). KBS applications make explicit the knowledge and reasoning used to arrive at a conclusion. They are able to handle cases when information is limited in quantity or quality (Turban, 1988). As well, when properly designed, they can guide naïve end users who may be unaware of their information needs.

Hypertext Mark-up Language (HTML) documents found on the Internet link end users to related topics of interest. However Web pages do not necessarily incorporate expertise nor are they always designed to specifically address clinical needs. Significant time may be required to locate useful sites, to download information and to search through this documentation for sufficient relevant knowledge. In contrast, a KBS application can guide users in the solution of a specific problem. Searching is limited to aspects or features of this problem and specifically yields clinically applicable knowledge. KBS applications can be run on dedicated machines or local area networks (LANs), thus acquiring pertinent knowledge potentially quicker than with the Internet.

KBS applications can incorporate conventional programs, such as databases or provide connection to the Internet when these types of computer programs will facilitate finding an adequate solution.

As with all technologies, there are disadvantages associated with the use of KBS applications. Although they can assist people, and in some cases operate relatively autonomously from them (Waterman, 1986), they do not have the same task versatility. Their ability to accomplish physical tasks is limited to the abilities of the peripheral devices to which they are connected (Waterman, 1986). They cannot socialize with or give emotional support to colleagues, nor correctly answer questions beyond the narrow range of problems for which they have been programmed. Knowledge-based system technology is relatively immature compared with most conventional programming techniques (Durkin, 1994; Hayes-Roth, 1992). There are limitations, costs and risks associated with the technology that may make it unsuitable for solution of some problems (Durkin, 1994). Even though investigative and demonstration projects may not be as sensitive to the limitations of knowledge-based system applications as projects to develop commercially viable applications, all may be sensitive to the risks and costs associated with development (Durkin, 1994).

4.3.2.3 Current Limitations of Knowledge-based system Technology

KBS technology cannot solve every problem requiring manipulation of symbolic knowledge (Waterman, 1986; Luger & Stubblefield, 1998). If a problem is not well understood, poorly focused, or ill-defined, or if the knowledge needed for even a partial solution cannot be acquired then neither KBS nor other decision support methods are apt to yield adequate solutions (Coiera, 1997). Knowledge-based systems can provide useful guidelines for numerous situations, but cannot give precise advice for every possible variation of a problem, because not all of the necessary information can be foreseen and encoded (Waterman, 1986; Coiera, 1997). During the knowledge acquisition process, some knowledge may be missed (Coiera, 1997). As well, "contextual information" which may have some significance in arriving at an adequate solution may not be presented to or understood by a KBS application (Coiera, 1997, p. 318).

Knowledge-based systems have difficulty solving problems that require reasoning with temporal and spatial knowledge, because these concepts are difficult to represent (Waterman, 1986). Temporal knowledge pertains to changes in conditions or states over time. For example, blood pressure and blood levels of pharmaceutical agents are characteristics that can change from minute to minute. Some KBS systems, such as VM and the Digitalis Therapy Advisor, are "unusual in that they give advice on the management of patients over time" (Galper et al., 1992; Rennels & Shortliffe, 1987, p. 586). Spatial reasoning includes such tasks as recognizing objects and their relationships in space to other objects and using physical analogies to solve problems (McDermott, 1992).

Problems that require reasoning with a great deal of common sense knowledge are not ideal candidates for KBS applications (Turban, 1988; Coiera, 1997; Luger & Stublefield, 1998). Common sense knowledge comes from experience and may be difficult for an individual to articulate (Durkin, 1994; Waterman, 1986). Common sense reasoning is a method for making obvious inferences from common sense knowledge (Davis, 1992). Common sense (knowledge and reasoning) is difficult to encode (Davis, 1992). A novice physiotherapist would be able to recognize that a patient with a rectus abdominus diastasis secondary to multiple gestations cannot also have prostate cancer. A KBS might fail to do so, however. To enable the KBS application to perceive the inaccuracy of this premise, the commonly recognized facts that human males cannot be pregnant and females do not have prostates would have to be included in the knowledge base or the rules relating to both conditions would have to be carefully worded and related to one another. However, exhaustive encoding of common sense is not practical, due to increased development time, decreased interaction speed and increased memory requirements (Waterman, 1986).

In the past, knowledge based systems had difficulty with inconsistent knowledge (Waterman, 1986). An example of inconsistent knowledge is that a knee joint may not have a capsule present on autopsy even though by definition it is a capsular joint. A novice physiotherapist may be able to reason that the capsule had been surgically removed or that the subject may have had a genetic mutation that curtailed formation of this capsule. Frame based representation is one method that allows for the inclusion of exceptions. However, Durkin (1994, p. 79) notes that this approach "is not very efficient in large applications".

KBS applications tend to perform reasonably well when problem solving involves paradigms such as diagnosis, but less well with paradigms such as planning (Durkin, 1994). KBS are poor at recognizing when the limits of their knowledge and understanding have been surpassed (Waterman, 1986). An application may give a recommendation regarding a condition for which it has inadequate amounts of knowledge encoded. KBS techniques lack the maturity of conventional programming techniques (Durkin, 1994; Hayes-Roth, 1992). They cannot be verified nor validated completely. These characteristics may render KBS applications unsuitable for use in critical processes or critical domains (Durkin, 1994).

Knowledge-based system applications are not suitable for problems that are exhaustive in breadth (Waterman, 1986; Coiera, 1997). Applications with a broad focus can be difficult to validate. Additionally, very large search spaces may result in prolonged interaction times, which could in turn negatively impact on user acceptance. In the domain of physiotherapy, it would be reasonable to construct an application to assist physiotherapists treating pressure sores in paraplegics, but not for the solution of all physiotherapy management problems related to neurological conditions.

Development and maintenance to attain an adequate level of performance requires significant time and money (Waterman, 1986), therefore knowledge-based systems are not ideal for problems that must be solved immediately, or are not stable with respect to their nature or their solution (Durkin, 1994). The knowledge base contents of some systems (Waterman, 1986) are changed annually; however more frequent or extensive changes might be cost prohibitive or not feasible.

Although in 1985 Reggia and Tuhrim expressed doubt that some of the limitations could be overcome, AI research continues to examine methods to improve KBS technology (Reggia & Tuhrim, 1985; Waterman, 1986; Hayes-Roth, 1992; Jackson, 1990). The AIM electronic mail (ai-medicine@med.stanford.edu) list for people interested in Artificial Intelligence in Medicine regularly posts conferences exclusively on such topics as temporal representation, spatial representation, automated knowledge acquisition and many other aspects of KBS technology.

4.3.2.4 Typical Resource Needs for Knowledge-based system Development and Deployment

Development and maintenance resources include funding, tools, people and knowledge, which are discussed further in the following sections.

4.3.2.4.1 Funding

Durkin (1994) reported that the average cost to develop KBS applications in 1991, including wages, software and other resources was estimated to be $10,000 to $50,000. Others (K. Hotz, personal communication, February 1996; M. Evans, personal communication, May to August 1997; D. Scuse, personal communication, May to August 1997) state that this figure is a significant underestimate of the costs for the average application created in 1997. Additional funds are needed to maintain an application and to train end users to use it (Durkin, 1994).

Information regarding the total cost of medical KBS applications is usually not reported in the academic literature and may be jealously guarded by companies or agencies undertaking their construction. Coiera (personal communication, June 11, 1997) states that although "there are typical cost factors to slot into the equation [such as wages, software and hardware] most projects vary substantially based upon local conditions, resources and needs."

On average, it takes one to three years to develop an application (Durkin, 1994). In the United States of America, (Durkin, 1994) some medical advice systems are categorized as medical devices. They are subjected to rigorous testing, increasing the cost to release a version and potentially delaying use with patients by several months or years (Durkin, 1994).

Experts in knowledge-based system application development note that it is particularly useful to have enough money available early on in the project to allow preliminary prototyping (Durkin, 1994; Waterman, 1986). Early prototyping can help to establish practicability for the project and enhance understanding of what will be needed to complete the project.

4.3.2.4.2 Tools

Hardware and software are required to develop and run knowledge-based system applications. Software may include a knowledge-based system shell or development tool, a programming language (e.g. Lisp, C++), a validation tool or other types of programs such as a spreadsheet (Hayes-Roth, 1992). Peripheral devices, such as a respirator, may also be required depending upon the project.

4.3.2.4.3 People

Members of the development team must have the time, willingness, expertise and skills necessary to complete the task (Durkin, 1994). Each member of the team requires experience in his domain and the ability to communicate well. Good communication skills are especially important for the knowledge engineer, who is responsible for extracting information from the domain experts and the end users, as well as coordinating the efforts of the entire team (Durkin, 1994). Software or hardware engineers may be needed to modify existing resources to allow integration of the KBS application. Instructors will be needed to train end users in the use of the application and the hardware upon which it will be run.

Domain experts who have not been involved in application development must validate the recommendations and explanations provided prior to application release (Durkin, 1994). Validation can be accomplished in a number of ways (See 4.7 Evaluation).

Domain experts and end users who do not harbor undue skepticism, anxiety or resistance to change related to the use of KBS applications and who can commit to the entire duration of development are necessary for knowledge base development, application design and testing (Durkin, 1994).

4.3.2.4.4 Knowledge

Since the knowledge base is the heart of the application, access to an adequate knowledge source is important for both development and maintenance of the application (Durkin, 1994; Waterman, 1986). The knowledge and reasoning strategies may be elicited from an expert, a group of experts, cases or the domain literature. In general, a case is an example of a domain problem and the knowledge and reasoning applied to solve it. In the health care domain, a case history is a record of relevant details concerning the condition of a patient and treatments he has received. A large set of cases is desirable, so that there are adequate numbers for development and for testing.

4.3.2.4.5 Risks

There are risks associated with every resource listed. Funding sources such as grants may not be renewed, software may have unforeseen bugs, team members may become ill or relocate, or an expert may be unable to make explicit all of the necessary knowledge and problem solving steps. Durkin (1994) provides some guidelines for making a formal risk analysis of applications that are intended for commercial level release.

4.4 Knowledge Acquisition

Knowledge essential to solving the problem and information about the environment in which the application will be used must be elicited, analyzed and organized by the development team. The facts, beliefs, heuristics and problem solving strategy used by the experts may be acquired by using a number of methods, either independently or in conjunction with one another. Typically, the knowledge engineers interview the domain experts (Luger & Stubblefield, 1998; Waterman, 1986). They may also analyze cases and research literature. Extraction of the knowledge from people, texts, databases, videos and other knowledge sources can be a time intensive activity (Waterman, 1986; Galper et al., 1992).

Interviewing or observation must be repeated several times before the problem solving strategies are made explicit and all relevant knowledge is identified (Waterman, 1986). Experts often have difficulty articulating their knowledge, because their reasoning strategies are no longer transparent to them (Waterman, 1986; Stafford, 1996). Unintentionally, they may provide irrelevant, incomplete, incorrect or inconsistent knowledge (Hart, 1989). When a group of experts is being interviewed, non-standard terminology can complicate communication (Durkin, 1994). Printed material is often not formatted for automatic or easy knowledge extraction. An individual case or even a group of cases may not be sufficiently representative of the entire set to allow collection of all relevant knowledge (Durkin, 1994). For these reasons, knowledge acquisition is frequently referred to as the bottleneck of knowledge-based system development (Waterman, 1986; Galper, et al., 1992; Jackson, 1999; Forsyth, 1989).

Galper and colleagues (1992) discuss TERESIAS and other development tools designed to facilitate heuristics collection on-line. These tools allow the domain expert to examine the reasoning path to each conclusion to determine if errors of commission or omission have been made and to change weightings of probabilities associated with each of the heuristics in a reasoning path (Galper et al., 1992; K. Hotz, personal communication, February, 1996; Waterman, 1986). More recently, Coiera (1997) notes the importance of neural networks and machine learning to automate knowledge extraction from cases.

Information from the end users about their characteristics, their duties and the target environment can be gathered by observation, surveying or interviewing prior to initiating the design process and during prototype testing. It is integrated into the design of the application interface, including the content and sequencing of screens and the level of explanation for recommendations offered by the application (Durkin, 1994).

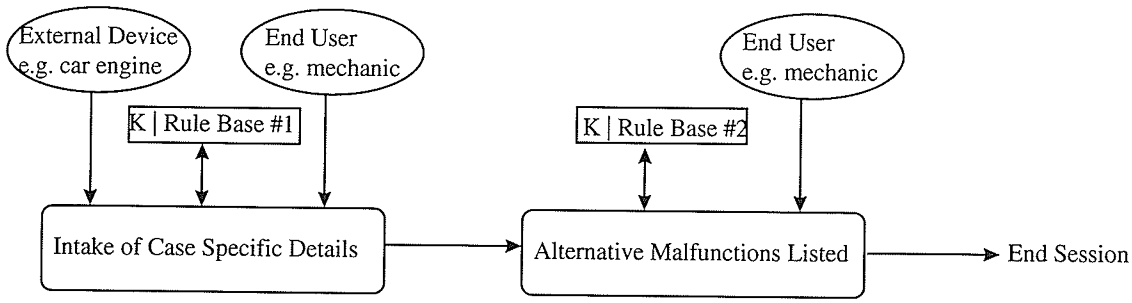
4.5 Design

4.5.1 Conceptualization

The knowledge collected is analyzed to identify key concepts, the relationships between them, their attributes and data types, and the overall problem solving processes (Durkin, 1994; Waterman, 1986). These aspects can be graphed on decision trees or flowcharts to organize the material and provide a framework of the general structure and operation of the application when completed.

For example, a process flow diagram (Figure 4-2) describes sub-tasks of the problem solving strategies, where input from the end user or another source such as a medical database may be required, the kind of knowledge processing to be done, the points at which output is expected, and other aspects of the processes executed to reach a solution. As the conceptualization becomes more sophisticated, the team is better able to recognize what other knowledge needs to be gathered to refine the application.

Figure 4-2: Example of a Process Flow Diagram



4.5.2 Knowledge Representation and Manipulation

When selecting a knowledge representation technique, the knowledge engineer evaluates which methods will be adequate to encode the knowledge and reflect the problem solving strategy employed by domain experts (Durkin, 1994). Although not ideal, the method may be constrained by the software that is most likely to be used, either due to finances or knowledge engineer preference. Software selection may depend on the funds to purchase it, the platform available to develop and operate the application, and the characteristics of other software with which the KBS application will be interacting (Durkin, 1994).

Durkin (1994) lists five commonly used techniques for representing heuristics in knowledge bases: object-attribute-value triplets, logic, semantic networks, rules and frames. Object-attribute-value triplets and semantic networks are similar to frames while logic is similar to rules. Rules, and to a lesser extent frames, have been used most often (Waterman, 1986) in medical knowledge-based systems. Rules can be used to formalize concepts such as strategies or recommendations (Waterman, 1986). They are practical for classification problems, especially those solved with a series of hypothetical statements (Durkin, 1994). Frames are efficient for problems involving causal relationships or simulations, because they can efficiently represent objects or concepts, their characteristics, their relationships and their effects on other objects or concepts (Durkin 1994; Waterman, 1986). In medical advice systems, rules could be used to represent rules of thumb about diagnosis or treatment (Waterman, 1986), while frames could efficiently represent knowledge about anatomical relationships. Some frame systems allow for the use of rules, creating a hybrid system that has the advantages of both approaches (Durkin, 1994).

Rules are composed of antecedent (IF) clauses that describe a premise or condition and consequent (THEN) statements of associated procedures or assertions (Waterman, 1986). The statements can be simple, consisting of a single IF and THEN combination, or complex with several conjunctions (ANDs), disjunctions (ORs), or negations (ANDNOT, ORNOT). Unlike lines of code in conventional programs, rules may not be executed if the conditional statement is not matched.

An example of a fact, a belief and an heuristic respectively expressed in rules follows in Figure 4-3.

Figure 4-3: Example of a fact, a belief and an heuristic expressed in rules

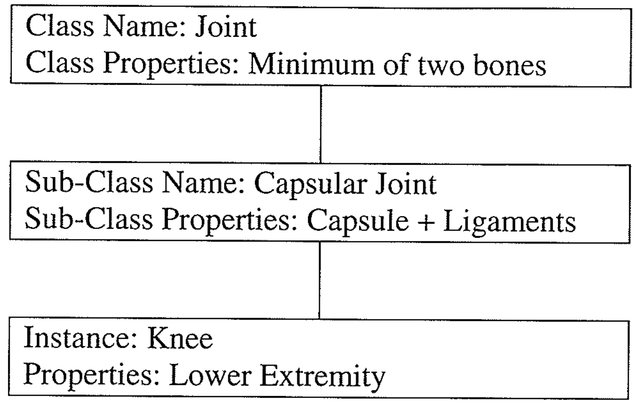
IF Fixed C or S shaped vertebral curve
THEN Scoliosis

If Scoliosis exceeds 25 degrees
THEN Frequent episodes of back pain will be experienced

IF One shoulder significantly higher than the other in standing
ORIF One pelvic crest significantly higher than the other in standing
ANDIF Comparisons in supine indicate equivalent bilateral leg length
THEN Fixed scoliosis may be present

Aggregate, association and generalization frames are three strategies used to organize concepts or objects into hierarchies of classes (Durkin, 1994). Aggregate frames link objects that are part of some larger entity. For example, a Body frame would include an Extremities class, which in turn would encompass a Legs sub-class because each is a part of the body. Association frames group objects that may seem unrelated but are connected in an abstract manner. For example, a Patient frame could have associated with it a room or an ambulation aid, because either can belong to a patient. Generalization frames classify objects that have similar characteristics. Interferential and ultrasound but not massage would be classes in a Modalities generalization frame because the latter is not a kind of electromagnetic treatment. The attributes or properties of an object or concept at a general class level are inherited by those at more specific levels, whether the values of these attributes remain static or change (Durkin, 1994).

Figure 4-4: Example of an Aggregate Frame



In Figure 4-4, the specific object (or, instance of a class) Knee inherits the property values of the more abstract levels. Therefore, the full representation of a Knee in this frame is capsular joint with at least two bones, a capsule and ligaments.

Decision making with inexact or incomplete knowledge requires judgments to be made. Probability, certainty factors and inference weighting values are some of the methods that have been used to represent the confidence associated with the validity of a conclusion in KBS applications (Coiera, 1997; Durkin, 1994; Gaschnig, 1983). A substantial amount of research in artificial intelligence is directed towards developing and refining computational methods of handling uncertainty in knowledge-based system applications. For an introduction to this topic, consult Durkin (1994).

The knowledge engineer also chooses a control strategy to manipulate the knowledge once it has been encoded. Two commonly used inference methods are forward chaining and backward chaining. Forward chaining is the process of inferring problem states from data that is known (Durkin, 1994; Jackson, 1990; Waterman, 1986). Backward chaining is the process of confirming a conclusion by collecting data that refutes or substantiates it (Durkin, 1994; Jackson, 1990; Waterman, 1986).

The reasoning strategy that is suitable will vary according to the problem and the manner in which it is solved by domain expert.. Forward chaining is ideal for data driven problem solving (Turban, 1988). It is a good method for applications that involve planning, monitoring, control and interpretation (Durkin, 1994). BABY uses this approach to monitor the status of neonates admitted to intensive care units and suggest corrective action when problems are detected (Durkin, 1994).

Backward chaining is hypothesis or goal driven (Jackson, 1990). It is an efficient approach for applications that involve diagnosis, prescription and debugging (Durkin, 1994). CLOT uses this strategy to evaluate evidence related to disorders of the blood coagulation system (Waterman, 1986). Mixed chaining strategies allow for the judicious use of each method (Durkin, 1994). ONCOCIN uses both backward and forward chaining to provide decision support for physicians managing cancer cases (Waterman, 1986).

Selection of the chaining method is simplified when systems that successfully solve similar problems exist, because the techniques they have used can be adopted with some confidence (Durkin, 1994).

4.5.3 Software Selection

Development platform choices can be either languages such as Lisp or C++, or shells such as LEVEL5 Object or VP Expert (Durkin, 1994). Unlike languages, shells have built-in KBS features. Depending upon the requirements of a particular project, these features may be advantageous or limiting. Built-in features can include: an inference engine; a developer interface (e.g. representation templates, rule base modules, external program access, debugging utilities, uncertainty management strategies); and a user interface (e.g. graphics, explanations, hypertext). Durkin (1994) lists forty-six expert system shells that were commercially available at the time of publishing.

The knowledge engineer chooses development software according to several considerations. Ideally, the software will support suitable knowledge representation and processing methods and be compatible with the hardware and software in the domain environment. Software that supports more than one representation or control strategy will allow more flexibility in design. The software should also be supported with manuals or instruction, have adequate tools for knowledge base development, have adequate user interface facilities, and have licensing fees that do not exceed project resources (Durkin, 1994; Waterman, 1986).

4.6 Prototype Evolution

The development team uses the software to implement the knowledge and reasoning needed to solve the problem. Early attempts will grossly model the structure and processing of the final version. They are important for demonstrating that the project is feasible, supporting the choice of knowledge representation, control methods and software. As well, the content and performance of each incarnation can be evaluated by the domain experts and end users for deficiencies requiring further knowledge acquisition or design refinement.

Ideally, all user specifications would be listed from the outset, but for some projects this is not realistic. End users and those who have requested that the application be produced may have only an incomplete comprehension of the capabilities of the technology and the knowledge engineers will not be able to elicit all relevant information at the beginning of a project. User interface specifications may be developed over time (Jackson, 1990). Each version of the prototype can incorporate functions detailed during the assessment process or newly identified during prototype evaluation. It is often difficult to anticipate some factors which become evident to the team only during field testing (Durkin, 1994), because problems not detected in the laboratory setting may become evident in the environment in which the application is actually to be used (Durkin, 1994).

The conceptual model is augmented and the design refined as more knowledge is acquired. As the breadth and depth of the knowledge base are increased, the prototype produces adequate recommendations for more types of problems or variations of a problem. The interface can be tailored as more information is gathered about the end users and the target environment.

4.7 Evaluation

4.7.1 Introduction

Evaluation can begin with the first prototype and may continue after deployment. It can be done informally or formally to validate conclusions and the reasoning used to attain them or to measure the degree of user acceptance. The type, formality, method and frequency of testing are dependent upon several factors, such as the purpose of the project, the purpose of the evaluation (Friedman & Wyatt, 1996), the current level of development, and the ramifications of system error. Durkin (1994, p. 653) notes that "...most knowledge engineers treat expert system testing and evaluation as a continual and evolutionary process..." that "...begins with an informal test of the initial prototype, and becomes increasingly more formal as the system is refined."

Evaluation of health care applications intended for use with patients is essential (Friedman & Wyatt, 1996; O'Keefe, Balci & Smith, 1987). The need to avoid harm to patients, to provide effective care, and to gain the confidence of the end users may have significant impact on the viability of a commercially destined application (Friedman & Wyatt, 1996). Regardless of the quality of the recommendations, lengthy or complex consultations, recommendations given in condescending tones, and other aspects negatively affecting user acceptance can render an application useless (Waterman, 1986; Friedman & Wyatt, 1996). For example although MYCIN performed better than many physicians in the task of managing bacterial infections, the time needed to procure advice was considered unacceptable by potential end users (Waterman, 1986).

4.7.2 Validation and Verification

In conventional programming, verification is done to ascertain whether or not software was built right, that is according to specifications (O'Keefe, Balci & Smith, 1987). Validation is done to determine if the right product was built (O'Keefe et al., 1987). Green and Eckert (1991) believe that "V & V [sic] as understood [in conventional programming] cannot be used to determine whether an expert system computer program is correct" (p. 399).

In the field of knowledge based expert systems, there is no "uniform agreement with the definitions for verifications and validation" (Adelman, 1992, p. 17). Adelman

(1992) suggests avoiding these terms and instead concentrating on different aspect of evaluation.

Gupta (1993) defines verification as the process of ascertaining that a conventional computer program performs as intended in the deployment environment. Applications are compared to some objective standard to determine if they completely satisfy the original requirements (Durkin, 1994). Verification is considered more difficult for knowledge-based system applications than for conventional programs (Green & Eckert, 1991), especially because comparison with objective standards is problematic (Durkin, 1994). KBS applications are usually developed to solve problems that do not have definitive correct solutions or for which there are competing opinions of equivalent merit (Miller, P.L., 1984, 1988; Rennels & Shortliffe, 1987; Shortliffe, 1987; Waterman, 1986).

Durkin (1994) notes that verification as defined for conventional software usually has not been done for KBS applications. Instead, validation which has less stringent criteria than verification is performed to ascertain that the system "satisfactorily performs the intended task[s]" (Durkin, 1994, p. 643; O'Keefe et al., 1987). One method entails testing the application to determine that its conclusions and associated reasoning are correct. For very small systems and for early prototypes, this process can be done by manually following all paths in the knowledge base. Unused, missing and conflicting knowledge and reasoning can be identified and amended.

Manually checking knowledge bases for completeness, consistency and correctness becomes impractical for large knowledge bases. Automated validation of a knowledge base ensures that it is consistent, but not that it is complete and correct. This may not be acceptable for some problems in critical domains such as health care.

Another validation method is to compare the recommendations of the KBS application to the advice of human experts on test cases representative of the ones for which the system will be used in the target environment (O'Keefe et al., 1987). O'Keefe and co-authors refer to this approach as face validation, however Gupta (1993) refers to it as construct validation. The domain experts performing the comparison are blinded with respect to the origin of the advice to minimize bias concerning the source. This method can be problematic, because the validating experts may not concur with the heuristics of the experts on the development team (Jackson, 1990; Waterman, 1986).

Validation may yield useful information for systems designed to research AI issues, but depending upon the specific project, user acceptance may be of peripheral significance. Conversely, user acceptance may be of primary significance for developers of demonstration systems (Friedman & Wyatt, 1996) or of commercial systems.

The evaluation done for this thesis includes user acceptance and face validation as defined by O'Keefe and colleagues.

4.7.3 User Acceptance

User acceptance is an indirect measure of the extent to which a system satisfies the needs of the users. Some of these needs will be identified during the assessment and design processes, but others may not manifest until field testing or release have been initiated.

Some requirements are common or standard for software of any type. Consistency, clarity and ease of operation are user interface elements that may enhance end user acceptance (Durkin, 1994). Navigation, starting and quitting should be intuitive. The contents and organization of screens should be organized in such a way to avoid confusion or distraction. GUIs with pull down menus and icons in combination with touch screens, light pens or mice can be easier to use than command and keyboard based interfaces. Accommodation for the varying levels of computer literacy of individual end users may also enhance acceptance.

Other requirements, such as provision of explanations and the relative experience of the end users with respect to solving the problem at hand are more specific to knowledge-based system applications (Miller, R. A., 1994; Galper et al., 1992). Explanations have been found to be necessary (Shortliffe & Clancey, 1984), which may be due to the non-deterministic nature of the problems and the use of heuristics to find solutions to them. Queries, recommendations and explanations produced by the KBS application must be worded to accommodate the varying degrees of competence of the end users. In the health care domain, for example, terms such as hematoma and micturition may be acceptable for some end users, while terms such as bruise and urination may be preferable for other user groups. Segments perceived to be condescending in tone or too abstract for comprehension may detract from user acceptance (Szolovits & Long, 1982; Bennett, 1983; Gorry & Krumland, 1983).

Some requirements will relate to the specific target environment (see the following references for information concerning the medical domain: Szovolits, 1982; Barnett et al., 1987). Coiera (1997, p. 326) emphasizes that for any system developed to fulfill "a relevant clinical role...must be developed to fit in with the work practices of clinicians." Each project will have specific requirements that reflect the characteristics of the end users. For example, time to interact with the application will be limited for most health care workers. Logically sequenced and uncluttered screens as well as utilities that are adequate in terms of function (e.g. print) and options (e.g. to printer, to file, to screen) may have greater importance than for other software due to their potential to enhance interaction efficiency.

User needs can be identified with the use of questionnaires or interviews. Evaluations of each main iteration of prototype, whether formal or informal, can provide useful feedback for the development team.

4.7.4 Formality Level

Informal or preliminary validation is done during development to identify weaknesses in the knowledge base that must be eliminated with further knowledge acquisition. Informal user acceptance can be measured throughout with surveys, interviews or questionnaires to provide feedback to refine the explanations, recommendations and interface. Informal evaluation in the lab may be sufficient for some demonstration or research projects and for early prototypes of applications intended for commercial release.

Prototypes intended to solve real world problems rather than strictly for research or demonstration are tested more formally. Formal testing consists of evaluating the performance of a prototype on test cases that earlier iterations of the prototype have already solved successfully and that are new or more complex. The recommendations of the system are evaluated by domain experts who were not involved with the development of the knowledge base and who do not know the source of the recommendations.

Different criteria have been used to evaluate the output of KBS applications, whether it be diagnoses, advice or recommendations. The criteria selected for evaluation and performance will depend to some extent on the specifications for the system (Jackson, 1990). It is unrealistic to expect infallibility from a KBS application, but a certain level of competence must be achieved to justify the development expenditures and to make the application useful in the target environment (Jackson, 1990).

When a prototype achieves a specified level of performance in the lab, it may be formally field tested in the target environment (Durkin, 1994). By allowing extant institutional procedures to be run concurrently during testing, the impact of problems due to remaining KBS application deficiencies can be minimized, end users can become familiar with the application, and comparisons of outcomes can be collected. In the health care domain, parallel usage would be a lower risk means of assessing the impact of the system on quality of care or efficiency of accessing expertise (Jackson, 1990).

Because few knowledge-based systems have been evaluated in this way, not many guidelines for formal field testing have been published (Durkin, 1994). In the health care domain, however, formal testing may be mandatory prior to commercial release. According to Horvitz (1997), the "FDA is currently regulating standalone medical decision-support software on a case-by-case basis based on draft policies issued in 1987 and 1989," and considers KBS applications to be medical devices.

4.8 Deployment

Knowledge-based system deployment is the process of integrating an application into the environment in which it is intended to be used. Applications developed for practical use rather than for purely experimental purposes must eventually be integrated into the domain environment in order to be useful. End users must be trained in the correct use of the application. Institutional procedures may need to be modified and equipment (e.g. terminals, networks, printers) may need to be introduced to facilitate use of the application. After release, the knowledge base must be kept current. Maintenance of the knowledge base may necessitate repetition of some or all of the development process tasks (Durkin, 1994; Waterman, 1986).

The deployment process includes such tasks as integrating the system into the target environment, training the users to use the application, and maintaining the application after release. Integration of the knowledge-based system may involve programming to allow it to interact with other software or peripheral devices. Additionally, use of the application will necessitate changes in the procedures (e.g. introduction of a printer, hiring of new staff for data entry) that have been followed to achieve goals in the domain.

End users can learn to use the KBS application by receiving instruction in a class, using on-line tutorials, using hard copy manuals or a combination of these methods. A telephone, E-mail or fax help line for access to the knowledge engineering team will be needed for questions not resolved by any of the instructional methods.

Maintenance of the system will involve repetition of the development tasks to greater or lesser extent. The frequency of application updates will be influenced by the stability of the problem, the knowledge to solve it, and the needs of the end users. To address new demands, the development team may eventually have to rebuild an application.

4.9 Documentation

Documentation is important at all stages of the project (Durkin, 1994). Recording the minutes of meetings, the output from knowledge elicitation sessions, and the reasoning behind significant decisions can help the current development team by serving as a reminder or guide over the long period of development (Waterman, 1986). An archive of this information is also helpful for new members of the development team and for the maintenance personnel. Similarly, archiving the reasons for changes made after the initial version was completed may aid future maintenance or redevelopment.

4.10 Summary

Knowledge base system development consists of several steps which are repeated many times to achieve an acceptable prototype. The following chapter details the rapid prototyping to create the first iteration prototype for the thesis.

Chapter 5: First Iteration of the Prototype Development

5.1 Overview

The first iteration of the prototype was developed by the author at the Faculty of Engineering of The University of Saskatchewan over a period of approximately six months in 1993. This estimate does not include the time for the author: 1) to collect the articles used to create the knowledge base; 2) to have the knowledge base validated by domain experts; and, 3) to learn to use the expert system development tool. As several of the articles could be acquired only through inter-library loan or by visits to other academic institutions, article collection occurred over several months. Validation of the declarative segments and rules of the knowledge base took place over approximately a six month period due to the availability of the evaluators as opposed to actual evaluation time. The author mastered use of Expert-2 in a few weeks, despite the lack of supportive documentation for that development tool. Table 5-1 provides an estimate of the duration of each development stage.

Table 5-1: Approximate Duration of Each Stage of Development for the First Prototype

Development Stage or Task	Number of Hours
• conceptualization of the application (including selection of the sub-domain problem)	50
• development of the knowledge base from printed materials and interviews (including heuristic extraction and preparation of the recommendation segments and details sections)	500
• knowledge representation and organization into rules, including manual debugging	200
• validation with real cases (collected from two clinics in two provinces)	25
• user interface evaluation with representatives from the potential end user group (including development of a questionnaire and a test with mock cases)	75
• modifications to the rule base organization and operation	50
• modifications to the details and extended recommendation segments of the knowledge base	25
Total	**925**

5.2 Development Team

When the thesis project was started, the author was a physiotherapist with five years of clinical experience. The author had experience managing orthopedic and neurological cases, but not specifically PPS cases. She fulfilled the roles of domain expert, potential end user, knowledge engineer and designer. She created the prototype and organized its evaluation by clinicians, academics and students. Denise Stilling, an electrical engineering doctoral student, provided information about operation of the toolkit and modified the KBS shell to satisfy requirements specified by the author.

5.3 Development

5.3.1 Assessment

The goal of the project was to demonstrate the feasibility of KBS technology as applied in the domain of physiotherapy, specifically with respect to clinical decision making associated with case management. The objective was to create a demonstration prototype, which Waterman (1986, p.139) notes can be used to "test ideas about problem definition, scoping and representation for the domain" as well as establishing that KBS technology "can effectively be applied" in that domain.

The research was justified by two complementary reasons. In the domain of physiotherapy, there is a need generated by restricted health care budgets and rapid growth of health care knowledge to find more effective and efficient ways to disseminate knowledge and expertise that is relevant to physiotherapy practice (Dennis, 2000). With the advent of personal computers and improved and expanded KBS techniques, KBS applications have gained potential as tools to solve real world problems. Although they have been used in other health care domains to support clinical decision making, their utility in physiotherapy has not been fully evaluated.

Subdomain Problem Selection

Support for management of PPS cases was deemed by the author to be a suitable problem. It satisfies viability criteria for KBS applications in general (Table 5-2) and the criteria for demonstrating feasibility in domains where few or no applications currently exist (Table 5-2). Although the points in both tables are similar, the points in Table 5-3 are specifically designed to facilitate demonstration of feasibility and gain acceptance of the technology.

Table 5-2: General KBS Application Viability Criteria

- problem is solvable, although complex
- problem scope is sufficiently broad to warrant decision support
- problem scope is narrow enough to be managed within a KBS application
- reasoning involves the use of heuristics and qualitative judgments, but does not rely upon temporal, spatial or common sense knowledge
- end product of interaction is a recommendation or advice rather than a discrete solution

Note: Adapted from Durkin (1994), Waterman (1986) & Dennis (2000).

Table 5-3: Feasibility Demonstration Prototype Criteria

- problem is non-trivial but *not* exceptionally complicated to solve
- problem has *relative* importance within the domain
- problem is small enough to be *easily* managed

Note: Adapted from Durkin (1994).

The sub-domain problem of PPS case management was chosen by the author for two main reasons. It would allow study of the feasibility of: 1) eliciting, representing and encoding knowledge for a disorder that involves multiple systems (cardiovascular, cardiopulmonary, neurological and musculoskeletal symptoms); and 2) designing a prototype for case management (which includes clinical decision making for prescription of treatments and referrals). Case management of PPS also conforms to many of the characteristics noted by Luger and Stubblefield (1998), Durkin (1994) and Waterman (1986) as being desirable for demonstration of the feasibility of KBS in a domain. Suitable problems have the following features: 1) the solution involves human decision making, especially using rules of thumb, making qualitative judgments and handling incomplete and uncertain knowledge; 2) the scope is restricted (i.e. limited number of complex aspects); 3) the solution is apparent and is more of a recommendation than a discrete solution; 4) a similarity to other problems that have been successfully addressed with KBS technology; 5) the solution has perceived value within the domain and the reasoning does not rely significantly upon common sense, temporal or spatial knowledge (Durkin, 1994); and, 6) there are willing and able experts in the area (Luger and Stubblefield, 1998).

5.3.2 Resource Assessment

Resource selection was limited by a lack of funding to support development. However, the project was assessed by the author as feasible because many resources were available at no charge to or were within the personal budget of the author.

Two releases of the Expert-2 ® knowledge-based system shell were available. The earlier version of the software was written for demonstration of the technology on the Atari-ST, and distributed as shareware. The newer version, written to run on Intel microprocessors was available commercially. It had fewer built-in tools, but a useful end user facility (a dictionary function) had been added by Denise Stilling (1989).

The knowledge base could be created with knowledge extracted from texts, journal articles and interviews with practicing clinicians. The author could search for and obtain most printed materials through the University of Saskatchewan and The University of Manitoba medical libraries.

The author would develop the prototype as a component of her graduate studies. Denise Stilling would provide technical assistance as her schedule permitted.

5.3.3 Knowledge Acquisition

At the outset of the project, the author had approximately five years of clinical experience, but had not treated any patients with PPS. Over a period of approximately four months, the author collected and analyzed medical literature indexed on the MEDLINE (Index Medicus), Embase-CD (Excerpta Medica) and The Physiotherapy Index databases from 1981 to August of 1993, inclusively.

Most of the knowledge and heuristics concerning PPS used to derive the rules in the knowledge base and create the discoursive segments was extracted by the author from articles.

The author used other sources less extensively in some of the details and extended recommendation components of the prototype. These sources included: an interview with Heather Flaig, a physiotherapist who had worked in a neurology ward for several years prior to developing PPS herself; a weekend seminar held by Dr. Feldman (a physician specializing in PPS cases) and Pat Gilchrist (a physiotherapist at The University of Calgary) in 1992; and articles from lay literature (e.g. issues of the Disabilities Magazine).

Early in the acquisition process, the author devised a method to organize the knowledge. PPS is characterized by three main complaints: unaccustomed fatigue; new weakness; and new pain (Dalakas et al., 1986). Using a flowchart on two adjacent chalk boards, the author sorted the heuristics elicited from the articles according to the main symptoms and the factors that contribute to them. The discoursive knowledge in the files details (DICT.TXT) and expanded explanations (RUN.TXT) was collated according to the main symptoms, patient education, and diagnosis of the Sequelae. Please refer to Appendix A.7 for a bibliography of articles used to create the knowledge base.

Information about typical end users and target environments came from the interning and working experiences of the author at a rehabilitation centre, an athletic therapy clinic, a large urban acute care adult hospital, a paediatric hospital, and small rural acute care hospitals.

5.3.4 Design

5.3.4.1 Conceptualization

5.3.4.1.1 Knowledge Base

The schema that facilitated extraction of the knowledge and heuristics from the literature was also useful for organizing the rules and discoursive knowledge in the knowledge base.

By providing knowledge directly related to problem resolution, this architecture could enhance knowledge transfer (Zimny, 1987). It could also conform with The Problem Oriented Medical Record (Weed & Zinny, 1989), a charting method which groups information about a patient's status and details about treatments that have been prescribed on the basis of problems being experienced by the patient.

5.3.4.1.2 System Process Flow

A simple structure for operation of the system was adopted. The physiotherapist would use information collected from the patient to respond to queries made by the prototype. The prototype would provide a recommendation based on the clinician's input.

5.3.4.1.3 Knowledge Representation and Inference Method

The author represented the heuristics exclusively with rules because that was the sole method available with the expert system toolkit. Certainty factors, that is, numbers representing the extent of confidence in a rule were not included. The data from the literature did not make reference to certainties or confidence in beliefs. Backward chaining was the sole reasoning strategy used, because it was the only method required.

Declarative knowledge (e.g. facts, general information, definitions) and deeper or more detailed explanations of the reasoning expressed in the rules were organized into topics saved in two different files. The details files could be accessed with a feature of the modified newer version of the development tool. The file of expanded explanations could be run by either version of the knowledge-based system shell.

Please refer to Appendix A.1, Appendix A.2 and Appendix A.5 for a complete version of the details, extended recommendations segments and the rules.

5.3.4.1.4 Software Selection

As noted in the assessment section, the software selection was limited by lack of funding. Both versions of Expert-2 ® were written in the programming language Forth. They used rules to represent knowledge, had backward chaining, and could run some other programs. Rules could be written in natural language with very little accompanying code. Neither version had built-in certainty factor representation, a working trace function, a rule consistency checker, nor a graphical user interface (GUI) development tool.

Expert-2 was written by J. Park in 1984 for university instructors teaching expert system courses. It ran on the Atari-ST and had explanation and change response functions.

The newer version, Expert-2 for PC Forth+ was distributed commercially. This version supported forward chaining as well as backward chaining. Modifications to this version were made by two graduate students at the University of Saskatchewan to satisfy the requirements of their own graduate studies. Westman (1987) added More Rules, a feature that enabled the system developer to segregate related rules into modules that can be accessed as required. Stilling (1989) appended a dictionary function which obviated the need to include definitions or short explanations in the rules themselves. Expert-2 for PC Forth+ did not include either explanation or change response features.

5.4 Implementation - Prototype Evolution

5.4.1 Early Stage

5.4.1.1 Knowledge Base Aspects

The rules representing the heuristics were encoded by the author into the shareware version of Expert-2 ®. Transferring the heuristics into a form that could be manipulated by the knowledge-based system shell was simple compared with using shells that require translation from standard English into a programming language. Antecedent and consequent statements were preceded respectively by the terms IF and THEN. Negation, inclusion and exclusion were accomplished by appending NOT, AND, or, OR to the statements. An asterisk was typed at the end of each statement to signal completion to the shell. Spacing was used to make the rules readable during operation, since the shell did not wrap text automatically. Text colour choices were limited to yellow and white.

An example of a rule as presented in the rule base is shown in Figure 5-1.

Figure 5-1: Example of a Rule

IF The therapist can facilitate the patient's independence in condition management *
ORIF Referral to a psychologist may be warranted and treatment must include education *
ANDIFNOT The therapist wants to review relevant components of patient education *
THEN Patient compliance may be improved with adequate education *

The spaces are due to the limitations of the editor and display capabilities. The asterisks are required for the inference engine.

The first rule module (PLAN.TXT) determined the appropriateness of consultation with the system. It provided the diagnostic criteria for PPS, and discussion of some of the associated issues. Three rule modules (FAT.TXT. WEAK.TXT, PAIN.TXT) contained the heuristics associated with treatment of the three main symptoms and their contributing causes. Another rule module (EDUC.TXT) provided access to educational information about the condition. Discoursive knowledge related to recommendations was accessed by invoking the program RUN.TXT.

The author created each rule module independently, and then tested it for completeness of the reasoning paths and correctness of the recommendations. As each rule module was completed, it was combined with the others into one larger rule base. Each time a rule module was added, the final hypothesis or conclusion of the rule base had to be changed to incorporate the new rules. The rule base was subsequently tested to ensure that no errors occurred as a consequence of the modules interacting or the changes to the hypothesis.

The testing was accomplished using two manual methods. The author visually inspected hard copies of the rule module files for typographical and logical errors, because the text editor on the Atari-ST did not have a spell checking tool and the shell did not have an automatic rule checking tool. The author repeatedly ran the prototype until every reasoning path to each of the conclusions and associated discoursive knowledge files had been traversed. The change response and to a lesser extent the explanation functions facilitated this effort. With the explanation functions how and why, a developer could move backwards or forwards in the rule base. Using the change response feature, each branch of a reasoning path could be checked without having to exit and restart the prototype.

5.4.1.2 User Interface Aspects

The author devised two different strategies to access the discoursive information associated with recommendations. Initially, a command (ANDTHENRUN TOPIC TITLE) was placed at the end of a recommendation, which caused the named segment of text to be displayed automatically when the rule was fired. The author noted that embedding the command in a rule following the recommendation would give the end user the option of viewing the material. As there were advantages and disadvantages for each strategy, the author used both methods for later preference testing with potential end users. In the following rule set (Figure 5-2), the first rule contains the recommendation, and the second rule provides the option to access the associated discoursive information.

Figure 5-2: A rule with the option to view an expanded explanation segment

IF Treatment is required to increase strength and endurance, with care to avoid exacerbating the overuse or precipitating muscle overuse in the disused muscles *
THEN Treatment may include a strengthening or a conditioning program *

IF Treatment may include a strengthening or a conditioning program *
ANDIF The therapist wants to review programs based on research *
THEN Complete articles cited for complete details *
ANDTHENRUN PROGRAMS

5.4.2 Transfer of Development Tools

The author transferred the rules to the commercial version of the shell. Expert 2 ® for Forth+ lacked some helpful functions (e.g. change response, how, why) that were part of the older shell, but it included tools (e.g. More Rules, dictionary) that could enhance operation and increase design flexibility. As well, transfer could facilitate testing with groups of potential end users, as several Intel computers were available but only one Atari-ST.

Transfer of the prototype began with electronically copying the rule base and discoursive information files from the Atari-ST to an Intel based computer. Documents could be now edited with word processing software such as MS Word. Control characters added by the word processing software would cause problems at run time; therefore they were eliminated in the MS-DOS editor prior to files being moved into the prototype.

5.4.3 Intermediate Stage

Knowledge Base and User Interface

After the transfer, the author segregated the rule modules into individual files. With this version of the expert system shell, each rule module could be called as required. Therefore rules that were not needed would not be presented to the end user as had been the case with the earlier prototype. A method to access the newly segregated symptom rule modules was required. As well, a recommendation for only one contributing factor of a symptom could be given each consultation. To acquire advice for other contributing factors or symptoms, the prototype had to be restarted. It would then ask about questions for which it had been given answers in the previous session. Meta-rules and navigational rules were added to address these deficiencies in operation.

The **Problem** rule module was created by the author to load the rule module for the symptom specified by the end user as being of primary interest. To facilitate consultation for all symptoms and all associated contributing factors in one session, a continuation rule was added to the end of the **Symptom** rule modules and the **Education** rule module. This rule provided three options: to end the consultation; to continue for the same patient; to continue for another patient. If the user chose to continue the consultation for the same patient, the **Problem** rules were repeated to allow for symptom rule base selection. If the user wanted to consult the prototype for a new patient, the **Plan** rules were presented. The user could then examine the discoursive segment on assessment, if necessary. As well, if the prototype was to be used several times in one day, this option allowed the user to avoid the start up procedure and screens.

At the request of the author, Denise Stilling added the continuation rule (ANDTHENRUN PLAN#) to the end of the **Problem** rule set to compensate for not having a change response utility. In this way, end users would not have to restart the prototype or follow an undesired symptom path to access the correct rule module if they mistyped or changed their minds about a response.

Some paths in the rule base did not end with a recommendation or operational rule. The author completed each of these logic branches with a rule designed to aid navigation through the knowledge base. An example of one of these **finishing** rules is found in the **Problem** rule module. This message explains why the user cannot get advice and is presented next with a continuation rule. The system advises the user that no other symptoms are covered by the prototype, when the user doesn't respond in such a way as to cause one of the associated rule bases to be opened.

Some statements in the rule base were not satisfactory because line length constraints forced unacceptably succinct expression of the heuristics or advice. At the request of the author, Denise Stilling changed the shell to increase the line length permitted. Many statements were elaborated upon or reformatted to take advantage of this modification.

The dictionary feature provided more flexibility to design for end users of varying levels of experience with PPS and in physiotherapy, without necessitating different rule bases for each level of understanding. A details file containing brief explanations of terms that potentially would be ambiguous or unknown to the end user was created. In the rule base, the terms elaborated upon in the details file were re-entered in upper case letters.

After these changes were made, the author manually tested all paths in the rule base to ensure that operation was not adversely affected, the new feature was functional, and the text in the information and dictionary files was readable. A few customizations were made to the application. The author created a title screen. As requested by the author, two of the prototype start up commands (1 LOAD, USING KBES) were changed by Denise Stilling to make them seem less technical and to coordinate with terms from the domain (PLAN, USING PPS). A disclaimer segment was added by the author. The term "dictionary" was replaced with "details" by the author in the response option instructions that accompanied each rule. This modification was made because discussions and instructions as well as definitions would be accessed with this feature in this prototype. The response option summary instructions were changed by Denise Stilling to include the term physiotherapist. On instruction by the author, the statement "Thank-you for using the PPS Expert System." was made to appear at the end of a consultation. Denise Stilling created a batch file to load all of the applicable files, including the title screen, the introductory segments, the rule modules, the inference engine, and the discoursive segments. At this stage of development, the author arranged to have the prototype informally evaluated by potential end users and physiotherapists with PPS or neurology expertise.

Please refer to Appendix A.4 for examples of an interaction with the first iteration prototype. In this example, the prototype provides an extended segment on patient education.

5.4.4 Evaluation

5.4.4.1 Introduction

Informal evaluation of performance was done by two different groups of potential end users. Three physiotherapists informally and independently validated the knowledge base. Seven test cases were run to compare the recommendations from the prototype to those of physiotherapists at two different Canadian hospitals.

5.4.4.2 User Acceptance Evaluation

Informal testing by potential end users was performed to gain feedback about: user friendliness (the perceived level of difficulty to operate the prototype and acquire advice at a suitable level of granularity); prototype aesthetics (preferences concerning screen appearance, including organization, font, and colour); and the perceived applicability and quality of the recommendations.

5.4.4.3 Fourth Year Physiotherapy Students

Subjects, Materials and Methods

Nine final year physiotherapy students evaluated the prototype as part of the requirements of the neurology elective half course in which they were registered. The students were given credit for attendance, which was mandatory. Their instructor and a clinical physiotherapist with experience in neurology also attended the evaluation sessions. Please refer to Table 5-4 for information concerning the students' physiotherapy and computer experience.

Table 5-4: Student Characteristics

Physiotherapy Experience	
Clinical experience with neurological cases	Mean = 13 cases
Clinical experience with PPS cases	0 %
Computer Experience	
Fairly or moderately comfortable using computer	>50%
Most commonly used software	games, word processing
Platform use	PC (5/9), Mac (2/9), Atari (1/9)

Just prior to the evaluation sessions, an error that caused problems with operation of the **Fatigue** rule module was introduced. Correction was achieved by the author between the two evaluation sessions.

The evaluation sessions were held one day apart in a laboratory containing about 20 computers. The author set up the laboratory prior to the students' arrival. At the beginning of the first session, the students were given a copy of the start-up sequence procedure to enable them to restart the prototype if necessary, mock case studies, and an evaluation questionnaire. The author created the mock case studies based on real cases and data from the literature. An attempt was made to present cases that would require access of all of the rule sets. Please refer to the Student Evaluation Session Schedules in Table 5-5 and Table 5-6.

Table 5-5: Student Evaluation Activity Schedule - Session One

Duration	**Activity**
30 minutes	Explanation of knowledge-based systems and prototype purpose
30 minutes	Instruction in prototype operation using case studies
60 minutes	Independent and group familiarization with prototype using 11 cases, with assistance

Table 5-6: Student Evaluation Activity Schedule - Session Two

Duration	**Activity**
60 minutes	Independent and group practice using 11 cases, continued
60 minutes	Mini-System User Interface Test

The author made notes of comments concerning the interface that were made during the familiarization period. Information was collected about typographical errors, unknown terminology or abbreviations, screen appearance, ease of operation, and actions that resulted in undesired termination of the consultation. The students could also use this time to respond to questions on the system evaluation questionnaire.

Modifications made between evaluation sessions

Between evaluation sessions, the author made a few changes to the prototype in response to student comments and observations of student needs. One change that facilitated navigation was the inclusion in one of the discoursive files of a table of the reasoning paths and recommendations in the knowledge base.

Of the two different strategies applied with the command THENRUN TOPIC TITLE, the students preferred having the option to view or skip declarative information associated with recommendations. The rule modules were modified to replace any recommendation rules with automatic display of declarative information with rule sets providing the option to access declarative information segments, continue with the consultation, or exit the prototype.

The advantage of automatic display is that the end user need not worry about inadvertently missing pertinent information. The advantage of optional display is that end users who are very familiar with the application or with PPS can access the information screens on an as needed basis. Within two hours of uninterrupted interaction with the prototype, the students became frustrated with being forced to see the same information screens repeatedly. End users consulting an application in the target environment might not become frustrated as quickly because the information would be needed, and recalling the information could be difficult if significant time passed between consultations.

Physiotherapy student prototype evaluation responses

Content

All of the students felt that the knowledge base was comprehensive. Most of them believed the wording in the rules and information to be of reasonable complexity and found the reasoning paths to be logical. Most rated the declarative information accessed through rule options or the dictionary function as comprehensive and "great for those with little experience."

Operation

Five respondents rated the prototype easy to use. All of the students stated that having a table of the reasoning paths made operation easier. Three thought that the system was too difficult to restart. Only one noted the inability to change one's response.

Aesthetics

Just over sixty percent preferred that the rules be expressed as questions rather than as assertions.

General

Responses to "Do you feel that expert systems can be useful in the field of physiotherapy?" were varied. Two students felt that knowledge-based systems would be helpful for students, but not necessary for licensed therapists, because the latter group were presumed to be nearly omniscient. Four students stated that knowledge-based system applications would be an efficient means to access knowledge. One respondent thought that the applications would be useful for newly graduated therapists. Another respondent was concerned about the cost of these applications.

Recommendations for modifications arising from analysis of the prototype evaluation responses

A number of recommendations arose from examination of the prototype evaluation responses. A statement explaining omission of respiratory cases could be placed in the introduction to the prototype to prevent frustration or disappointment after a consultation.

It was clear that the role of the prototype as a guide rather than as an authority had to be emphasized more strongly early in the consultation. One rule set required modification to improve transparency of the reasoning. Some students did not read the declarative segment explaining why a psychological consult might be needed for patients with fatigue arising from an impaired reticular activating system. This information could be placed in an intermediate rule or an elaboration of the current recommendation for easier access. A statement at the beginning of the PROGRAMS segment could: 1) explain that articles of exercise program details are limited and not all are of good quality; and 2) re-emphasize that the prototype is to be used as a guide and not as a source of proscriptions of behavior.

The data from the sections on aesthetics and operation suggested that many aspects of navigation and presentation should be improved. Modifying the rule base to allow entry of all symptoms and contributing causes at once could be accomplished and might make the application more practical in the clinical setting.

The ability to change the appearance of the information screens was limited. In any case, the process would consume much energy for little reward. Major modification would be needed of the development shell to allow the user to go backward in the reasoning path or through the information screens. Being able to change one's response would allow the user to simulate **how**, but would not address the absence of a **why** explanation feature. In addition to these hindrances, the interface was command based. The author concluded that transfer of the knowledge base to software with better user interface development tools would likely be the best means to make the interface navigation and appearance acceptable.

Modifications based on perceptions of user needs derived from observation of student interaction with the prototype

The author observed that as the students became more familiar with the prototype, exposure to certain screens and procedures became unnecessarily redundant. Changes were made in the rule base and in the shell to address this issue.

The author added a rule set that included the assertion The therapist requires more information about the PPS(ES). A negative response caused only the disclaimer and program instructions to be displayed prior to loading the **Problem** rule module. Users more experienced with the prototype or with PPS could avoid the screens containing the introduction to expert systems, and the knowledge about how PPS is diagnosed. They also skipped the rule module (PLAN.TXT) that helps the user to determine if consultation is appropriate for a given case and provides an option to access a declarative knowledge segment on assessment components.

Following the author's instructions, Denise Stilling replaced the single startup command with STARTUP1 and STARTUP2. STARTUP1 included the introduction, the disclaimer, PLAN.TXT, and the instructions. STARTUP2 included only the disclaimer and the instructions. She wrote an extension to RUN.TXT to allow reloading of appropriate rule modules but "keep the shell, introduction screen, dictionary and run words loaded" without causing logic errors. PLAN# included an instruction to clear the stacks of results from previous consultations prior to the reloading of a rule module.

PLAN1 loaded PLAN.TXT, PLAN2 loaded the **Problem** rule module, and the PLANs numbered from three to six inclusively loaded the **Symptom** and **Education** rule modules. PLAN2 was appended to the rule including STARTUP2 so that the **Problem** rule module was loaded.

Mini-System User Interface Test Results

The Mini-System User Interface Test was intended to act as an indirect measure of the ease of operation of the prototype. The instrument, originally designed to tap all of the rule modules and most of the declarative information segments was modified to exclude the **Fatigue** rule module for the first test session but returned for the second test session. The test consisted of ten questions including three case studies.

The students accessed most of the recommendations and declarative information required to complete the test. Of ninety possible responses (ten questions by nine students) for the group, eighty-two percent were correct. All students responded correctly on five questions. On three questions, only one student responded incorrectly. Four students did not recognize that the prototype provides advice only for cases with a confirmed history of poliomyelitis. For the question regarding exercise advice for a poliomyelitis survivor not symptomatic of PPS, none of the students responded with both exercise and education. However, eight answered with either education or exercise. Less than five percent (4/90) of incorrect answers were due to an inability to locate the information in the knowledge base.

Note that of ninety possible responses, 82% were correct and that less than 5% of incorrect responses were due to an inability to access relevant knowledge using the prototype.

5.4.4.4 Informal Testing with Licensed Physiotherapists

Two licensed physiotherapists working at the Royal University Hospital in Saskatoon volunteered to evaluate the prototype. The prototype the clinicians evaluated contained the changes made during and after the student evaluation sessions. Please refer to Table 5-7 for information regarding the clinical and computer experience of these physiotherapists.

Table 5-7: Licensed Physiotherapist Characteristics

Physiotherapy Experience	**Physiotherapist 1**	**Physiotherapist 2**
Number of years treating neurological cases	5	>5
Number of years of practice	5	8
Number of PPS cases managed	5	0
Computer Experience		
Comfort level using a computer	low	Low
Previously used software	games	None

Please refer to Table 5-8 for the Evaluation Activity Schedule.

Table 5-8: Evaluation Session Activity Schedule

Duration	**Activity**
15 minutes	Explanation of knowledge-based systems and prototype purpose
30 minutes	Prototype operation demonstration using case studies
30 minutes	Independent and joint practice using case studies, with assistance
15 minutes	Mini-System User Interface Test

The author gave the clinicians copies of the questionnaires that had been given to the students. After the author received the completed questionnaires, she informed the evaluators that a donation would be made to a PPS support group in their name.

Licensed physiotherapist prototype evaluation responses

Content

One physiotherapist felt that the: 1) knowledge base was sufficiently comprehensive; 2) discussions of the terms accessed by the dictionary function were adequate; 3) rules were expressed with a "good" level of complexity; and, 4) level of declarative segments was "good." She concurred with the advice offered by the prototype.

With the exception of rating the declarative segment level of explanation as "reasonable", the other physiotherapist stated that interaction time was too limited to make a fair assessment of the content. She stated that she "did not find any discrepancies with what [she] has read" of the PPS literature and the PPS (ES) knowledge base.

Operation

Operation was rated as difficult by both physiotherapists. The two factors that they attributed with hindering location of relevant heuristics were: 1) the artificial nature of using case studies compared with having a real patient; and 2) inexperience with computers.

Both physiotherapists preferred having the option to view declarative segments to having them presented automatically after triggering of a recommendation rule. One physiotherapist felt that once the user was familiar with its operation, using the application might be more efficient than collecting "the same information through reading articles." The other evaluator stated that consideration of efficiency of collecting information should be tempered with evaluation of the quality of the knowledge acquired.

Aesthetics

One physiotherapist preferred that the rules be expressed as assertions, rather than as questions.

General

Both physiotherapists felt positively about the use of knowledge-based system applications in the domain. One physiotherapist believed that these applications could serve as a "great reference-and not just for sole charge physiotherapists." The other physiotherapist believed that these applications could be used by recently graduated physiotherapists, physiotherapists rotating onto a service in which they had little or no experience, and physiotherapists trying to enhance their abilities. Both physiotherapists felt that these applications could be an acceptable alternative to other means of knowledge transfer. One suggested that the applications could be "convenient" resources that could be accessed when 'patients cancel' or during other unexpected periods of uncommitted time. Both physiotherapists remarked that there was a lot of material on each screen and in each declarative knowledge segment, making it difficult to ingest all of the material at once. The ability to print screens was accepted as a solution to this problem.

Modifications or recommendations based on analysis of the prototype evaluation responses

Overall, the evaluations by the clinicians were positive. However it was clear that a longer period of interaction was necessary to yield more feedback about the needs of the end users, particularly in the clinical setting.

Both physiotherapists had difficulty navigating through the prototype. The reasoning structure was not readily transparent. Through the details feature, they could access a table of the decision making paths. However, this version of the expert system did not include the how, why and change response functions. Therefore, they could not easily move along a particular logic path by going backward toward the original assertion nor by going ahead towards the goal (i.e. a particular recommendation). In a clinical setting, having to access the dictionary function or even to use an explanation function to view the knowledge base architecture might take an unacceptable amount of time. Not being able to print an entire declarative file nor being able to scroll though one in either direction could also be inconvenient in the clinic. Consideration of these points led the author to conclude that modifications were needed to augment the shell with user development tools or that the knowledge base should be transferred to a shell with built-in GUI capabilities.

Mini-System User Interface Test Results

Both physiotherapists responded correctly to the first five questions. Neither physiotherapist had sufficient time to complete the remaining five questions. The physiotherapists completed half of the test in about one quarter of the time that the students required to complete the entire test. No changes were made to the prototype as a result of this data.

Modifications or recommendations made on the basis of mini-system test results

The licensed physiotherapists found relevant information more quickly than the students. No changes were made based on the feedback from this test, as they found the correct information on all questions answered.

5.4.4.5 Informal Knowledge Base Validation

An informal validation of the rules and declarative knowledge file was performed by three physiotherapists, all of whom had experience treating patients with PPS but none of whom was labeled an expert in this part of the domain. All of the validators had a bachelor degree in physiotherapy. Heather Flaig had over a decade of clinical experience working with neurological cases and had been diagnosed with PPS. Laura Klassen held a Master's degree in Rehabilitation Medicine and taught at The University of

Saskatchewan School of Physical Therapy. Monika Kilfoil had a Master's degree in Medical Rehabilitation and taught at The University of Alberta. Her graduate thesis was entitled Reliable Isokinetic Evaluation of Strength and Neuromuscular Fatigue to Determine the Effects of Pyridostigamine in Subjects with Post-poliomyelitis Syndrome. The first two validators had seen the prototype in operation, during the end user evaluation sessions with the physiotherapy students.

All three validators were given hard copies of the rule modules and declarative knowledge files. An examination of the annotated material indicated that there was no discord and some overlap between the three evaluations. All three evaluators were of the opinion that the knowledge base was comprehensive and accurate.

Most of the comments related to the declarative segments. Suggestions included adding, modifying or clarifying some of the phrases and concepts. All three evaluators stated that the utility of the prototype could be enhanced by the inclusion of more citations in the details and the extended recommendation segments. Two other comments were notable due to concurrence and importance. Mrs. Flaig and Laura Klassen wanted an elaboration of the segment on RAS. All three evaluators were unfamiliar with the expression, "condition management dependency" and the POMR.

Ms. Kilfoil felt that references to relevant literature at the end of each heuristic would also be beneficial to end users. In the **Pain** rule module she suggested the addition of: hydrotherapy as a pain alleviation treatment option; a precautionary note regarding the use of heat; a rule or segment about ruling out compression neuropathies; and a rule or segment noting that myalgic pain secondary to fatigue or overuse was amenable to treatment with low doses of anti-depressants. Mrs. Flaig suggested that one recommendation in **Pain** rule module include referral to a pain clinic. Miss Klassen did not note any deficiencies in the rule modules.

Changes made and proposed to the knowledge base as a result of validation

The author made many changes to address the points concerning the declarative knowledge segments. For example, in response to a comment made by Mrs. Flaig during the first student evaluation session, the symptoms were categorized as primary or secondary. The inclusion of references was part of the original design. However, it was not implemented prior to potential end user or domain specialist evaluation because the method to do so had not yet been determined. The author had considered placing them in the body of the declarative text, listed at the end of each declarative knowledge segment, or in a file that could be accessed with an optional rule or by use of the dictionary function.

The comments about the information available for the segment entitled RAS (about fatigue related to changes in the reticular activating system) highlighted the need to describe the role and capabilities of the prototype clearly and strongly early in the consultation. In some cases, a prototype may not be able to provide enough information because the knowledge is not yet part of the scientific data base. Clarification of the first problem in the problem list could be attained by changing it to read, the patient cannot manage his condition independent of physiotherapy at this time. Alternatively, it could be replaced with inadequate knowledge about PPS. Neither of these solutions, however fully addresses the issue of unfamiliarity with the POMR. Revising the problem segment to make it more generic might increase the portability of the prototype between institutions with different charting methods.

5.4.4.6 Performance on Real Cases

The prototype was consulted on seven case histories which had been sent to the author from two different clinics and had been managed by three different physiotherapists. The author compared the results to the actual treatment plans that had been created by the physiotherapists in charge of each case. For a brief description of these cases, please refer to Appendix A.6

A clinician who had been licensed for twelve years sent a synopsis of three cases she had managed at a clinic in Halifax. All three cases had a confirmed history of polio and had been referred for treatment with the diagnosis of PPS, therefore it was determined that consultation with the prototype was appropriate.

Two clinicians working in a clinic in Toronto to which many Post-Poliomyelitis Sequelae cases were referred from other regions, sent a total of four cases. The identity of the clinician managing each case was not specified. One had been a licensed physiotherapist for almost one year and had treated 105 patients with PPS. The other physiotherapist had seventeen years of experience and had managed 65 PPS cases.

The recommendations and suggestions made by the prototype were generally consistent with those made by the therapists on all cases for the PPS symptoms specified and the patient data provided. Some differences were noted, however.

The treatment plans devised by the clinicians detailed the exercise regime that was prescribed. When the prototype advised exercise, the author did not select any of the protocols archived in the knowledge base because she felt that the case data provided was insufficient to appropriately tailor them. For example, case synopses stated strength decrement but did not include the manual muscle testing results or indicated fatigue but did not describe associated precipitating activities. This difference was likely an artifact of testing which would not manifest when the prototype was being used clinically or when more data about the case was provided.

In the second, third and fourth cases submitted by the therapists from Toronto, it was specifically noted that the patient had fatigue. The prototype advised energy conservation, but this intervention was included explicitly in the treatment plan for Case 4 only. This difference could reflect a variance in charting methods or logistics between the two therapists or between the therapists and the prototype.

In the same three cases, inadequate knowledge about the Sequelae appeared in the problem list, but a corresponding note to educate the patient was not on the treatment plan list. Patient education may not be listed separately because it is considered a part of other treatments. Alternatively, in a large rehabilitation center, responsibility for addressing educational needs including energy conservation methods may fall to other allied health care professionals, such as occupational therapists or nurses.

In the fourth case, the practitioner linked the patient with the Fibromylagia Society. The prototype did not make this recommendation. The prototype does not contain knowledge to treat fibromylagia. Neither the research literature nor the physiotherapists who reviewed the knowledge base suggested referral to a Fibromyalgia Society for Post-Poliomyelitis Sequelae patients. Although the two conditions are distinct, there is overlap in symptoms. Thus, a referral of this kind, at the very least for social support and in the absence of a group specifically for PPS patients is reasonable.

It is uncertain if the limit of the knowledge base was recognized with the fourth case. Since this symptom is associated with both PPS and fibromylagia, it is unclear whether the fatigue was secondary to either or both conditions. Neither the cause nor contributing factors of the patient's fatigue were specified in the problem list. The author assumed that the fatigue was due to PPS, but had insufficient data about the patient to obtain a recommendation from the prototype. I deduce Fatigue upon arising, local fatigue and generalized fatigue are the three main types of fatigue included in PPS(ES) was the response that the prototype gave when none of these choices had been selected for the case. Therefore, the tacit advice from the prototype was to gather more information about the patient to rule out inadequate rest, inadequate sleep, pain and other factors for which the prototype does give recommendations. The author noted a need for the addition of a statement such as the following to make the prototype's performance degrade more gracefully: More information about factors contributing to the patient's fatigue is required. Do not consult the prototype for fatigue caused by other conditions (e.g. hypothyroidism, diabetes, depression) or by medication (e.g. analgesics containing codeine). Alternatively, the knowledge base could be modified to include referral to support groups for patients with similar symptoms but different conditions, if a PPS support group was not nearby. These measures might help the system performance to degrade more gracefully.

5.5 Initial Prototype Description

The resulting prototype had a comprehensive knowledge base and could provide advice and supportive information for most of the major complaints experienced by the PPS population that were amenable to physiotherapy treatments. The rule base consisted of ninety rules and yielded twenty-three recommendations. Please refer to Appendix A.5. The declarative knowledge files contained information on seventeen topics and explanations or definitions of nine terms and phrases. Please refer to Appendix A.1 for the explanation segments and Appendix A.2 for the recommendations segments. Summaries of seven exercise protocols from the medical literature are available for perusal.

End users could enter patient specific data by typing their responses to queries posed by the prototype. End user options included: 1) accessing details about terms in intermediate rules; 2) accessing declarative segments on treatments and assessment; and 3) continuing to consult the prototype for the same patient or for more than one patient without having to exit, then restart it.

5.6 Summary

Initial rapid prototyping yielded a system that provided advice and recommendations for the physiotherapeutic management of PPS cases. Deficiencies noted by the licensed physiotherapists and physiotherapy student as well as questions regarding the suitability of alternate KBS development techniques could be addressed through further development of the prototype.

Chapter 6: Development of the Second and Third Iterations of the Prototype

6.1 Introduction

The first prototype demonstrated that the reasoning and knowledge required to generate recommendations for PPS case management could be represented in a KBS. However, informal evaluations indicated that the feasibility of designing an adequate user interface required further exploration.

The versions of Expert-2 used to create the first prototype did not include a graphical user interface (GUI) toolkit. Therefore, interaction between the end user and the prototype consisted of the former using the keyboard to respond in the affirmative or the negative to questions displayed by the prototype. This format limited the transparency of the reasoning and the ease of use. Additionally, there was no facility to save sessions nor to print anything but the current screen, both of which could impair the utility of an application were it deployed to clinics.

Jackson (1990), Waterman (1986) and Durkin (1994) note that transfer of development tools is not infrequently required for project completion. Tools ideal for quick prototyping may be inadequate for full development or deployment. The Expert-2 shell could have been augmented with GUI development capabilities; however it would be more efficient to use software incorporating this feature.

The Level 5 Object (L5O) knowledge base development tool was selected for future iterations of development. It has a rich assortment of tools with a GUI for knowledge base development (e.g. goal and data directed inference methods, rule and frame representations) and graphical user interface development (e.g. radio boxes, check boxes, pull-down menus). Unlike the Expert-2, Level 5 Object was supported with on-line and hard copy documentation.

Change of the development tool and research environment also afforded an opportunity to investigate alternative methods of development. In 1995, two teams of computer science graduate students taking the course 74.717 *AI Implementation* at the University of Manitoba created second iteration prototypes. Rather than simply transferring the rule modules from the first prototype to the new tool these teams, in conjunction with the author, explored the feasibility of knowledge acquisition techniques and sources, conceptualizations, knowledge representation methods, control strategies, user interface designs, and development tools different from those used for the first prototype. Comparison of the processes and prototypes produced could be used to suggest guidelines for future application development (Friedman & Wyatt, 1996). Additionally, a prototype combining the best features of each of these prototypes with the complete knowledge base from the first prototype could be designed by the author to yield a third iteration of development.

As previously indicated, KBS development is iterative. The author assumes the role of documenter to describe each team's approach for each stage of development and the resulting prototype. This is done to provide a framework for the analysis that follows.

The author assumes the role of evaluator (verifier and validator) to analyze the methods and results of each team's projects. This is done to: 1) provide information to further refine the thesis prototype; and, 2) evaluate the utility of each approach for KBS designed for the domain of physiotherapy.

A conceptualization of the third iteration of the prototype, including a complete rule base, concludes the chapter. A discussion of the merits of alternate development methods for physiotherapy KBS is presented in the following chapter.

To describe various GUI features of the prototypes discussed in this chapter, underlining will denote <u>pull down</u> or <u>fly out</u> menus and the commands available through them, bold will signify **push buttons**, and italics will refer to *displays*.

6.2 AI Graduate Course Prototypes Created with Level 5 Object

6.2.1 Introduction

Each development tem consisted of two computer scientist graduate students and the author. The knowledge engineers for Team One were Sonia Narang and Murray Sneesby, and for Team Two were Basil Baluta and Jason Dueck. The author fulfilled the roles of domain expert, potential end user, documenter, verifier and validator.

Both teams used the same knowledge acquisition methods and knowledge sources. Knowledge acquisition is discussed in this section. Other aspects of each team's approaches, such as interface design and system process flow, are presented separately because each team took a unique approach.

The author gave lectures and provided handouts to the teams about physiotherapy in general and case management of PPS in particular. Handouts included key articles and real cases from the medical literature, mock cases, mock charts and other materials.

Only a subset of complaints managed by the first prototype was included in the cases presented. However, a complete knowledge base was not necessary to study user interface design feasibility and the subset was adequate for exploring the merits and difficulties associated with the alternate development methods used.

The teams used the author as both domain expert in PPS case management and as an end user group representative. Therefore, they asked the author questions designed to identify key concepts necessary for problem solving and consulted with her concerning design issues (e.g. user interface needs, target environment conditions). The teams also had access to the initial prototype and could interview its developer (the author) about its construction.

6.2.2 Team One Prototype

6.2.2.1 Design

Knowledge Base

The knowledge engineers chose to organize the data and knowledge into a hierarchical structure based on the Problem Oriented Medical Record (POMR) and the SOAP (Subjective, Objective, Assessment, and Plan) charting methods (Weed, 1989). The main categories selected to collect, arrange and analyze data included patient information, history of present illness, past medical history, and physical examination. Each main category was comprised of one or more sections designed to collect and analyze more specific information. For example, the history of present illness category was subdivided into five sections which grouped information concerning PPS associated complaints (weakness, pain, cold intolerance, fatigue, morning headaches) and patient needs (current aids).

The knowledge engineers felt that this architecture would "help significantly in the incremental development of the prototype" (Narang & Sneesby, 1995, p. 6); facilitate logical extraction of case specific information from end users; and "make the maintenance procedure simple and efficient" (Narang & Sneesby, 1995, p. 6).

Process Flow

The end user enters case specific data collected from a history and physical examination of the patient into the appropriate categories and sections. The prototype analyzes this data to provide a recommendation or request more information.

Knowledge representation and inference strategy

Rules were selected as the method to represent the heuristics because they are suitable for "diagnosis and prescription paradigms" (Narang & Sneesby, 1995, p. 7) and have a "declarative nature" (Narang & Sneesby, 1995, p. 7). A mixed mode inference strategy was adopted. Forward chaining was employed to derive a prescription. Backward chaining was used to determine which factors were contributing to a symptom.

6.2.2.2 Implementation

Knowledge Base

Seventeen demons (forward chaining rules) represent a subset of the heuristics initially identified. When triggered, eight of the demons lead to the display of recommendations for eight complaints (inadequate knowledge of PPS, sleep apnea, inadequate rest, excessive workload, excessive recreational exercise, muscle overuse, excessive fatigue and night pain). The attribute CONCAT, appended to some consequent statements displays more declarative knowledge relevant to the recommendation. The remaining rules allow the user to access explanations of the advice provided.

User Interface

Accessing and Quitting

The prototype can be started by clicking on an icon representing it or by selecting it from a list after opening Level 5 Object. Exiting the prototype can be done from all screens by selecting the Exit command (System pull-down menu) or clicking an **Exit** button on some screens (e.g. *Main Menu*, *Recommendations*). **More** (*Recommendations*) allows the user to continue entering data for the same patient, beginning at the *Main Menu*. **Restart** (*Recommendations*) and Restart (System) return the user to the title screen for entry of particulars about a new case.

Navigation

Once having entered the application, the end user usually has the option of selecting either a button or a pull-down menu to navigate its eighteen displays.

Buttons:

The main menu screen, entitled *PPS Treatment System*, acts as an index. It has buttons that link the user to five main categories of displays (Patient Information/Social History, HPI, Polio History, Physical Examination and Evaluate). The main screens in each group can alternatively be reached using the Patient Information and System pull-down menus.

In the HPI category, **Next** and **Previous** allow the user to move between the symptom screens without having to use Symptoms. The **OK** button returns the user to the main screen of a category from another display in that group, or to the main menu display from the main screen of each category. For example, clicking **OK** in *Occupational Information* causes the *Personal Information* screen to be displayed. Selecting **OK** in *Personal Information* results in the index menu *PPS Treatment System* being presented.

Pull-down Menus:

There are five pull-down menus. The System menu contains the options to Restart, Exit, and Evaluate the data currently entered, or to go to the *PPS Treatment System* (Main Menu) screen. The Patient Information menu lists the main screen for all but the *Evaluate* category of displays and several of the associated screens. The Physical Examination menu accesses the physical examination and medications/tests screens. PMHx connects the user with the main displays for two of the main categories (HPI and Personal Information) and with the sole associated screen for the past medical history category (PMHx Symptom). Symptoms, available for all of the HPI category of displays, lists the screens for each complaint for which the prototype gives advice and the main screen for the HPI category. The Patient Information, Symptoms, and Physical Exam pull-down menus are the sole means of reaching displays associated with the main screen of each category.

Data Entry

Users can select the appropriate pre-defined item in a radio or check box or indicate the status of a condition (true or false) to provide the inference engine with the case specific data required to make a recommendation. For charting purposes, additional data can be entered by keyboard into fields located on some of the displays.

Functionality and Features

The user can restart the prototype to enter data about a new case, or return to the main menu to enter more information after receiving a recommendation. New information or amendments to previously entered data can be made by returning to the relevant display. The prototype can be used to extract advice and for charting.

Advice

Recommendations are presented in the 'Treatment Display' box on the *Recommendations* screen in response to the request to 'Evaluate.' Explanations of the reasoning leading to the conclusions can be accessed by selecting the **Explain** button, which displays the *Explanation* screen. The *Explanation* screen contains the recommendations and a summary of intermediate conclusions reached by the prototype based on data entered by the user.

A more detailed description of the prototype can be found in the Appendix B.1.

6.2.3 Team Two Prototype

6.2.3.1 Design

<u>Knowledge Base</u>

On the basis of domain relevant knowledge supplied by the authors, the knowledge engineers organized the knowledge primarily according to anatomical locations rather than physiological systems or type of complaints. They felt that this approach gave them "flexibility to have very different attributes to describe symptoms, examination results, causes and treatments depending on the location in the body" (Baluta & Dueck, 1995, p.14). It also facilitated a hierarchy ranging from a very general level (i.e. overall body) to an intermediate level (e.g. lower extremities, trunk), through to a more specific level (e.g. right hamstring, left knee).

Process Flow

In the proposed process flow, the end user collects information about the case and enters it into the patient profile screens. The prototype analyzes the initial data to determine which screens are appropriate for display to extract more case specific data. As well, the prototype interacts as needed with a number of databases: electronic patient history or medical records; dictionary and reference; images; and cases. The prototype gives definitions or displays images as requested by the end user during a consultation. A recommendation is provided after data from the physiotherapist and the databases have been analyzed. The process flow implemented for this version of the prototype is limited to interaction between the end user and the application, exclusive of electronic databases.

Knowledge representation and inference strategy

Initially, the knowledge engineers considered an object-oriented representation. However they abandoned this method because aside "from the patient, there weren't any domain objects to map into classes… [and]…the attributes and their legal values that could be defined for each symptom class" (Baluta & Dueck, 1995, p.14) varied too much to make use of this conceptual entity efficient. Baluta and Dueck (1995) adopted a rule based representation because this method has been used to successfully develop prototypes designed for solution of diagnostic problems (Baluta & Dueck, 1995, p.14). Forward chaining was the inference method they selected for both treatment and identification of underlying causes.

Although conceptually similar to a frame based representation, neither inheritance nor other object oriented properties were used in this prototype (Baluta & Dueck, 1995). However, the team noted that the structure lent itself to being implemented with a relational database in addition to a knowledge-based system (Baluta & Dueck, 1995, p.15).

6.2.3.2 Implementation

Knowledge Base

"The prototype is limited to demonstrating effective clinical decision making for four case studies provided by" the domain expert (Baluta & Dueck, 1995, p. 19). The heuristics are coded into 27 demons and grouped into four separate classes which represented each section of the patient history and the recommendations. Advice is generated for problems such as sleep apnea, general pain, excessive workload, weakness, inadequate rest, cold intolerance, and inadequate sleep.

User Interface

Accessing and Quitting

The prototype can be started by clicking on an icon representing it or by selecting it from a list after opening Level 5 Object. Quitting the prototype can be done from the *Main Menu* screen only. Selecting the **Main Menu** button returns the user to the *Main Menu* screen from which other displays can be accessed to change or add new values. A **Restart** button on the *Main Menu* screen allows entry of data for a new case.

Navigation

Buttons are used exclusively for navigating through the eight screens. From the *About*, *Recommendation* and all of the history category of screens, the sole button on these screens returns the user to the *Main Menu* display.

Data Entry

Users select the appropriate pre-defined item in a radio or check box to provide the inference engine with case specific data required to make a recommendation. No provision is made for charting of information not needed to reach one of the recommendations made by the prototype.

Functionality and Features

New case information or amendments to previously entered data can be made by returning to the relevant display. To enter information about a new patient, the user clicks on the **Restart** button. The prototype remains on the *Main Menu* display, however all values from the previous consultation are deleted.

Advice

Advice is presented on the *Recommendations* screen when the **Go!** button on the *Main Menu* screen is selected. This version of the prototype is capable of providing advice for only one of the main complaints each consultation. The knowledge engineers note that the recommendations currently in the knowledge base would need elaboration (Baluta & Dueck, 1995). As well, advice for more than one complaint would be necessary for a production version of the application (Baluta & Dueck, 1995).

A more detailed description of the prototype can be found in the Appendix B.2

6.3 Informal Evaluations of the Prototypes

6.3.1 Introduction

The prototypes created by both Baluta & Dueck (1995) and Narang & Sneesby (1995) are sufficiently complete to demonstrate the feasibility of designing a user interface that meets the needs of the end user and the target environment. The GUI features of Level 5 Object supported designs that allow for quick and simple data entry, navigation, and extraction of advice, and access to explanations for the recommendations. Additionally, by providing optional access to definitions and deeper explanations the hypertext feature can facilitate designs that are suitable for both the novice and the more experienced physiotherapist. Although not implemented by either team, saving and printing are possible, as is acquisition of information from electronic databases.

Informal evaluation of the prototypes produced with Level 5 Object was performed to determine which characteristics required reformulation, refinement and redesign (Waterman, 1986) to advance towards the ideal implementation. The evaluations were performed by the thesis author acting as both domain expert and potential end user.

6.3.2 Team One

Knowledge Base Informal Evaluation

The knowledge base is incomplete and contains some errors. However, the organization chosen is logical and will likely simplify further development and maintenance. The explanations given for the recommendations are currently superficial, however there is potential for enhancement. The knowledge representation and inference methods selected are functional.

User Interface Informal Evaluation

The system process flow provides a basic option for consultation with the application. However, it does not include the possibility of data extraction directly from electronic databases or patients. As well, no provision is made for an instructional tutorial. More importantly, there is no mechanism to exclude inappropriate cases. Starting and quitting the prototype can be done easily, especially compared with the first iteration of prototype. In the target environment interruptions are common, therefore the ability to exit from any point in the prototype is convenient. Changing values for the current consultation or clearing values to begin a new consultation are relatively simple procedures. The inability to save values and recommendations for each session however, limits the utility of the application. If a consultation is not completed prior to exiting, values are lost and must be re-entered to gain advice. As well, comparisons cannot be made over time because there is no facility for permanent charting. The usefulness of the application may also be minimized by the absence of a print function to render the recommendations and values for each session onto hard copies.

In general, the displays are comprehensive in the items included. For charting purposes, more instances of a complaint are required to track behavior in different areas independently. An example is that weakness in one muscle group may change at a different rate than that for another muscle group.

Text boxes are located on many displays for recording information not presented in the check box, radio button or Boolean (true/false) areas, supporting the role of the application as an electronic medical record. Efficient use of the application for advice exclusive of charting is not possible, because the data required for making recommendations is interspersed with non-relevant items and is not identified as being salient with respect to garnering advice.

The use of colour to differentiate the group of radio buttons and check boxes related to each complaint may facilitate ease of use. Colour acts as a cue indicating that the user has moved from one display to another or is still in a particular display. This is advantageous, as the typical end user is likely to be interrupted several times throughout a consultation.

The ability of the order to control displays, although desirable for the user who has experience with both computers and the application, may lead to confusion for other users. Navigation is impaired by some design elements. For example, the path to reach some screens is not intuitive, which may result in incomplete data entry. This problem is exemplified by the route to reach the symptom displays. To enter data about the complaints currently being experienced by the patient, the user must first go to the *History of Present Illness* display, then select other applicable displays from the Symptoms pull down menu. No buttons or fly-out menus exist to guide the user to these displays.

Misleading names are another impediment. One pull down menu is labeled Symptom and another is entitled Symptoms. The former is part of the PMHx pull down menu group and refers to a display that collects information about complaints experienced during the acute poliomyelitis attack and subsequent rehabilitation period. The latter, which appears only on the only on the HPI category of displays, connects the user to the members of this group. The infrequent user may confound the two menus, reducing data entry efficiency and increasing user frustration.

Finally, labeling a push button with a name that differs from the display to which it refers may obscure the connection. The display entitled *Personal Information* is reached from another screen by selecting a push button labeled **Patient Information**.

This version of the prototype does not support multiple instances of contributory causes for some complaints. For example, recommendations for one type of pain only can be given each session. Augmentation of the rule base would be required to allow all potential contributory causes of all complaints to be considered in the same session.

The Explanation feature requires further development. Currently, values selected by the user for key items are reiterated above the field in which the recommendations appear. The association between the recommendations and the items is unclear, however. When several recommendations are listed, the end user may be uncertain as to which key item caused a given piece of advice to be displayed. By locating key items beside the related recommendations, transparency of reasoning may be achieved.

Another source of reasoning opacity is the key item labeled ‘muscle overuse’. The value of this item cannot be set directly by the user because it does not appear in any of the other displays. It is set to the value of true when rest or sleep are inadequate, pain is burning or occurs at night and for some other conditions. These relationships are not elucidated by the explanation feature. It would be possible to organize the display layout in such a way as to highlight the reasoning, however.

The resulting superficial level of explanation could be deepened with hypertext links from the key items to lengthier declarative segments.

Please refer to Appendix B.3 for raw notes of the analysis of this prototype.

6.3.3 Team Two

Knowledge Base Informal Evaluation

The knowledge base is incomplete and contains many errors. The architecture is based on anatomical regions, which is arguably not ideal for the case management of PPS.

User Interface Informal Evaluation

The proposed system process flow has many options regarding the acquisition of data needed for charting and advice purposes. Electronic databases are exploited for information about particular patients, definitions, references or abstracts, images, case studies, and saved sessions. Not all of these features have been implemented in this version of the prototype, however. Currently, the prototype receives data from the user and provides applicable treatment recommendations. A tutorial for novice or infrequent users is not included.

The application can be started easily. Quitting from any display other than the *Main Menu* requires return to that screen to select the **Quit** button. Although this requires only one additional step, it may be perceived as an inconvenience especially to the frequent user. Changing values for the current session and restarting to make entries for a new case are easily accomplished. The proposed complete implementation facilitates saving values from interrupted sessions. Printing sessions was not implemented in this version of the prototype. Data is entered mainly by clicking to select appropriate buttons or boxes.

Omission of relevant information might result in recommendations that are incorrect or inadequate. The displays in this version would require more items to collect the patient specific information to elicit all advice available in the complete knowledge base. No accommodation is made for charting of demographic particulars, response to treatment, or details concerning the patient's condition that are at a lower level of abstraction than that used to obtain advice. This streamlined approach ensures efficient extraction of advice, but may be inadequate to satisfy the needs of some end users, especially with respect to charting.

The user has limited control with respect to the order of screen display. All displays are accessed exclusively from the *Main Menu* display and only with push buttons. To reach another history display or the recommendations, and to exit or restart the consultation, the user must always return to the Main Menu. This minimizes confusion for the user who is not familiar with the application or who has forgotten its layout. However, field testing will be necessary to determine if the inability to move directly to desired displays is considered inconvenient by the frequent user.

The proposed explanation feature was not implemented in this prototype. Recommendations that have been triggered are presented in a field on the *Recommendations* display. They are brief and do not give any indication as to the reason they have been made. A feature to access explanations or more comprehensive recommendation segments is required to make the reasoning transparent to the physiotherapist.

Notes on the analysis for this team are located in Appendix B.4.

6.4 Proposed Third Iteration Prototype Design

6.4.1 Introduction

The initial and AI Implementation class prototypes demonstrated that creating a knowledge-based system application for PPS case management is feasible. However, all three prototypes required further refinement. In 1995, the author identified the best features of each of these prototypes, then combined and extended them to describe a conceptualization of the next iteration of development. The new design included desirable elements of the class prototypes and of the initial prototype. Additionally, the author made augmentations so that the prototype would more closely approximate the desired behaviour with respect to the adequacy of the reasoning and of the user interface. Level 5 Object was maintained as the development tool because it produced an adequate user interface for this iteration of development.

Design

The following is a description of the proposed third iteration of prototype. It was not fully implemented however. Screens based on the author's design can be seen in Appendix B.8.

<u>Knowledge Base</u>

The knowledge and reasoning are organized according to PPS complaints and associated factors because this structure: 1) reflects the method in which problem solving and charting are frequently performed in the domain; and 2) facilitates maintenance of the knowledge base as research yields information that has an impact on treatments directed towards various symptoms of the Sequelae.

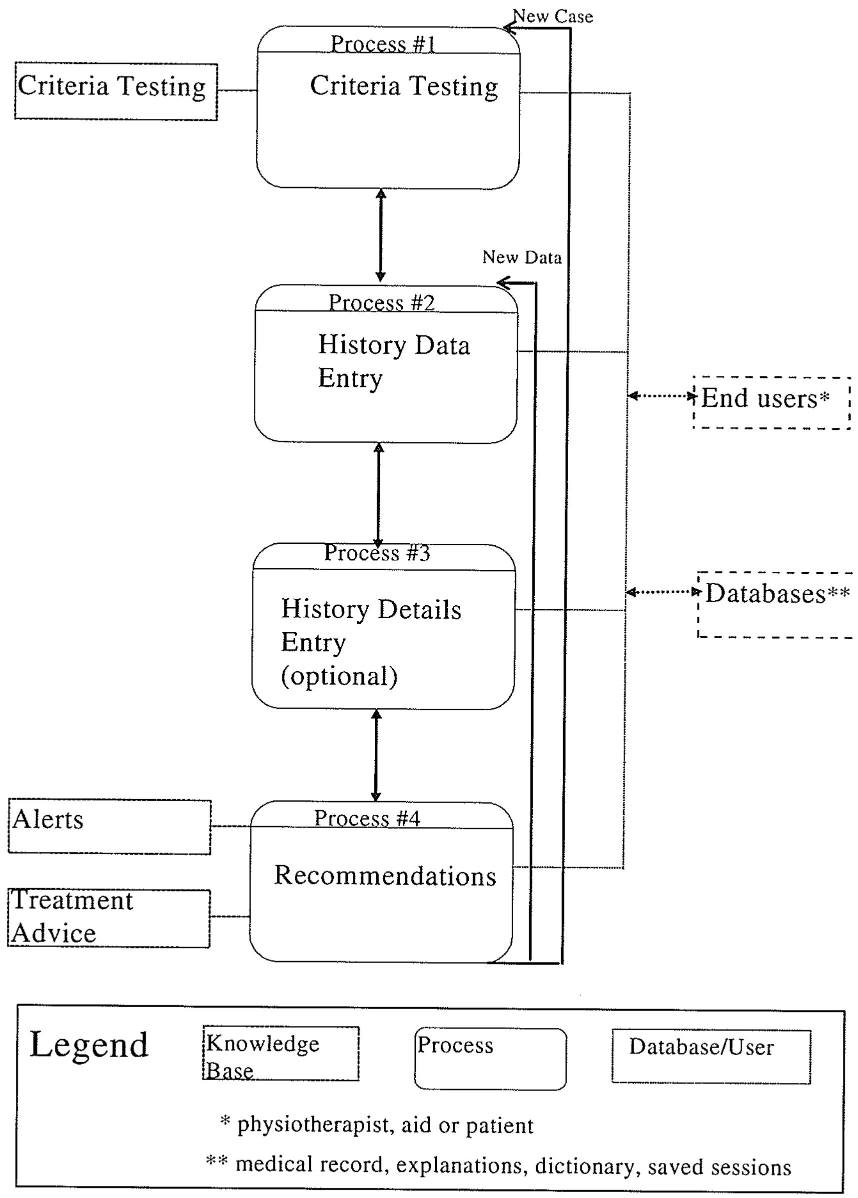
<u>Process Flow</u>

The application interacts with humans and electronic databases (where available) to gather data about each case and provide explanations or definitions when requested by the end user. An overview of the system process flow is presented in Figure 6-1.

<u>Knowledge representation and inference strategy</u>

Rules, effective as a means to represent knowledge in the prototypes, will also be utilized for the knowledge base in this implementation. Backward chaining is the sole inference method employed. It was functional in the earlier prototypes and continues to be appropriate because the number of recommendations is significantly smaller than the amount of data needed to achieve them (Waterman, 1986). In this implementation, forward chaining is not required to yield clinical diagnoses from the raw data. With guidance from the *Main Complaints* display, the practitioner is responsible for making decisions concerning information at a lower level of abstraction. For example, the physiotherapist must identify weakness by finding a grade of one out of five from doing a manual muscle test.

Figure 6-1: Knowledge Base System Process Flow



6.4.2 Implementation

Knowledge Base

The rules from the first prototype were converted into a form suitable for Level 5 Object (L5O). Rules that were required for operation of the first prototype were omitted as they were not necessary in L5O. Rules to alert the user were added to customize recommendations through this mechanism rather than by including the information in the lengthier advice segments. Lengthier advice segments were edited to reflect these changes and titles were added to relate the patient specific data entered with the recommendations made.

The resulting knowledge base has a total of forty-four rules and is divided into three modules. Three rules in the PPS Diagnostic Criteria Confirmation module determine the appropriateness of using the application for each case. When triggered, the nineteen flags of the **Alerts** module add case specific advice to the recommendations subsequently given. The **Treatments** module contains the twenty-two heuristics required to yield the recommendations. These rules are located in Appendix B.5.

Please refer to Appendix B.8 to examine the notes labeled "Description of the Proposed Third Iteration Prototype Design".

User Interface

Accessing and Quitting

The application is opened by clicking on a representative icon. To start it, the user must enter a user identification number and password. This mechanism is intended to limit use to those who have a valid purpose for examining the saved sessions which may safeguard the privacy of the patients for whom the system has been used. An *Introductory Screen* with options to do an on-line tutorial, to open a saved session or to obtain advice for a new case is presented next. Selecting a saved session takes the user to the *Main Menu* screen for that file. Initiating a new session invokes a second safeguarding mechanism, the PPS Diagnostic Criteria Confirmation rule module.

When the PPS Diagnostic Criteria Confirmation rule module determines that a case is not suitable (because the diagnosis of PPS is suspect), it recommends that the patient be referred to a physician for further assessment, gives an explanation for each failed item on its checklist and returns the user to the *Introductory Screen*. When the case satisfies the diagnostic criteria for PPS, the *Main Menu* screen is displayed. The *PPS Diagnostic Criteria Confirmation* screen values are automatically entered in relevant sections of the History screens.

For a mock consultation, please refer to Figure B.9-11 and Figure B.9-12. When the clinician does not have a confirmed history of poliomyelitis, the prototype explained why it should not be consulted for the case management of this patient.

Exiting the program can be accomplished from any display in the application with the **Quit** button or Quit option from the System pull down menu. Quitting from any of the history or recommendations displays results in a dialogue box that prompts the user to save the session values. Open/New allows the user to open a saved session by entering the patient's identification number and visit date or to start a new consultation.

Navigation

Navigation is accomplished using a mouse to activate push buttons and pull down menus. In many cases, the end user has an option of selecting either of these methods to accomplish a particular goal. An option to restrict navigation to buttons for infrequent or novice users could be added should field testing indicate confusion due to the presence of both navigation methods. The user chooses the order in which screens are displayed, however this aspect could also be restricted on the basis of the familiarity of the end user with the Sequelae and with the application, should it become evident with field testing that limited options are more user friendly .

Displays/Screens

There are five categories of screens, grouping displays according to their content. The three introductory displays include the title, introduction and tutorials. The diagnostic category contains only the *PPS Diagnostic Criteria Confirmation* display. The main history category is comprised of nine displays that collect information about the present and past medical history of the patient. More specific information, such as which joints are painful or the strength grade of particular muscle groups can optionally be recorded in the six details history category of screens. *Recommendations* and *Treatment Record* are the two displays in the recommendations group.

For a more detailed description of the implementation, please refer to Appendix B.5.

Buttons

Selecting the **Quit** push button prompts the user to save entries made during the session prior to closing the application. **Main Menu** returns the user to the display of the same name. **Treatment Record** gives access to the screen of the same name for charting purposes. **Continue** connects the user to the *Introductory Screen* from the *Title Screen*.

Pull-Down Menus

There are three pull down menus. System is located on all but the Title Screen display. With this menu, users can: quit the application; acquire help; open saved sessions; initiate a consultation for a new patient; save sessions; print; or compare some session values from visit to visit. The Advisor menu provides access to definitions, lengthier recommendation segments, the *Recommendations* display, and references. History Menus links the user to the History and Details categories of displays, as well as the *Treatment Record* screen. All displays are listed under the pull down menus.

Data Entry

Information about each case will be acquired automatically when possible from electronic databases. For example, when a ward clerk has entered the patient's health insurance number, where available the application contacts the appropriate medical database for information such as the patient's full name, date of birth and mailing address. Other information such as medication names or presence of certain symptoms, may be scanned in from forms completed by patients, or entered manually into a subset of the displays by a department clerk.

These options would limit physiotherapist interaction with the application to entry of data that requires domain training to collect (e.g. assessing the absence or presence of lax ligaments) and to acquiring advice. Alternatively, the physiotherapist can collect all of the data required to elicit advice or required for a medical record and enter the information manually or by completing forms to be scanned or transcribed by clerks.

One disadvantage of scanning information into the application is the loss of interactivity. By doing all of the data entry, the physiotherapist can ask for definitions and clarification throughout, potentially enhancing understanding of and confidence in the recommendations. Field testing is necessary to determine the impact of this option.

Manual data entry is accomplished through a variety of methods, including selecting radio buttons, check boxes, and Boolean (true/false) boxes or typing information into text boxes. All data required to yield a recommendation and associated patient specific advice is entered by clicking the mouse to make a selection. Only specific details regarding complaints or special notes must be typed.

6.4.3 Features

Tutorial

From the *On-line Tutorial* display, accessed from the *Introductory Screen*, the user can acquire general instructions or receive training with examples of case studies in the use of the application. The general instructions, which include a list of all of the displays and their contents, can be accessed from Help in the System pull down menu.

Charting and Saving

The full implementation of the application optionally serves as an electronic medical record database for each case. This function necessitates implementation of security measures to ensure that patient confidentiality and record integrity are maintained. Patient confidentiality is protected by the requirement of user identification and passwords to consult with the application, and thereby gain access to saved sessions. Record integrity will be an issue for those target environments where the application will be used as a database.

To increase flexibility, the application provides the user with three options regarding saving. The user can decide not to save values at the end of a consultation, save them into files that can be modified later, or submit them to a database. When the application is being used as an official record, the second option lets the physiotherapist make additions or changes over a period of time. Changing values of items in records not yet submitted is accomplished by returning to the relevant display prior to exiting from a session. This facility is beneficial because in the target environment, consultations frequently may be interrupted, resulting in termination prior to completion. All saves are logged in a directory that records the time and date, specific modifications, and user identification. The log acts as a record for legal purposes. It is hidden from and inaccessible to the user. Once all session data has been entered, the physiotherapist can submit the record to a secure database, after which it can be read but not modified. A password must be entered before the record will be saved to this database, protecting the physiotherapist and the patient. The submission date is entered automatically, and may be different from the visit date. Consultations that have not been submitted could potentially be considered the equivalent of notes on scrap paper, rather than an official record. For facilities that did not utilize the database feature of the application, hard copy output could be added to the patient's chart.

Printing

Sessions can be printed in their entirety or with only the recommendation displays material. Each print-out includes the visit and session submission dates. Hard copies can be affixed to the paper chart or forwarded to the attending physician as an update.

Assessing Patient Progress

PPS case management may extend over a long period of time. The ability to quickly view the behavior of certain complaints and the effectiveness of treatment for a given duration could be an efficient tool for the physiotherapist.

Compare causes values for some of the history and details screens to be displayed in tabular form for all visit dates. This allows the physiotherapist to assess changes in symptoms and signs from the initial assessment to the date when the comparison is requested. Figure 6-2 displays data as it would look with when the Compare feature was invoked. Use of Compare may depend upon the extent to which the application is used for charting rather than for advice. Values for the fields may come from: 1) an entry made by the clinician; or, 2) a calculation based on other information entered by the clinician or accessed from an electronic medical record.

Figure 6-2: Example of Data Displayed by the Compare Feature

Patient Status According to Visit

Date/Characteristic	Visit #1	Visit #2	Visit #3
Weight Status	obese	obese	normal
Weight Behavior	stable	decreasing	Stable
Ambulation Status	1 cane	1 cane, 1 assist	wheelchair
Knee AROM E / F	-5 / 130 degrees	0 / 120 degrees	0 / 90 degrees

Advice

Recommendations of two hundred words or fewer in length are provided in response to the data entered. Fuller recommendations can be accessed using one of two methods. The physiotherapist can click on the applicable hypertext on the recommendation display or find the appropriate labeled fly-out menu of More in the Advisor pull down menu. Additional advice is triggered to tailor the recommendations for some cases (e.g. patient taking CNS depressants). Each recommendation is prefaced with a statement that explains the reason for this advice being given. An example is provided in Figure 6-3.

Figure 6-3: Example of a Recommendation

You have indicated that your patient has muscle overuse. Energy conservation techniques are recommended for patients with muscle overuse. This may reduce the associated fatigue, pain or weakness. For more information about these techniques, refer to the **MORE Segment** on **Muscle Overuse**.

Advice versus Charting

To acquire recommendations exclusive of tailored advice, the physiotherapist is directed to enter data exclusively on the Main Complaints display. The rules for all of the recommendations are triggered by the values for items on this screen. The associated alerts are triggered by data entered in the other main history category of screens. Information at a level or of a type not needed to acquire advice need not be entered. This option provides an efficient means to acquire the recommendations. For example, the actual grade of weakness need not be recorded to access advice on strengthening.

For end users interested in using the application for charting as well as for advice, it may be considered redundant for the physiotherapist to analyze raw data that is already available to the application. To minimize interaction time, the application could process the raw data with a meta-rules module that translates the information into assertions recognized by the Treatment Rules module. For example, when a grade of 2+ is assigned to a muscle group by the physiotherapist, the intermediate conclusion of weakness is deduced and passed to the Treatment Rules module.

If this feature were implemented, data could be obtained by the inference engine optionally from the *Main Complaints* display or from the details history category of displays. Further field testing to examine the need and desire for automatic analysis at this level of abstraction is essential.

For more detail, please refer to Appendix B.9 for sample screens of the proposed implementation.

6.5 Summary

The primary purpose of the second iteration prototypes was to investigate the implementation of an interface that would be acceptable to potential end users. Level 5 Object, a development tool that has GUI capabilities for the user interface was selected for this purpose. With the feedback discussed in Chapter 4 in mind, the author evaluated each of two prototypes created with L5O. Although these two prototypes were designed and implemented differently, relative to the first iteration prototype they were both characterized by intuitive navigation, transparent reasoning, and ease of use. However, neither was completely implemented and both would require further refinement to be deemed adequate.

The best elements from each prototype were combined to yield the design for the third iteration prototype. An implementation from this design would require field testing to acquire evaluations from a larger, more representative and more objective group of potential end users and to identify factors that would have impact if the application were deployed. More iterations of development would be required prior to attaining a commercially viable version of the application.

Chapter 7: Project Analysis and Discussion

7.1 Introduction

This chapter begins with a brief summary of the results of the rapid prototyping described in Chapters 5 and 6.

The next section outlines the lessons learned from rapid prototyping. An analysis of all three prototypes from the first and second iterations of development was done by the author to ascertain which methods might be useful in the creation of KBS in the domain of physiotherapy (Durkin, 1994; Friedman & Wyatt, 1996). Considerations for research to extend the findings of this project are included in each section of development, as applicable.

The thesis focused on the question of whether a functioning physiotherapy clinical decision making system could be **developed**. However, whether an expert system can be successfully deployed, that is adopted and used, is also an important question. A brief discussion of some of the issues surrounding deployment follows to provide a broad perspective of what would be entailed in introducing a KBS into practice.

7.2 Summary of Prototype Development Results

For the first iteration prototype, the author (who was a domain member) collected articles and interviewed a clinician to develop a knowledge base. The knowledge acquired was represented with rules. A backward inference strategy was employed. The prototype was evaluated and changes made accordingly to the knowledge base. The user interface required refinement that was not attainable using the initial expert system shell.

The two second iteration prototypes focused more on the user interface and less on the knowledge base, the reverse of the first iteration. Knowledge acquisition was done mainly by interviewing the author and examining the first iteration rule base. The knowledge was represented with rules; frames were considered but ruled out. Both forward and mixed inference strategies were used. A different expert system toolkit was employed. An improved user interface was produced.

The best of elements on all three prototypes (first and second iterations) were combined in a conceptualization of a third iteration prototype. The third iteration prototype, once transferred to a development tool that is being supported, could be formally evaluated and ultimately deployed for field testing.

7.3 Lessons Learned

7.3.1 Development Team

While demonstration prototypes can be constructed independently by clinicians using shells, the input and participation of those with computer software expertise is imperative for commercial systems. This was evidenced during the first iteration of development. The author created the rule modules independently but required the programming expertise of Denise Stilling to append an introductory splash screen to the beginning of the rule base.

Clinicians are invaluable because they contribute to the content of the knowledge base and the design of the user interface. In industry, it is felt that clinical specialists who have an understanding of how systems are created can help to streamline the process of knowledge acquisition and encoding (Rick Workman, Momentum Healthware, Inc., personal communication, May, 2005).

In the second iteration of the prototype, the author felt that understanding how knowledge-based systems are constructed was helpful in selecting and preparing materials (e.g. medical articles, case studies) for the graduate computer science students in a manner that would facilitate encoding of the expertise. Cases were presented as much as possible in consistent and standardized formats. For example, all cases were translated into the SOAP charting method rather than some being in SOAP and others in DARP.

The involvement of people who are not members of the domain in the development of the knowledge base has been considered advantageous (Jackson, 1990). By identifying missing steps in the problem solving process, the non-domain development team member can help the expert to elucidate his reasoning, potentially improving the granularity of his explanations.

The computer scientists in the second iteration prototype projects often asked questions irrelevant to the process of clinical decision making in physiotherapy. This may have been due to their inexperience as knowledge engineers or to insufficient knowledge about physiotherapy. The projects were undertaken during one university term (four months), so there was limited time for lectures on physiotherapy case management per se. Given a longer development time period, they may have learned enough about the discipline to be able to ask germane questions. The results of a study of other KBS projects to determine an adequate amount of time for knowledge engineers to become familiar with a domain prior to working on a specific problem would be instructive and interesting.

The author's experience being involved in development of both the first and second iteration prototypes was that a novice domain member could extract knowledge more efficiently from both printed materials and clinicians than the computer scientists. A possible explanation is that knowledge of the basic processes of physiotherapy assessment and treatment is key in both knowing what to ask and organizing condition specific knowledge onto a physiotherapeutic case management structure.

Some expert systems projects have utilized teams of experts to develop and sometimes test the knowledge base (e.g. Boyette et al., 2001; pp 80-81; Delitto et al., 1989). It is unknown if this approach results in a better knowledge base in terms of completeness and comprehensiveness than when only one person's input is used, as was the case for this thesis. Although common sense would suggest it would, research is required to support or refute this assumption. Similarly, end user acceptance may be directly correlated to the number of experts or the development team, but this too would need to be researched. In some cases one widely acclaimed expert may be considered equivalent to or trump the value of several experts with lesser status.

Confounding this situation is the difficulty in objectively identifying experts in this domain (Delitto et al., 1989). Boyette and colleagues (2001) used experts selected because they had conducted research on, published articles about or had clinical experience with the patient population of interest. All of the experts had graduate degrees. Research would have to be conducted to determine whether physiotherapists would value the expertise of academics as much as those of clinicians. Research is also needed to determine the number and characteristics of experts involved in creation and evaluation of the knowledge base to engender physiotherapists' confidence in the recommendations of a KBS.

Dennis (2000, p. 4) opines that "[i]deally, experts would come to the consensus regarding decision rules to be programmed into an expert system," but notes that "there may be more that one opinion about an appropriate course of action for a given clinical problem." Delitto and colleagues (1989) had a great deal of difficulty achieving consensus on the NIOSH Low Back Atlas, and this was given as one of the reasons it failed to be implemented into a prototype.

There is the possibility that with more clinicians involved a system may be more robust. In the case of dissension, it is not impossible to provide different approaches as recommendations. Clinicians may be more predisposed to use a system with many options. If patients do not respond to a given approach or if the clinician does not have the still set to accomplish a given procedure, another option could enhance success of physiotherapeutic intervention.

It is advisable to have more than one physiotherapist as part of the development team, from the outset of a project to reduce risk. This might minimize the impact of unplanned development team changes. For example, reporting on the thesis project was delayed due to injury and illness.

Having a development team member who has training in the domain, and is familiar with expert system development was invaluable for extracting relevant knowledge from the literature while providing the framework of clinical decision making in the domain. However, it is less desirable for the evaluation of the prototype's performance on real cases or validation of the knowledge base.

Domain members who were not involved in the creation of the knowledge base are important for evaluation of it. The author worked alone on the knowledge base. She was not an expert in PPS case management, so an objective review by other physiotherapists yielded an improved prototype.

The author's involvement in design of the first prototype made her very familiar with navigation of the KBS. The interaction of naïve subjects with the initial prototype revealed deficiencies that would otherwise have been overlooked.

The author performed a subjective evaluation of the prototype's performance on real cases. Although sufficient for early prototyping, this would not be acceptable for later stages of development. In commercial systems, physiotherapists blind to the source of the recommendations would be needed to minimize bias, either against the software as has happened historically (Durkin, 1994, p. 647) or in favour of it, which was likely the case with the author and the thesis prototypes.

7.3.2 Assessment

Although this project was solution driven (Durkin, 1994), PPS was chosen because it could reasonably simulate a problem driven project. PPS case management presents a problem suitable for the development of a demonstration prototype, that is one "that handles a portion of the problem … to convince potential sources of funding that AI and expert system technology can effectively be applied … and to test ideas about problem definition, scoping, and representation for the domain" (Waterman, 1987; p.139). This thesis prototype performed adequately on a test suite, demonstrating that encoding the requisite knowledge in an expert system is possible. It is conceivable that expert system technology could be applied to create knowledge bases to address other patient populations (e.g. those with myasthenia gravis or chronic obstructive pulmonary disease) that present clinical decision making challenges in physiotherapy. However (Friedman & Wyatt, 1996, p.6), note that "simply because an information resource is safe and effective when used in one center or patients with a given diagnosis, one is not entitled to prejudge the results of evaluating it in another center or in patients with a different disease profile". Field research would be required to assess the efficacy and safety of expert systems in the clinical setting and of expert systems for other patient populations.

In determining which problem driven projects would be undertaken, monetary and non-monetary factors such as number of cases, the ramifications of less than ideal treatment, the cost of having to relocate physiotherapists for training or patients for treatment and the cost of other clinical decision making aids such as the Cochrane database would likely be considered.

Friedman and Wyatt (1996; p.3) believe that an ethical reason for performing evaluation of medical computer systems is to "justify [them] in preference to other information sources and the many other health care innovations that compete for the same budget." Cost is not an insignificant factor. Dennis (2000; p. 3) states that the ELEXSYS, although "a valuable product" was "defeated by the costs" of development. Parry (personal communication, 1994) did indicate that funding had been an issue. Other clinical decision making tools or aids, such as the Cochrane database or MEDLINE may be effective for some disorders or diseases, especially if there are no significant decision making challenges. For example, a memo to inform in-patient orthopaedic physiotherapists that non-weight bearing is more damaging to hip replacements than partial weight bearing in the acute post-op phase should be sufficient; the expense of devices, charts or software could not be justified. However for rare or highly complex cases such as post-op heart transplant cases, an expert system might be required.

Some of the data from this project for example, the number of hours involved in rapid prototyping, could be used to provide a rough estimate of the cost of a problem driven project, if it could be determined that the problem in question was of a similar scope to that of the physiotherapeutic intervention in PPS.

7.3.3 Knowledge Acquisition

For this project, knowledge acquisition primarily involved identification, acquisition and analysis of relevant research articles and texts. This process was time consuming and costly due to the need for inter-library loans.

Extracting pertinent knowledge from the articles collected was time consuming. Each article had to be reviewed for quality; all elements including subjects, methods, and statistical analysis had to be examined to determine if the conclusions based on these were valid. Most of the articles came from health care disciplines other than physiotherapy. Sometimes this meant that the knowledge was not applicable to physiotherapy practice, however all articles had to be read before their utility could be determined.

Extracting knowledge from Mrs. Flaig may have taken less time than it may have from other clinicians, because she was committed to the project. As well, she had several years of experience supervising physiotherapy students and thus had practice explaining concepts and elucidating her decision making steps. Certainly acquiring knowledge from her was easier than obtaining it from a physiotherapist less enthusiastic about the project.

Early on, an organization structure for the knowledge was determined; subsequently, data collected was sorted according to symptoms. Future projects may be facilitated by a similar method, however it should be noted that this schema was not used by Stone and Parry (1991).

Access to experts was limited to their availability and as their involvement was voluntary; their participation may not have had high priority. A hospital administered project or monetary remuneration for expert participation may have improved access to experts. It should be noted that no regulatory body officially identifies or acknowledges physiotherapy expertise in PPS case management. The selection of physiotherapists to serve as experts was done on an ad hoc basis. However, all participants had several years of clinical experience, advanced academic training or both in a relevant sub-discipline.

For the second iteration of development of the thesis prototype, it was observed that the computer scientists required more time than the author to elicit relevant knowledge. A clinician who is not an expert with respect to the problem at hand may more efficiently extract requisite knowledge because he has a better understanding of the field.

7.3.4 Design

7.3.4.1 Process Flow

The process flow remained the same from the first to the second iteration. Field testing would be needed to determine if this approach would work in the clinical setting.

The data from testing sessions with physiotherapy students and licensed physiotherapists was used mainly for knowledge base refinement. However, it was suggested that for deployment purposes, an expert system should be sufficiently flexible to allow interruptions in either charting or advice seeking and to allow interactions over several sessions for a given patient. This would be resolved with a **Save** function. Preece (1990) noted that the ergonomics of a system must meet the requirements of the end users prior to the system being accepted. Rick Workman of Momentum Healthware, Inc. (personal communication, 2005) agrees that systems must be easy to use and robust. As well, he believes that in health care, it is especially important that practitioner end users feel they have control in use of the system and application of the advice given.

Field testing of the prototype's third iteration version would be required to further hone the user interface by identifying preferences and needs.

7.3.4.2 Conceptualization

Not all health care institutions use the Problem Oriented Medical Record (POMR) (Weed & Zimny, 1989). The POMR was chosen for this project because: 1) the author was familiar with it; 2) it is used in all of the small and large facilities located in the Western provinces in which the author had worked; and, 3) it presented a logical schema to collect and analyze data for PPS. One of the knowledge base validators was not familiar with the POMR, but did not note this as an impediment to using the initial prototype. Prior to deployment, further investigation would be required to determine if the POMR would be suitable in environments with different charting methods, suck as DARP especially if the commercial software was to be used for both charting and recommendations (Preece, 1990).

Organization of knowledge bases can be done in a variety of ways. In the first iteration, the knowledge base was organized according to symptoms. In the second iteration of prototype development, one of the groups chose a schema based on anatomical location. Although this would facilitate a frame based approach for charting, that particular implementation did not allow for efficient access to advice. For each limb in which the patient had weaknesses, for example the physiotherapist would have to navigate all relevant menus. This would be redundant in cases where the patient had weakness in greater than one limb, as the recommendations were general enough to apply to all limbs. It is conceivable that it could be made to be efficient, however more research would be required. As well, different problems may require different frameworks and this would also require more research. Each project would have to be evaluated to determine which approach would be suitable. For example, any of the physiological system, anatomical location or signs and symptoms may be suitable or preferable for a given system.

In the domain of physiotherapy, referring to first principles is not always sufficient for problem solving (Dennis, 2000). Additionally, reliance on evidence based outcome measures is not always possible, as the research may not yet have been done or is equivocal (Dennis, 2000). Different models have been developed to support different treatment approaches. These models often conflict (Dennis, 2000). For example, Bobath and the NDT approach to treatment of neurological conditions is not consistent with that of Carr and Shepherd. Dennis (2000) suggests consensus among experts would facilitate acceptance, but it is possible that a system that did not include all approaches would not be accepted. Surveying of potential end users prior to knowledge base development would be advisable to determine attitudes held by physiotherapists.

7.3.4.3 Knowledge Representation

The three prototypes demonstrated that either backward chaining, forward chaining or a mixture of backward and forward chaining could be used to achieve a successful implementation for this type of problem. Durkin (1994) notes that for diagnostic reasoning backward chaining is adequate. This approach was congruent with the author's own reasoning however, Stafford (1996, pp. 8-9) and others have noted that strict adherence to strategies employed by human experts does not always yield the most efficient expert system.

Delitto and Snyder-Mackler (1995) suggest that clinicians form an hypothesis early in the examination process, then gather data to support or refute it (p.205). They speculate that this is done to "shift an ill-defined open-ended problem… into a series of better defined problems" (Delitto & Snyder-Mackler, 1995, p.205). This strategy is consistent with backward chaining. However, whether the manner in which clinicians currently problem solve is superior to others would have to be researched. Dennis (2000) was of the opinion that good clinical decision making involved appropriate selection of questions to ask and assessment tests to conduct, lending support to the superiority of early hypothesis formation. Jackson (1990) noted that the reasoning method and the chaining strategy need not be the same.

To date, all knowledge-based systems developed in physiotherapy and reported in the literature (Stone & Parry, 1991; Dennis, 2000) have employed rules. In the second iteration of prototype, both Team One and Team Two proposed frames, however neither used them. More research is required to determine if frames would be preferable for knowledge bases for other conditions such as lupus erythmatosis or ankylosing spondylitis, which can have both anatomical and physiological characteristics.

7.3.4.4 Software Selection

Shareware and freeware expert system shells are available for rapid prototyping, but not all are feature rich nor have graphic user interface and developer tools. To develop commercial software that would satisfy end user requirements and decrease development time, even a mature tool such as Level 5 Object may be inadequate.

For deployment, the expert system shell needs to interact with databases (e.g. medical records) or other programs (Rick Workman, Momentum Healthware Inc., personal communication, 2005; Ian Fish, 2005). The better the specifications prior to development, the easier it will likely be to choose software that will be adequate for all stages (Rick Workman, personal communication, 2005; Durkin, 1994).

Ultimately, transfer to a language such as C++ or Java may be advisable both for prototypes and commercial systems. Support for a shell may end before a prototype developed with it is no longer desired for use. The PMP created by Dennis (2000) originally ran on an Apple Macintosh computer, but had to be transferred to a version of Authorware that ran on IBM compatible equipment (Dennis, personal communication, July, 2005). Problems arose due to differences between the versions of software used. For example, display screens required a new layout to be intelligible (Dennis, personal communication, July, 2005). Eventually, the cases were moved to web pages and the entire "concept simplified" because the "students did not have access to Authorware" anymore (Dennis, personal communication, July, 2005).

Level 5 Object, used for this thesis, is no longer supported. The design for the proposed third iteration prototype would have to be applied to another shell or implemented with a language.

Maintenance and support of a shell may be discontinued or it may become too costly to purchase a license for the shell. In contrast, a well documented application written in a widely used language could have a longer life.

7.3.5 Evaluation

The efficacy of the KBS was examined by; 1) comparing the records for real cases of the systems with practitioners; 2) having the knowledge base examined by domain experts; and 3) having students in the domain use the system to solve mock cases.

Real Cases:

The cases from clinics in Toronto, Ontario and Halifax, Nova Scotia were used to evaluate the adequacy of the recommendations produced by the knowledge base in the first iteration prototype. The information was useful for development purposes and it was deemed that the system performed well. Including records from more centres may increase end user confidence, however the precise number and criteria for selection is unknown and may be a challenge to determine. For many conditions, there are neither formally designated centres of excellence nor agreement among physiotherapists on treatment approaches (Dennis, 2000). The number of cases required for statistical significance or confidence, which may not equate to those required for end user confidence, would vary according to condition.

"One would expect differing results in a study of an information resource's accuracy depending on whether the test data were abstracted by the developers or the intended user" (Friedman & Wyatt, 1996, p. 10). The author was involved with development in all three iterations of the prototype. The role of potential end user was limited by the roles of domain expert, knowledge engineer and designer; it was difficult to be objective about how the prototype worked because the author was not naïve about its design and content.

Prior to deployment, to increase confidence in the performance of the system evaluation by someone other than the author would be required and a greater number of cases used to test the system for comprehensiveness and correctness (Dennis, 2000). As well, an objective set of criteria to determine adequate performance would have to be established.

Knowledge Base Content Validation:

Three licensed physiotherapists, two in academe and one with several years of clinical experience in neurology evaluated the knowledge base for the first prototype. Their feedback helped the author to refine the system. However, determining which and how many physiotherapists would be acceptable to evaluate the construct validity (i.e. "that the model correctly and truly represents expert behaviour" (Gupta, 1993, p. 334)) of commercial expert systems will be challenging. For many conditions and even some treatment techniques there are no objective standards or solid research to substantiate a given approach. Research is needed to determine if other standards would suffice and what these might be. It is possible that outcome measures research may reduce the uncertainty associated with treatment protocols. Further investigation would be required to measure acceptance and confidence levels of end users and performance of each system. It is important to note that a knowledge base based on "extensive library research…is clearly consistent with the concept of evidence based practice and thus may have a role in practice," (Dennis, 2000) which may result in the acceptance of a system.

User Acceptance:

Testing with and surveying of physiotherapy students and licensed physiotherapists indicated that an uncomplicated graphic user interface was optimal. In a keyboard based environment or with a graphical interface that has many alternative navigational options, new users and infrequent users have difficulty finding what they need.

With the first prototype, which was navigated via text and keyboard, the students found relevant recommendations despite only a few hours of training (see Chapter 4) and the licensed physiotherapists required less training time. For the ONCOCIN system, the average training time was thirty minutes (Bennett, 1983 p. 50). The average amount of training to reach proficiency in use or a clinical expert system should be further investigated.

Field testing in a clinical environment would be required to determine interface need for end users and for legacy systems such as patient record databases. For example, common sense suggests that less time to wait for a recommendation is preferable, but does not indicate what length of time is unacceptable (Friedman & Wyatt, 1996).

Acceptance may also be influenced by how integration of the software affects relationships and responsibility between allied health care team members (Friedman & Wyatt, 1996). For example, if a system reduces paperwork and the need for notification of treatment plan changes to several people, will that adversely effect patient safety or enhance it?

Overall, the attitude of the clinicians and physiotherapy students who interacted with the first prototype in 1993 was positive. Over half of the students (56%) believed that KBS decision making support would be helpful for clinicians, while 22% felt they would benefit students. Only one student had an equivocal response related to the cost of creating a KBS.

Both clinicians stated that a KBS for decision making support would help clinicians, especially new graduates and sole charge physiotherapists. It is important to note that the participation of the clinicians was voluntary. Hence, they may have been biased unduly, either in support of or against a KBS.

A physiotherapist from academe expressed the opinion that computers and software are infallible. She believed that a KBS would always provide an answer and that it would always be correct.

Conventional applications, such as billing systems do not always yield the correct result, whether due to data entry errors or mistakes in coding. KBS are applied to types of problems for which even a human expert will not necessarily be able to provide a single correct answer. A KBS may provide one or more adequate, but not necessarily the best solutions.

An unrealistic conception of computer software could result in disappointment in a KBS. End user education to clarify the strengths and limitations of KBS technology should be done prior to initiating a project.

7.4 Specific Deployment Issues

The focus of this thesis was to demonstrate the feasibility of **developing** a KBS to support clinical decision making in physiotherapy. Before these applications are embraced by the domain, however several clinical concerns evinced during the development of the thesis prototypes and in the literature (e.g. Friedman & Wyatt, 1996, and Stafford, 1996) would have to be addressed.

The issues identified by the thesis research came from responses to informal surveys administered within the domain, questions and comments raised at a presentation in 1996 of the thesis project at the Bannatyne Campus of The University of Manitoba, and interviews with physiotherapy colleagues and athletic therapists (a discipline whose scope of practice overlaps that of physiotherapy).

In 1996, the author gave a presentation at the Bannatyne Campus of The University of Manitoba about KBS for clinical decision making support. She distributed surveys (Appendix A.8) to qualitatively gauge the feelings of physiotherapists concerning computerized aids.

Eleven surveys were collected. One was submitted by an occupational therapist, one was completed by an undergraduate physiotherapy student and the remainder were filled out by physiotherapists.

For the latter group, the mean number of years since graduation from a physiotherapy degree or diploma program was 16.6. The mean comfort level with respect to using a computer was 2.8. A response of zero indicated that the respondent was **not at all** comfortable using a computer and five indicated that the respondent was **very comfortable** using a computer.

Four of the physiotherapists had greater than 20 years of experience. 75% of these indicated that they were **not at all** or only **somewhat** comfortable using a computer.

Two of them felt that computerized decision support would be "OK" or "an asset". The other two were concerned about training time and misuse (e.g. "if being used to decide funding or licensing exam, etc. (sic)"), respectively.

82% of respondents felt that clinical decision making aids can be useful. One added the caveat that this is true only when they are "valid and reliable". One respondent did not answer this question.

73% of respondents felt positively about computerized clinical decision making aids. Comments included perceptions of these aids as "useful", "an asset" and "valuable". However, some respondents had reservations. One felt that these aids would be acceptable provided that they "didn't go too far". One physiotherapist was concerned that funding might be diverted to support only this type of solution, to the detriment of others.

Other concerns included 1) loss of judgment skills due to reliance on computerized aids (27%); 2) misuse or abuse (e.g. use by non-physiotherapists, replacement of physiotherapists with computer applications) (27%); 3) flexibility of a computer application (e.g. to accommodate patient uniqueness) (18%); and, 4) ergonomics (e.g. access to computer applications, training time) (18%).

Cost was the barrier to computerized decision support aid usage listed most frequently (45%) by the respondents. Acceptance in general and computer literacy were the next most frequently mentioned potential barriers (at 27% each). Access to suitable equipment was also mentioned as a possible barrier.

The respondents perceived a variety of benefits from using computerized decision making aids. 28% identified support for clinicians who were sole charge or remotely located as being a potential benefit. Other responses were diverse, ranging from standardization of terminology to decreased paperwork.

Of the varied functions listed as being essential for inclusion in a computerized clinical decision making aid, the most common (28%) was connection to the Worldwide Web. Next frequently listed was the ability to generate reports (18%) and interact with an electronic medical record database (18%). Access to Medline, the ability to collect and generate statistics, and the capacity to chart were also listed. Of significance to KBS applications, one respondent listed the need for full explanations of recommendations, and another the need for updating of the application.

In summation, acceptance of computerized clinical decision making support was not highly dependent upon the number of years of clinical experience or the perceived computer literacy of the respondents. For example, despite having been in the domain for more than two decades and not being comfortable with computers, two respondents could appreciate the utility of computerized clinical decision making support. This attitude was shared by a majority of the respondents.

Formal studies with a rigorously devised instrument and a larger number of practicing clinicians must be done to more extensively describe opinions of this potential end user group.

The following discussion is illustrative rather than exhaustive of some of the concerns mentioned during conversations with physiotherapists and athletic therapists.

Some informants indicated that they would feel it a burden to have to learn how to use a computer program as well as incorporate the new treatment techniques, new policies, and new medical information that are constantly being presented to them. Two informants reported that at one institution they were not given adequate training nor did they have an adequate number of stations to access a computer program to record treatment units. This generated a great deal of resentment and ultimately the abandonment of the program. Minimally, adequate training time and access to workstations would be required. Research is required to determine what amount of training time is adequate. Ergonomic factors on the wards or in clinics may be less problematic with the advent of more powerful and reasonably priced personal digital assistants (PDAs), however this will not allay the fear of the as many as "25 to 50 per cent [sic] of the population … who are anxious about any interactions with computers" (Foran, 1995, p. 29).

Physiotherapists tend to be very busy with hands on treatment; charting and research is sometimes done in unpaid time. Acceptance of a clinical decision making tool such as an expert system might be enhanced by allowing the physiotherapists sufficient time while working with the patient to interact with the software. Research to determine an acceptable time for consultation is needed.

The thesis expert system is intended as a guide and is not proscriptive; other expert systems could potentially have alternative intents. Stafford (1996, p. 10) noted that in health care there is "concern ... that systems ... designed for a specific scenario of use may be marketed and purchased for a different use." For example, a system "conceived and designed to support [sic] decision-making may be either marketed or purchased to fully automate [sic] decision making" (Stafford, 1996, p. 10).

Some physiotherapists, such as G. Pereira in the School of Medical Rehabilitation at the University of Manitoba expressed concern that although expert systems could be designed as decision making aids, they might be used by insuring bodies to limit the choices for treatment made by the practitioner. As with any tool, its use and abuse are not a fault of the tool.

Some physiotherapists were concerned about liability. Holtzman (1989, p. 115) notes that designers and end users can be assigned liability when a poor decision is made. According to Friedman and Wyatt (1996, p. 6) "it is not clear whether [complex] regulations apply to all computer based information resources or only those that manage patients, without a human intermediary." Perry Poulson of the Winnipeg Region Health Authority (personal communication, June, 2005) stated that the onus is on the software vendor to produce a safe product and to update it as necessary. But he added that the practitioner should also ensure that system maintenance is done in a timely fashion and that he apply his expertise to determine that advice supplied by the software is reasonable. Rick Workman of Momentum Healthware, Inc. (personal communication, July, 2005) stated that software designed for health care is equivalent to a medical device, and as such the practitioner must ensure that he is properly trained in its use and uses it in conjunction with his own expertise, not in lieu of it. The United States Food and Drug Administration supports this view for consultation software (Shortliffe, 1987, p.65). Tuthill (1991, p. 50) interprets American law as holding the practitioner using an advice system as responsible for using his "professional judgment concerning actions based on system outputs."

Security and confidentiality of patient data is an issue whether the data be archived on paper or saved electronically. Garry LeDoux, the Acting Director General of the Public Health Agency of Canada, stated that this issue has not been insurmountable with hard copy nor with other electronic sources such as medical records (LeDoux, 2005). Additionally, in Canada all health software must meet minimum safety requirements set by the federal government (LeDoux, 2005).

Issues of authority, control, scope of practice, liability, privacy, responsibility and many others require further research as they will likely affect to what extent knowledge based expert system are adopted in physiotherapy.

Despite these concerns, there is interest in the use of KBS for clinical decision making in physiotherapy. It is encouraging that the author was contacted by an Australian physiotherapy clinic owner (Monte Issa, personal communication; 2000) who was interested in purchasing the thesis application and developing clinical decision making aids for other conditions.

7.5 Conclusion

The thesis project was solution driven rather than problem driven (Durkin, 1994). The motivation was to show the potential of KBS technology in physiotherapy.

The author created a demonstration prototype to "test ideas about problem definition, scoping, and representation for the domain" (Waterman, 1986, p. 139). The thesis prototypes demonstrated that it is possible to acquire and represent knowledge required for clinical decision making for case management of a condition whose pathophysiology is unknown and that can affect the cardiorespiratory, neurological and musculoskeletal systems simultaneously.

The results of the thesis work add to the knowledge contributed by Dennis (2000) and Stone and Parry (1991) about what types of physiotherapy expertise can be acquired and which methods can be used to represent it in a KBS. It extends their work by showing that a KBS can be designed for clinical decision making support as well as for computerized assisted instruction.

The first and third iterations of the prototype contained approximately 50 to 100 rules, could "[handle] a portion of the problem" of PPS case management and performed adequately on a small sample of cases (Waterman, 1986, p. 139). Thus, they meet or exceed Waterman's (1986, p. 139) criteria for a demonstration prototype; that is, one designed to demonstrate the likelihood of feasibility of KBS application in a domain.

The model used was PPS case management. More formal evaluation and development would be required before the third iteration prototype could be released commercially. As well, more research is needed to determine if KBS can be applied to other conditions.

The thesis results are not tantamount to confirmation of the utility of KBS to support all physiotherapy case management issues. For example, physiotherapists can use PA pressures to assess or treat patients with back problems. Grades are assigned to indicate in which part of a spiral joint's range the pressure is being applied. A KBS would not be an ideal tool to determine if the correct grade was being applied for treatment purposes because this task relies on spatial knowledge. Although perhaps not impossible to support with a KBS, a conventional programming approach would be adequate and likely less expensive.

The thesis results also suggest other questions to research, in terms of both development and deployment of a KBS.

Additionally, as Delitto and colleagues (1987) did for low back assessment and treatment and Stone and Parry (1991) did for safe and efficacious use of modalities, this thesis has formalized an area (PPS case management) of physiotherapy expertise.

The process of collecting, extracting and organizing knowledge to support PPS case management highlighted the dearth of physiotherapy specific literature and the need of more research with a clinical application.

KBS as clinical decision making aids have potential to be powerful tools, once deployed. Potential barriers to development such as concerns about liability and KBS maintenance are not insurmountable, but more study is required to identify these issues and find means to resolve them.

Appendix A First Iteration Prototype Materials

Appendix A.1 Explanation Items from the Initial Prototype (DICT.TXT)

Note: In the first prototype, the explanation items were single spaced. Double spacing has been applied for inclusion in the Appendix. No other changes have been made.

HELP

Options available in the PPS may be accessed according to this outline:

EDUCATION

PAIN:

1) Minimize/eliminate

1. headaches upon arising
2. nighttime limb cramping-cold intolerance or poor sleeping posture
3. burning pain/crawling sensation-muscle overuse, inadequate sleep
4. localized joint pain-biomechanics, lax ligaments or contractures
5. localized muscle pain-inadequate rest or muscle overuse

2) Alleviate

FATIGUE:

1) Upon awakening

1. sleep apnea/hypoventilation

2. musculoskeletal pain

2) Local

1. weakness

3) Generalized (peaks midday)

1. inadequate rest

2. inadequate sleep

3. muscle overuse

4. deconditioning

WEAKNESS:

1) Deficit in strength

1. disuse

2. overuse

3. both disuse and overuse

2) Deficit in endurance

3) Recuperation from muscle overuse

1)-3) provide the options either of reviewing salient considerations in designing an exercise program or of reviewing exercise programs from research protocols

COLD_INTOLERANCE

Intolerance or increased sensitivity to cold in PPS may be the result of:

1) inadequate vascularization, secondary to disuse or paralysis;

2) chronic vasodilatation of the peripheral vasculature secondary to sympathetic vasoconstrictor outflow impairment (controversial);

3) decreased muscle bulk secondary to paralysis or disuse, and thus more rapid cooling;

4) inadequate capillary to muscle fiber ratio-as an adaptation to decreased motor units, muscle fibers may hypertrophy, however this addition of strength may be insufficient for endurance activity, which is necessary to stimulate capillary growth (Borg & Hendriksson, 1991)

This impairment may present as a decrease in strength, because muscle tissue is contracting at less than optimal temperature for enzymatic activity and nerve conduction is slowed or as pain in the affected extremity

FATIGUE

Fatigue may be local or central. Local fatigue is a failure of the motor unit. Central fatigue is a failure of central neural drive

DISUSE

Muscle disuse may be secondary to decreased activity subsequent to biomechanical stress related pain in muscles or joints, altered movement patterns (e.g. hip circumduction to compensate for paretic quads may eventually result in atrophy of unused dorsiflexors), or prolonged bed rest during illness or following injury/surgery. Since disuse atrophy may present in either polio affected or unaffected motor units, care must be taken to avoid rehabilitation plans which have the risk of provoking muscle overuse

GENERALIZED (pain)

This type of pain has also been described as flu-like, hitting a wall, overwhelming exhaustion, and marked decrease in energy level with or without decreased mental alertness.

OVERUSE

Muscle overuse is a term used to refer to the condition which exists when workload demands exceed the physiological capacity of the neuromuscular system. The neuromuscular capacity in the PPS patient is lower than the non-poliomyelitis affected individual because:

1) polio killed some anterior horn cells, thereby decreasing the total number available;

2) polio scarred some anterior horn cells, thereby decreasing their ability to function;

3) surviving healthy or scarred anterior horn cells may be innervating more muscle fibers than they are physiologically equipped to do without damage;

4) fewer muscle cells are innervated and those which are may be working at maximal levels to perform ADL/ambulation or other basic activities;

5) about twenty percent of all enervations express faulty function at the neuromuscular junction.

The neuromuscular reserve in PPS patients will demonstrate marked variation, depending upon such factors as the extent of enervation at the acute onset of polio, the balance between ongoing enervation and enervation, and possibly the extent of cross-enervation. Clinically, weakness due to muscle overuse may be difficult to distinguish from weakness due to disuse. EMG is not discriminatory for symptomatic versus non-symptomatic polio affected muscles, according to all but one researcher (Feldman, 1990). CK level abnormality is present in only about one-third of symptomatic individuals, therefore it can be considered as supportive evidence, only. MRI will show amount of muscle tissue in a limb, but will not indicate the cause of the condition of that muscle tissue. Biopsy findings are equivocal Subjective findings, including data from activity diaries or information about occupational and domestic demands, may help to identify the workload demands on the neuromuscular system, its response to these and an indication as to which muscles may be receiving a given amount of use although one study (Einarsson, 1991) indicates that the PPS neuromuscular system has some capacity to respond to challenge via neural adaptation, this route is limited. Enervation hypertrophy is another means of adapting to challenge. Strength acquired through this process is limited, too. These muscles are at greater risk of developing overuse because their maximum ability to adapt to further physical challenge may have been reached. The presence of weakness in muscles with relatively large bellies is a sign of overuse, and may result in death of muscle fibers.

WEAKNESS

The term 'weakness' may imply different things to different people. It is important to establish the specific type of weakness which the patient is experiencing. Decreased endurance is a condition which exists when the motor unit is not capable of sustaining continuous or repeated contractions over a given period of time. An associated complaint may be that the patient is unable to walk as many blocks as he is accustomed to traversing This deficit may also be described by the patient as 'fatigability.'

NB: Local muscle fatigue is distinct from central fatigue, which is a manifestation of difficulty with central neural drive. Decreased strength is a condition which exists when the motor unit is incapable of producing a given output of force. Maximum force output may be measured quantitatively with a dynamometer. An associated complaint may be that the patient has difficulty stepping onto curbs or ascending a staircase without using his arms on the handrail. In PPS, decreased strength may be a manifestation of disuse or overuse

PAIN

There are several potential reasons for this impairment in PPS. Patients may experience a burning pain deep in the muscles and bone, which may or may not be altered with activity. Hyperesthesia may be associated. This pain may be a chronic manifestation of the mylagic pain which results from muscle overuse, and has been reported as the most difficult to treat. Nighttime muscular cramping may be experienced in the lower extremities. Contributing factors include muscle overuse, posturally induced radiculopathy or decreased circulation, cold intolerance and low serum calcium levels.

Localized muscle and joint pain is exacerbated by and may be experienced during and following activity. Biomechanical stress in posture maintenance or movement production may cause either of these symptoms. For example, ligaments surrounding a hyper extended knee and muscles on the convex side of a scoliotic spine will be stretched. Additionally, muscle pain may result from: 1) inadequate rest (insufficient depth or time for healing); 2) inadequate energy conservation (including pacing of physical activities); 3) excessive use of remaining motor units; 4) misuse of muscle secondary to compensation of weaker muscles; and 5) degeneration of transplanted muscles

Joint pain may result from: 1) contractures; 2) failing of surgically fused joints; and 3) muscle imbalances, all of which may contribute to biomechanical stress. Management focuses on simultaneously eliminating or minimizing the causes of pain and ameliorating the intensity of residual or persisting pain Holistic treatment may include: postural re-education; movement pattern/gait re-education; orthotic/ footwear/ assistive device/ mobility aid prescription; gentle stretching (with care to avoid detriment to compensatory adaptation); energy conservation; patient education; Jobst stocking prescription; strengthening of muscles surrounding lax joints (with care to avoid causing/exacerbating muscle overuse); massage; thermal or modality intervention; gentle mobilizations; referral to a physician for NSAIDS, analgesics, or serum calcium level evaluation; and referral to a psychologist for unremitting pain.

PPS DIAGNOSTIC CRITERIA

Patients who satisfy all of the following criteria are diagnosed with PPS:

1. The patient had partial neurological and functional recovery following the acute episode of polio;
2. The patient experienced a period of neurological and functional stability for greater than or equal to 10 (some workers use 15) years following recovery;
3. The patient has begun to experience gradual or abrupt onset of new neurogenic weakness in muscle affected or unaffected by polio, with and without accompanying deterioration of function, excessive or unaccustomed fatigue, cold intolerance, atrophy or muscular or joint pain unexplained by other medical diagnosis. (Adapted from Einarsson, 1991a and Halstead, 1991).

Symptomatic individuals who never recovered from polio are not likely suffering from PPS, as it is currently understood. Individuals who were infected more recently than the criteria specified number of years for functional stability may still benefit from the education segment; however any symptoms they are experiencing may not be due to PPS. Individuals who meet the first two, but not the last criteria may be at risk for developing PPS, and therefore may benefit from the educational segment of the PPS(ES) and a baseline assessment followed by annual re-assessments.

Appendix A.2 Recommendation Segments from the Initial Prototype (RUN.TXT)

Note: In the first prototype, the explanation items were single spaced. Double spacing has been applied for inclusion in the Appendix. No other changes have been made.

ASSESSMENT

Assessment of the PPS patient requires attainment of population/ syndrome specific data in addition to the usual components of a comprehensive examination. It may be necessary to acquire this data over several sessions to accommodate the energy levels of the patient. A thorough assessment will assist the therapist in identifying disabilities and impairments, and in setting treatment objectives and goals.

Subjective Information

PMHx:

1. age at onset of acute polio infection;
2. presentation and course of acute illness (severity, bulbar/spinal, ventilation, paresis/paralysis);
3. course and extent of recovery (mobility aids, assistive devices, orthoses);
4. functional status and age at peak recovery (occupational, recreational, ADL);
5. associated surgical interventions (joint fusions, muscle transplants, Harrington rods);
6. residua (weakness, functional limitations, orthotics, mobility aids, assistive devices).

This data provides a baseline upon which new symptoms can be compared and progression of functional decline gauged. In asymptomatic clients with a history of polio, it may help to identify those with a higher risk of developing PPS.

HPI:

1. onset of new symptoms (note associated stressors, if any, including pregnancy, prolonged bed-rest, surgery, injury, psychosocial trauma, recent weight gain, change in level of physical activity);

2. nature of new symptoms (cold intolerance, fatigue, weakness, pain, morning headaches);

3. pattern of decline (step-wise/gradual, rapid/slow);

4. degree of decline (functional changes);

5. # years since polio onset.

This data can be used to identify patient disabilities/impairments, guide physical assessment and establish treatment goals/objectives

Surgery: Determine overall physical status.

Meds:

1. note all pharmaceuticals which may exacerbate or mimic PPS;

2. note all non-prescribed substances which may exacerbate or mimic PPS (e.g. herbal remedies);

3. quinine may be prescribed to reduce muscular cramping but may be contraindicated as it can cause muscular weakness;

4. pyridostigamine (anticholinesterase; a.k.a. Mestinon) in one study (Trojan DA, 1988 APMR) was found to decrease subjective weakness in some patients;

5. muscle relaxants may have a twofold potency in polio compared to non-polio population (Gyermek L, J of Clin Pharmacol, 1990, 30:170-173).

This data may be essential in evaluating patient performance and response to treatment.

Lifestyle:

1. occupational history since recovery, especially details concerning type, intensity, frequency and duration of physical labor; opportunity to alter work station and to take rest breaks; relevant reasons for job changes (e.g. inability to perform duties due to residua or new symptoms);

2. volunteer work (same details as #1);

3. recreational activities (sports, hobbies, exercise programs); type, frequency, intensity, and duration and relevant reasons for changes in activity pattern;

4. diet (especially in chronically obese or recent weight gain);

5. smoking (especially for those with acute bulbar involvement;

6. EtOH/illicit drugs (effect on neuromuscular integrity may be enhanced compared to non-polio population).

This data may assist with referral to other health care professionals (e.g. OT, dietitian), evaluation of functional deterioration and symptom progression, and response of the system to physical stress.

Social:

1. dependents - # and level of demand on patient (children, elderly, disabled);

2. education;

3. financial status.

This data provides further information about the physical demands of the patient, and may indicate the need for referral if a team evaluation has not been done.

Aids:

1. orthotics/prosthetics: condition, type, adequacy, dependency level;

2. mobility: condition, type, adequacy, dependency level;

3. assistive devices: condition, type, adequacy, dependency level.

This information will guide objective assessment and identify the need for new prescriptions. Diagnostics:

1. MRI: atrophy/hypertrophy pattern and extent;

2. Biopsy: atrophy/hypertrophy pattern and extent;

3. EMG: rule/out or identify non-polio pathology, confirmation of polio, ongoing denervation/innervation, Feldman (1991) differentiate non-symptomatic polio survivors from those with PPS;

4. PFTs: resistive dysfunction/residual bulbar or abdominal weakness/scoliosis;

5. Sleep Lab: apnea and hypoventilation in this population has been associated with pain, morning headaches, and fatigue;

6. Sub-maximal Exercise Test: reason for cessation, specifics of testing protocol; deconditioning may be due to pain, fatigue, or weaknesses well as contributing to the development of these symptoms; modification of the testing protocol may be necessary due to residua or to prevent overwork/exhaustion in this sensitive and vulnerable population (Dean & Ross, 1988).

Objective Information

Mental Status:

1. cognition: may have been affected by acute bulbar involvement and recently due to sleep apnea or hypoventilation or deteriorating reticular formation status;

2. affect: response to a second disability, concern re: nature of progression, adequacy of coping skills, support network.

Oral Function:

Swallowing and the volume of speech may reflect residual bulbar weakness or new weakness in clinical or sub clinical bulbar/medullar patients.

Respiratory/CV Status:

Coughing strength may be affected by residual or new weakness due to weak intercostals/diaphragm/abdominals. Note status of accessory respiratory muscles. Assessment is especially important for bulbar affected.

Sensory:

Some PPS have reported hyperesthesia pain in muscle and intolerance to cold. Other sensory signs and symptoms may be indicative of a concomitant pathophysiology.

Musculoskeletal Status:

General Appearance: deformities due to residua (e.g. genu recurvatum, scoliosis).

ROM: note contractures due to altered postures, adaptive shortening, joint fusions (surgical), instability, and subluxation.

Strength: note enervation hypertrophy, atrophy, and paralysis. Several sessions may be required for manual muscle testing to avoid fatiguing the patient. Palpation of the muscle being evaluated and close observation of the movement is necessary to ensure that muscle substitution is non-contributory. To control the influence of fatigue on reliability, re-testing from day to day must be done: 1) following similar activity levels; and 2) at the same time of day. As well, to account for the effect of fatigue on validity, the first effort must be recorded. Testing must be done at a similar temperature to control for the negative influence of cold on strength in PPS. Observed fasciculation however, note that one study found no correlation between their occurrence and relative weakness. The use of dynamometers provides more accurate and reliable data than does manual muscle testing, because the latter underestimates severity of involvement (up to 50% loss of anterior horn cells occurs prior to detection with MMT) and is insufficiently sensitive to gauge the difference between grades (evaluation of Grade 4-good is 40% and of Grade 5-normal is 75% of true normal (Agre JC, 1989). Note the effect of joint fusion and overstretching on muscle performance and overall function. Note that transplanted muscles typically show signs of weakness even in asymptomatic polio survivors

Posture: Note kyphosis, scoliosis, and lordosis with special attention to the relationship with function, joint abnormalities or muscle weakness. Observe or request information about sleeping, sitting, standing and ambulating postures. Due to residua (e.g. weakness, deformity), many polio survivors developed compensatory movement patterns and postures. New symptoms may cause a deterioration of these adaptations, which may themselves be responsible for excessive stress on ligaments, joints and muscles, pain and fatigue. Assess the need for supportive devices such as cervical pillows, armrest, elbow crutches, lighter orthosis.

Pain: Severity, exacerbating/alleviating factors, location, type (general/local; causalgic/myalgic/biomechanical stress).

Fatigue: Onset, antecedent events, etiology, course, mitigating factors, severity, time between precipitating activity and presentation, Borg or analog scale ratings or activity diary data if previously assessed by OT.

Functional Status: Ambulation (distance, time, speed)/gait assessment, transfers, mobility, stairs, ADL, need for ambulation/mobility aids/ assistive device prescription.

NOTE:

1. PPS is a diagnosis of exclusion. For this reason, during reassessment the therapist may observe signs and symptoms atypical of PPS and indicative of another pathophysiology which is responsible for complaints attributed incorrectly to PPS.

2. The typical PPS patient is in mid-life. For this reason, some complaints may be due to age-related conditions such as menopause, trauma secondary to a motor vehicle accident, cancer, or alcoholism related degeneration.

BIOMECHANICS

Poor biomechanics in posture or movement can impact negatively on muscle status and energy level as well as joints; however weakness and fatigue are unlikely to present independent of joint pain. Polio survivors are prone to altered stance and movement patterns in compensation for paralyzed or paretic muscles. For example, knee hyperextension may be utilized to provide stability in standing, hip circumduction may be utilized to provide foot clearance during the swing-through phase of ambulation, and

shoulder girdle hiking may replace the function of weak deltoids. Compensatory patterns will vary from patient to patient. Manual muscle testing may alert the therapist to weak muscles prior to observation of functional activities and assessment of muscle usage in stance or movement production. Commonly affected lower extremity muscles are: dorsiflexors, quadriceps, gastronomies. Commonly affected upper extremity muscles: deltoid, abductor pollicis brevis Retraining may be time intensive and prolonged, as existing patterns were established during or since polio rehabilitation and muscles necessary for changes may be weak from disuse. Care must be taken to avoid further stressing maximally taxed muscles, and changes which are dysfunctional or will result in a reduction in safety. Orthotics can provide support to decrease the stress on joints and concurrently decrease demand on surrounding and distal muscles. For example, a Swedish knee cage or de-rotational brace set at ten degrees beyond full extension and allowing full flexion decreases the stress of greater hyperextension in the unsupported lax knee, while still allowing enough hyperextension to compensate for weak muscles.
A few articles specifically concerning this issue may be consulted for more details: 1) Waring, W.P. et al. Influence of Appropriate Lower Extremity Orthotic Management on Ambulation, Pain and Fatigue in a Post polio Population. APMR May, 1989. Vol.70 pp. 371-375): 2) Perry, J. et al. The Post polio Syndrome: An Overuse Phenomenon, Clinical Orthopedics and Related Research. Aug., 1988. No. 233 pp. 145-161; (especially Therapeutical Implications, pp 160-161): 3) Werner,R. et al. Risk Factors for Median Neuropathy of the Wrist in Poliomyelitis Patients. APMR June 1989. Vol. 70 pp. 464-467): 4) Ontario March of Dimes. 1988 Proceedings of the National Conference on the Late Effects of Polio. pp. 161-172; 5) Biomechanical Investigation on Static Weight-

bearing Patterns of Post-polio Rehabilitees. Indian Journal of Medical Research. May, 1986, pp. 509-518.

COLD_EXPOSURE

The adverse affects of cold intolerance may be mitigated or avoided by minimizing the possibility of the patient becoming chilled. Adequate clothing must be worn at all times, whether indoors or outdoors. During repose, heating blankets, down comforters, long underwear or flannels, and socks may help to keep the patient adequately warm.

CONDITIONING_AND_STRENGTHENING

STRENGTHENING AND CONDITIONING: GENERAL CONSIDERATIONS

Few articles have been published concerning exercise programs designed specifically for the PPS population. In general, the quality of these studies is poor for several reasons: 1) the subjects are poorly described; 2) the exercise protocol is poorly detailed; 3) the subject number is very low; 4) lack of a control group; and reliance on insufficiently sensitive manual muscle testing to measure strength. Additionally, the long-term effects of all protocols are unknown.

A number of contraindications to exercise prescription are generally recognized:

1) presence of cramping or pain in muscles;

2) presence of unrelenting/excessive fatigue (general or local);

3) rigorous/fatiguing exercise especially that which would result in hypertrophy;

4) presence of muscle overuse or situation in which individual is maximally working to perform daily functions (e.g. work, ADL).

Some precautions or recommendations which are less universally accepted but may be helpful as guidelines in the prescription of exercise are:

1. ensure a minimum of one day of rest between each exercise session to minimize risk of muscle overuse;

2. incorporation of rest intervals during each exercise session to minimize fatigue;

3. intensity, duration, and frequency of exercise within patient's pain and fatigue tolerance levels; instruct the patient regarding acceptable maximum pain/fatigue level based on Borg Perceived Exertion or analog scales;

4. caution re: exercising 'unaffected muscles' because they may have been sub-clinically affected by polio or may be overtaxed due to compensating for weaker muscles;

5. caution re: stretching; avoid increasing ROM when safety or function will be compromised;

6. avoid exercises which will exacerbate polio or PPS complications (e.g. biomechanical stress related injuries or further degeneration of tissue);

7. consider exercises in water (swimming, running, acquasize) to minimize complications associated with biomechanical stress, promote pain reduction and relaxation, provide adequate warmth (in therapeutic pool) for exercise;

8. determine initial levels of intensity, duration and frequency of exercise on the basis of activity-rest-fatigue level log/Sub-maximal exercise test/MVC %;

9. determine exercise prescription parameter appropriateness with qualitative and quantitative data (e.g. MRI/EMG/muscle biopsy/dynamometer /subjective complaints);

10. consider functional activity (e.g... walking, rolling wheelchair) as exercise: potential benefits (e.g. increase in movement economy) and risks (stressing muscles already working at maximum capacity);

11. modify programs to reflect the altered physiology of the disabled

12. NB: in PPS, a longer course of time may elapse prior to observation of physiologic adaptations because exercise sessions will tend to be at a lower intensity and for shorter duration than for healthy individuals;

13. NB: Agre and Rodriquez (1991, APMR) found that PPS strength recovery post-exertion at maximum strength and endurance is impaired relative to healthy individuals;

14. NB: Agre and Rodriquez (1990, APMR) found that endurance levels were similar to but maximum torque production (measured quantitatively rather than with manual muscle testing) was less than that in healthy individuals;

15. NB: Agre and Rodriquez (1991, APMR) found that PPS patients were able to adequately (compared to physiologic measures of fatigue) rate exercise associated fatigue using the Borg Perceived Exertion scale;

16. no articles report restoration via exercise of function in paralyzed muscle; and 'there is no proof that <electrical stimulation> enhances enervation of totally enervated muscle' (Herbison, G 1985 MOD Series, p175), however note that Pape (1992, OMD Proceedings) reports 'growth in blood vessels, muscles and nerves' due to the trophic effects of 'low level electrical stimulation...for hours at a time over months'

17. studies which report on muscle grade improvement following exercise indicate that muscles with greater than grade three strength have potential for increasing strength, but that muscles with less than grade three have potential for maintaining strength, only;

18. consider the benefit-to-risk ratio associated with prescription of exercise versus rest and type of exercise; consider whether an exercise program will translate into functional gains;

19. for bulbar affected: consider residual respiratory impairment in terms of potential for developing overuse and small amount of respiratory reserve available; in a Dean and Ross (1991) study, after participating in a walking program which did not have a conditioning effect, two bulbar affected patients did not suffer any deterioration in cardio respiratory function, however the long-term effects of this program are not known; Einarsson (1991 SJMR) concluded that as PFT's in those polio survivors with poor tolerance ventilatory assistance were no different than other patients with a low respiratory reserve, rapid respiratory muscle function deterioration is unlikely at work; Feldman & Gilchrist (1988, Supplement to Clinical & Investigative Medicine 11(4)) have reported biopsy of the diaphragm to establish polio/PPS involvement, however this procedure is not routine and therefore cannot be relied upon for confirmation of polio involvement.

General indications for the prescription of exercise in the PPS population are:

1. to increase function by improving endurance, strength, efficiency and coordination;

2. to rehabilitate following disuse due to surgery, illness, prolonged bed rest, or rest prescribed for muscle overuse; initiation of rehabilitation in the asymptomatic and the symptomatic polio survivor is crucial as lost muscle is difficult to regain and has a greater functional significance than in the non-polio population;

3. to improve cardiovascular fitness.

PROGRAMS

PROGRAM EXAMPLES

The following are brief descriptions of the philosophy and protocols of studies concerned with exercise in PPS. Philosophies stated by authors may not have support from the entire medical community. This list is not comprehensive, as some authors (e.g. Owen RR, 1985 Birth Defects Series) list but do not detail components of programs, or describe highly questionable protocols. Therapists are encouraged to read the original articles cited, and to reefer to the Post-Polio Current Bibliographies in Medicine, national Library of Medicine, Dept. of Health & Human Services, Public Service Division, Bethesda, Maryland, USA 20894, for more recent article listings.

I. Einarsson, G. Muscle Adaptation and Disability in Late Poliomyelitis The Scandinavian Journal of Rehabilitation Medicine Suppl. #2 1991, pp1-76

Philosophy: Brief contractions do not damage motor units. Short term resistance exercise can increase strength via neural adaptation rather than via muscle hypertrophy, which is associated with greater risk of overuse damage.

Protocol: 'heavy resistance' to increase strength

Frequency and course: 3x/week x 6 weeks

Routine: 5 minute warm-up at 30W load on cycle ergo meter Cybex II isokinetic dynamometer - 12 sets x 8 reps/set @ 180 degrees/sec angular speed + 12 sets x 4 sec/rep isometric @ 180 degrees.

Findings: no new histopathologic changes on EMG immediately and 6-12 months post-training; 29% mean increase in isometric and 24% mean increase in isokinetic strength;

strength increases retained 6 to 12 months post-training, however fatigue levels increased.

Recommendations: short-term training period 1 to 2 months x1-2/year to maintain strength while potentially avoiding fatigue secondary to over-training/overuse.

II. <u>Feldman RM The Canadian Journal of Diagnosis, Nov. 1991 pp. 127-134</u>

Philosophy: Muscles affected by polio can be either 'essentially normal' and exercised without regard for fatigue, or 'post-polio' which are clinically weak due to a loss of 50% of motor neuron junctions and must be exercised with non-fatiguing strengthening exercises. Absent or markedly reduced insertional activity during EMG testing is considered a sign of PPS. (NB: Other researchers have not supported this finding.

Protocol: muscle specific to maintain or increase strength.

Frequency and course: every other day.

Routine: establish maximum amount of weight which can be moved through range x5 rep without fatigue (patient and therapist are both responsible for looking for these e.g. synergistic or gross movement, grimacing, decrease in quality of movement); initiate program with prescription of 5 reps x 50% of established baseline maximum resistance; progress gradually with increase in number of reps to 30, progress further by increasing the resistance to 75% of baseline maximum and reduce reps to 5; progress further by gradually increasing reps to 30; progress further by increasing resistance to 100% of baseline maximum and reduce reps to 5; progress by increasing number of reps to 30; on discharge, maintain level of reps and resistance achieved without the development of continuous fatigue.

Findings: in 'essentially normal' polio affected muscles - 68% increase in strength, 32% no change in strength ; in post-polio muscles - 70% increase in strength, 30% no change in strength (increase in strength implies > one manual muscle grade); greater than or equal to grade 3 rated muscles had potential to increase strength, however less than grade three rated muscles maintained strength only.

Recommendations: Maintain exercise program to maintain strength

III. Fillyaw, M. et al Post polio Sequelae: The Effects of Long-term Non-fatiguing Resistance Exercises in Subjects with the Post-polio Syndrome Orthopedics, 1991 14(11) pp. 1253-1256 Philosophy: strengthening can be achieved relatively safely with non-fatiguing exercises Protocol: isotonic strengthening with a Cybex II isokinetic dynamometer at 90 degrees knee/elbow flexion

Frequency and course: every other day

Routine: pre-program exercise test: 5 maximal volitional contractions x 5 sec with a 10 sec inter-trail rest followed by a continuous contraction x 60 sec/failure, max. torque=muscle strength, area under the torque curve=endurance interval; training protocol: 10 reps/set x 3 sets (first set x 50% maximum weight moved through full ROM without pain, second set 75%, third set 100%) with 5 minute rest between sets, maximum weight re-evaluated every two weeks, weight increased when # reps in third set increased to 15.

Findings: strength gains without detriment in short-term (two years post-training)

IV. Dean E and Ross J Effect of Modified Aerobic Training on Movement Energetics in Polio Survivors. Orthopedics Nov. 1991 14(11) pp 1243-1246

Philosophy: decreasing the energy cost of movement and increasing the endurance of polio survivors may enhance productivity and quality of life, if done following a protocol designed to minimize risk of injury and further deterioration.

Protocol: modified walking program on treadmill.

Frequency and course: x3/week x 6 weeks.

Routine: establish pre-program level of cardiovascular fitness via a sub-maximal steady-state exercise test on a treadmill consisting of: 2 minutes at 1.6k/hr, 0.8 increments of speed each minute until a comfortable cadence achieved, grade increased by 2.5% for those not attaining target heart rates, steady-state reached within 5 minutes to avoid fatigue, cool-down and post-exercise recovery, evaluation of exertion and pain with Borg scales; session length and intensity determined by patient rating of pain (maintain below 3/10) and perceived exertion (maintain below 5/10) Findings: this protocol is insufficient to elicit a cardiovascular training effect because subjects exercised at only 55-70% of predicted heart rate, however exercise time and perceived exertion decreased, which may be advantageous in weight reduction and ability to do work.

Recommendations: Benefit-to-risk ratios for all exercise prescriptions must be considered.

V. Dean E and Ross J Modified Aerobic Walking Program: Effects on Patients with Post polio Syndrome Symptoms. APMR Dec. 1988 Vol. 69 pp. 1033-1038

Philosophy: general body conditioning may increase endurance, coordination, strength and efficiency while avoiding the risk of overuse of specific muscles or undue biomechanical stress on joints and muscles attendant to weight training in those patients not requiring ambulation aids who have a history of bulbar polio involvement and are currently complaining of decreased endurance and breathing difficulties

Frequency and course: x3/week x 8 weeks.

Routine: pre-program exercise test: 1 mph at 0% grade with 0.5 increments in speed every 1-2 minutes until termination when heart rate exceeds 70% of age predicted maximum/systolic blood pressure exceeded 180 mm Hg/perceived exertion exceeded very heavy or pain was greater than moderate on a Borg scale; treadmill training at 0% grade with daily monitoring of fatigue and session cancellation when pain/fatigue greater than light; speed and time gradually increased as tolerated according to pain/fatigue criteria.

Findings: subjects exhibited an increase in walking time, a decrease in fatigue during ADL, and decreases in VO2 (training effect in 2/7 subjects), heart rate and blood pressure secondary to increased biomechanical efficiency of walking and increased efficiency of oxygen transport. Recommendation: Bulbar PPS must have respiratory status monitored regularly.

VI. Jones et al. Cardio respiratory Response to Aerobic Training by Patients with Post poliomyelitis Sequelae. JAMA June 9, 1989 Vol. 261 No 22. pp 3255-3258

Philosophy: conditioning is possible and may be done with a minimum of short-term risk in the PPS population.

Protocol: conditioning with a cycle ergo meter Frequency and course: x3/week x 16 weeks. Routine: pre-program exercise test: 50-70 rpm pedaling cadence, first minute without resistance, increments of 1W/minute to 20W reached to fatigue within 5-8 minutes (to eliminate the role of local muscle fatigue in test termination) or until VO2 failed to increase with workload /respiratory ratio exceeds 1.0/cardiovascular abnormalities/ volitional fatigue/inability to maintain pedaling cadence of 40 rpm; training at 70-75% reserve heart + resting heart rate x 15-30 min./session divided into bouts of 2-5 minutes of exercise interspersed with one minute rests

Findings: no overuse noted; no difference in the VE between bulbar and non-bulbar affected patients; 15% improvement in VO2 max.

Recommendations: one day minimum rest between sessions, patients with pre-program MET level >6 begin with 4-5 minute exercise bout duration, <6 begin with 2-3 minutes.

VII. Kriz et al. Cardio respiratory Responses to Upper Extremity Aerobic Training by Post polio Subjects. APMR Jan. 1992 Vol. 73 pp. 49-54

Philosophy: conditioning is possible and may be done with a minimum short-term risk in the PPS population.

Protocol: conditioning with a cycle ergo meter modified for upper extremity use.

Frequency and course: x3/week x 16 weeks.

Routine: pre-program exercise test: 50 rpm cadence, first minute without fail to increase with workload/cardiovascular abnormalities/volitional fatigue/inability to maintain pedaling cadence of 30 rpm; training at 70-75% reserve heart + resting heart rate x 15-30 minutes/session initially divided into bouts of 2-3 minutes of exercise interspersed with one minute rests; session length increased to 20 minutes when rating of perceived exertion is less than 13(Borg), after 2 weeks, exercise bouts increased by 1 minute as tolerated with careful monitoring of pain/ fatigue Findings: no overuse noted; definite cardiovascular conditioning signs: improvement in VO2 max, VCO2 max, power, exercise time, VE max.

Recommendations: one day minimum rest between sessions, excellent compliance when exercise intensity modified according to rate of perceived exertion.

MUSCLE_OVERUSE

Muscle overuse is the result of an imbalance between workload demands and neuromuscular system capacity to do work In the PPS population, the integrity of the neuromuscular system has been compromised by poliomyelitis and workload demands for ADL may be greater than that for healthy individuals due to polio residua Physiotherapy intervention must enhance performance of the remaining neuromuscular system, while concurrently reducing excessive demands on it.

REDUCING DEMANDS

<u>Reduction of the demand on the neuromuscular system may be accomplished in many ways:</u>

Energy conservation techniques:

1. assign a priority to each task to determine which may wait and which must be done immediately;

2. time management- plan each day in such a way as to avoid doing several physically intensive activities sequentially/concurrently;

3. pace activities- segment large tasks into smaller ones which can be performed with intermittent rest breaks or over a longer period of time;

4. orthotics/footwear- adequate bracing can decrease the energy cost of movement or posture maintenance; Cuban heels, Swedish clogs, cowboy boots;

5. ambulation aids and assistive devices- distribute all or some of the workload to stronger muscles or increase mechanical advantage;

6. mobility aids-elevators, electric wheelchairs/scooters, handicapped parking pass;

7. weight maintenance or non-lean body mass loss in the obese (dependence solely on exercise to attain this goal contraindicated and the loss rate must not be so rapid as to result in excessive loss of muscle tissue due to the difficulty in increasing this safely in the PPS patient);

8. gait and postural re-education;

9. allow more time for task completion;

10. delegate tasks;

11. facilitate efficiency by planning task completion procedures;

12. occupation modification: 1) reduce hours; 2) reduce physical components of job or responsibilities; 3) change jobs.

Young, GR (Orthopedics, 1991, 14(11), PP 1233-1239) has developed a booklet for PPS (Energy Conservation & Work Simplification for Persons with Post-polio Syndrome)

ENHANCING PERFORMANCE

1. pacing activities-intermittent rest can increase overall work capacity on a daily basis (Agre & Rodriquez, 1991);

2. rest an adequate period (until symptoms have dissipated to an acceptable low level or disappeared) for neuromuscular recovery when fatigue/weakness is intense and constant (Dean, 1991a) followed by gradual increase in activity and rehabilitation via conditioning or strengthening programs;

3. maintenance of CV fitness within system tolerance;

4. attainment of CV fitness via a modified conditioning program within system tolerance (Dean & Ross, 1988);

5. attainment/maintenance of strength via resistance training (NB: controversial);

6. schedule daily naps/rest breaks;

7. maintain adequate nutrition (especially important for those on caloric restricted diet, as lost muscle is difficult for this population to regain);

8. gait /postural reeducation;

9. sleep lab;

10. adequate protection against environmental cold to avoid decreased performance secondary to cold intolerance induced decreased nerve conduction and muscle swelling.

ORTHOTICS

Conservative treatment of ligament laxity is preferable to surgery because: 1) anesthesia contraindication/precaution for bulbar affected with/out residual disability; and 2) post-operative bed rest can cause /exacerbate loss of strength or endurance, which may result in further loss of function. Strengthening muscles around the joint, whether to delay or prevent surgery or as post-op rehabilitation, must be done within the patient's tolerance level to avoid muscle overuse and is contraindicated during acute muscle overuse or when muscle overuse is likely to develop due to rehabilitation demands increasing the total beyond capacity.

PPS_DIAGNOSTIC_CRITERIA

Patients who satisfy all of the following criteria are diagnosed with PPS:

1. The patient had partial neurological and functional recovery following the acute episode of polio;

2. The patient experienced a period of neurological and functional stability for greater than or equal to 10 (some workers use 15) years following recovery;

3. The patient has begun to experience gradual or abrupt onset of new neurogenic weakness in muscle affected or unaffected by polio, with/out accompanying deterioration of function, excessive or unaccustomed fatigue, cold intolerance, and atrophy or muscular or joint pain unexplained by other medical diagnosis. (Adapted from Einarsson, 1991a and Halstead, 1991)

Symptomatic individuals who never recovered from polio are not likely suffering from PPS, as it is currently understood. Individuals who were infected more recently than the criteria specified number of years for functional stability may still benefit from the education segment; however any symptoms they are experiencing may not be due to PPS. Individuals who meet the first two, but not the last criteria may be at risk for developing PPS, and therefore may benefit from the educational segment of the PPS (ES) and a baseline assessment followed by annual re-assessments.

PROBLEM_SEGMENT

PPS PROBLEMS

The three main PPS problems are:

1) condition management dependence;

2) insufficient knowledge about the syndrome;

3) decreasing physical function (e.g. inabilities to climb stairs/egress from a bathtub/walk to the corner store/maintain standing balance).

Independence of management can be facilitated by addressing the other two problems Insufficient knowledge about the syndrome may affect patient compliance, affect and management independence. Comprehensive treatment of the PPS patient must include patient education. Education of the non-symptomatic polio survivor may avert development of some impairments or disabilities.

Decreased physical function is most commonly due to: 1) weakness; 2) pain; and 3) fatigue. These impairments often interact. For example, overwhelming fatigue may result in decreased activity which eventually will cause decreases in strength and endurance; the compromised neuromuscular system is now at risk of sustaining conditions such as bursitis or fasciitis and the pain from these may lead to a further reduction in activity level.

Treatment strategies to ameliorate one disability or impairment may concurrently alleviate another disability or impairment. For example, prescription of a lighter orthosis to replace a heavier one will address the need to decrease demand on overused muscles and reduce the energy cost of movement, which may lessen general fatigue and pain. When the therapist has identified a disability, the PPS (ES) will present a treatment strategy for the selected potentially contributive impairment. The therapist may then choose to continue treatment planning with the PPS (ES) to select a different potential contributory impairment or another disability, or to exit the program. The PPS (ES) will consider only one disability and related impairment at a time; therefore, when patients present with more than one complaint, each of these must be pursued independently with the PPS (ES).

RAS

The determination of whether or not this condition pertains cannot be made with a physiotherapy assessment. Electromagnetic testing may detect deterioration of this area or a neurologist may indicate a suspicion of involvement in a chart note or referral to physiotherapy. No articles in the PPS medical literature state that physiotherapy can address this impairment directly, therefore treatment must be supportive. Select 'The patient's knowledge of PPS must be augmented with education.'

ROM

Care must be taken to avoid increasing range when compensatory adaptations are necessary for safety or function (as defined by the patient's needs).

REST

Adequate daytime rest is essential to prevent the development of overwhelming fatigue which necessitates early repose and decreased productivity, and to minimize the development of muscle overuse. It may be beneficial in pain reduction, as well. Energy levels in all individuals vary according to time (day to day, seasonally, throughout the day), nutritional status, emotional status, fitness level, workload demands and several other factors. An activity-rest log can facilitate evaluation of relative fatigue associated with a given activity or time of day, and assist in planning activities in such a way as to avoid exhaustion, yet still accomplish requisite goals in a timely fashion. A one week log of fifteen minute period entries of activity description and fatigue level attribution, using the Borg Perceived Exertion scale (Agre and Rodriquez, 1991 APMR) can be reviewed by the therapist and the patient, to determine the number, duration and timing of rests throughout the day. To be maximally effective, during rest periods the patient must recline in a fully supported, comfortable position, on comfortable furnishings, in a room with minimal distractions and an adequate ambient temperature. Sleep is not necessary. Recommended minimum duration for effective rest ranges from 30-60 minutes. The patient must be instructed to be sensitive to stressors which may contribute to fatigue and overuse, and to minimize these as able.

SLEEP

Adequate sleep can reduce fatigue and pain and is essential for muscle tissue repair. Sleep may be inadequate due to poor sleep hygiene (e.g. irregular schedule, caffeine consumption prior to repose), emotional distress, mental illness or any of a number of reasons. Referral to a psychologist for behavior modification or other intervention may be helpful. Those causes under the purview of physical therapy include sleep disturbed by musculoskeletal pain (general/cramping), apnea or hypoventilation. The latter two causes can be investigated in a polysomnographic study (sleep lab) and may require the fitting of an oral orthosis, modification of sleeping posture or bed angle, bulbar muscle strengthening, etc. Musculoskeletal pain may be due to daytime activities, cold intolerance or poor posture in bed.

The former topics are discussed in the pain segment of the PPS (ES). Poor bed posture may be corrected with supportive orthoses (e.g. cervical pillow), pillows located between the knees in side-lie and under the knees in supine-lie, the use of supportive stockings or change in bed angle in the case of circulation compromised by poor vasoconstriction secondary to polio involvement (controversial).

SLEEPING_POSTURE

Correction of poor sleeping posture can facilitate avoidance of nerve root entrapment or circulation impediment. The sleeping surface must give adequate support, whether it is a box spring, futon or waterbed. Cervical pillows, pillows between or under the knees may be necessary to maintain and support proper spinal alignment. Patients must be discouraged from prone-lying, using no pillow or too many pillows under the head, sleeping with an arm under the head or trunk, crossing the legs or having the legs at too great of an angle from horizontal.

EDUCATION

<u>POLIOMYELITIS</u>

Poliomyelitis is an enterovirus with three immunologically distinct strains. Infection may occur via the respiratory or alimentary systems. The majority of infected individuals do not experience any noticeable symptoms. The remainder experience fever, aching and GI symptoms for an average period of five days. Only one percent will develop spinal, bulbar, or bulbospinal symptoms. Motor neurons in the lateral anterior horn of the spinal tract may be killed or damaged, resulting in asymmetrical and scattered paresis or paralysis of lower>upper extremities and a loss of coetaneous and tendon reflexes. Involvement of cranial nerves or of the medulla may result in respiratory or degluttinatory impairments. A very small percentage may experience polio encephalitis. Maximal recovery following the more severe affliction with polio may take a few months to two years. The neuromuscular system responds to the insult of polio by recovered and unaffected anterior horn cells re-enervating some but not all orphaned muscle fibers. Consequently, the number of muscle fibers per motor neuron increases beyond the usual number, fewer muscle cells are innervated and some cross-enervation occurs. Muscle fiber splitting and hypertrophy are other means taken to increase surviving motor unit strength. Transformation from Type II to Type I muscle fiber type transpires when functional demand exceeds system work capacity. Residual impairments include: paralysis, paresis, altered gait patterns, reliance on respiratory/ambulatory/mobility/assistive devices, ligament laxity, and joint deformity. Some common surgical interventions in this patient population include: correction of equinus/ genu valgus/genu recurvatum/limb length discrepancy, fusion of ankle joints, support in kyphotic or scoliotic spine, and muscle transfer, (especially for dysfunctional lower extremities).

Most polio survivors lead normal lives including holding a job and raising families, following recovery. Many have achieved more than their peers, possibly because of a goal-oriented attitude developed during rehabilitation for polio.

In North America, the last major polio epidemic occurred in the mid 1950's Vaccines developed and administered nationally since then have significantly reduced the incidence in developed countries. Polio is still a major agent of disease in many developing countries.

PPS

In the early 1980's, a small number of polio survivors began to experience new and unexplainable weakness and fatigue. Initially, their symptoms were attributed to a number of different diseases or illnesses including chronic fatigue syndrome, depression, dysfunctional Type A personality and an unusual form of ALS. As the incidence increased and more research was done, 'post-polio syndrome' received recognition from the medical community. Since then, a number of symposia have been held and research has been focused towards finding the cause of, a diagnostic tool for identifying, and appropriate treatments for the late effects of polio.

INCIDENCE AND PREVALENCE

Estimates as to the number of polio survivors who will develop PPS range from twenty to eighty percent. It is assumed that the largest number of new diagnoses in North America will occur in 1993, as this coincides with the average time (37 years) from polio infection to PPS presentation for those infected in the last large epidemic. Incidence and prevalence of this syndrome are difficult to determine because it may be misdiagnosed and individuals with mild symptoms or who are in denial may not seek medical intervention.

ETIOLOGY

The pathophysiology of this syndrome is currently unknown. Some of the earlier proposed theories, such as forme fruste (a variant form of ALS), have been discounted.

Theories with current support include:

1) anterior horn cell death secondary to normal aging with greater effect on function than in the healthy individual due to the increased number of muscle fibers associated with each motor neuron. (NB this may be spurious, as significant anterior horn cell loss is considered to begin after the age of sixty years, and most PPS are younger;

2) inability of anterior horn cell metabolism to continue supporting an excessive number of muscle fibers;

3) muscle overuse secondary to an insufficient number of surviving motor units to provide for ADL/ basic activity, thus remaining muscle cells are chronically subjected to a heavy resistance training to achieve 'normal' output;

4) terminal axonal dysfunction/impaired impulse transmission/unstable neuromuscular connections (in both asymptomatic and symptomatic polio survivors, there is EMG

evidence of constant enervation and enervation, and as many as 20% of all enervations will have faulty neuromuscular junctions).

There is no test which has universal acceptance as being pathognomic for PPS. Feldman (1991) has reported that insertional activity in EMG testing is abnormal in PPS affected muscles, but this finding has not been replicated by other researchers.

SIGNS AND SYMPTOMS

This list, adapted from an article by Dean (1991a), is representative of primary and secondary problems listed by most articles in this area:

PRIMARY COMPLAINTS:

new weakness (>80%) ^	muscle cramping
new pain (>80%) ^	muscle twitching-fasciculations
fatigue (>80%) ^	sensitivity to cold
decreased endurance (>80%) ^	atrophy*

SECONDARY COMPLAINTS:

decreased balance-falls	increased shortness of breath
peripheral neuropathy	anxiety/depression
joint deformity	sleep apnea
dependent edema	snoring morning headaches
tendonitis	weak cough
genitourinary problems	daytime somnolence
ligament laxity	poor memory/concentration
GI complaints	increased weight
	difficulty swallowing/choking

^ These percentages reflect the average of incidences reported in the literature.

* It has been speculated that PPMA (progressive post-polio muscular atrophy) is the end-stage neuronal reaction to the ongoing process of enervation and enervation; the neuron's ability to maintain the integrity of distal nerve terminals is exceeded and muscle fiber atrophy results (Einarsson, 1991a). Alaska (1991) and co-workers were unable to find rapid deterioration in PPS patients. Over the course of 12 years, a mean of only 1%

decrement in strength was observed. PPMA is considered to be rare and may be spurious. The incidence of new respiratory or deglutination problems is also considered to uncommon (Einarsson, 1991a), but when present can cause serious dysfunction.

RISK FACTORS:

Pathophysiology of this syndrome is uncertain; however several of the currently supported theories are consistent with the following data which correlates highly with the development of PPS:

- hospitalization with the acute onset of polio
- polio infection after the age of 10 years
- mechanical ventilation
- paralysis in all four limbs
- rapid recovery post-infection, with greater recovery and higher life-time activity level

PPS is considered to be benign because loss of strength is relatively slowed (e.g. compared to ALS) and the syndrome is not life-threatening except for the bulbar affected, who can be given respiratory support as required. Motor and other impairments, however, can result in severe disability and handicap. The effect of a second disability, especially one arising from a disease already fought, may be especially devastating emotionally. Additionally, because polio survivors were encouraged during polio rehabilitation to view exercise as a means of attaining 'wholeness' and the use of aids as a sign of weakness or lack of commitment to independence, they may have to change long-held attitudes in order to behave in a manner which is currently in their best interests. It is essential to keep these facts in mind when considering ways in to facilitate patient compliance.

Holistic treatment may include intervention by occupational therapy, social work, psychology/psychiatry, medicine, and orthotics as well as by physiotherapy. Until the pathophysiology of this syndrome is known, treatment will likely continue to be directed towards minimizing the effects of symptoms, rather than towards a cure. Physiotherapy can play an important role in improving quality of life.

FUTURE:

Research to understand the pathophysiology, to detail the natural history, and to determine long-term effects and effectiveness of various treatments continues. Two Canadian physicians (Dr. Feldman and Dr. Pape), reporting success with their treatment protocols may conduct and publish results of randomized controlled trials which can then be subjected to review by their peers.

Potential Prophylactic Measures for Asymptomatic Polio Survivors:

Lifestyle changes which may have potential as prophylactic measures, in accord with popular pathological theories include:

1. avoidance of high intensity exercise (e.g. weight-training, heavy manual labor) for sub clinically and clinically affected muscle groups;
2. adequate rest during activity and throughout the day;
3. annual re-assessment of function;
4. optimal fitness level maintenance via non-fatiguing protocols;
5. optimal lean-fat body mass ratio and nutrition;
6. smoking cessation, especially for the bulbar affected;
7. judicious use of mobility/ambulatory/assistive aids and orthoses;
8. energy conservation techniques (consider occupational therapy intervention);

9. stress management; 1

10. avoidance of exposure to environmental cold (maintain optimal conditions for muscle contraction).

NB: These recommendations are made by Myrna Donald. Some of them may reduce the potential of motor unit loss secondary to muscle overuse. They are not supported by research.

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OTHER CONTACTS:

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3581 University Drive, Fairfax, Virginia USA 22030

Roosevelt Warm Springs Institute for Rehabilitation
PO Box 1000, Warm Springs, Georgia, USA 31830

Gazette International Networking Institute

4502 Maryland Ave., St. Louis, Missouri USA 63108

REFERENCE:

An informative and inexpensive pamphlet entitled 'The Handbook on the Late Effects of Poliomyelitis for Physicians and Survivors' edited by G. Laurie et al, is published by International Polio Network, 5100 Oakland Ave. #206, St. Louis, Missouri, USA 63110.

AM_FATIGUE

The causes of the musculoskeletal pain must be identified and treated, to facilitate improvement in the quality and quantity of sleep the patient is receiving. Select 'The patient has PAIN' rather than 'The patient has FATIGUE,' to address this problem.

LOCAL_FATIGUE

Fatigue which is localized in the muscle is likely due to a deficit of strength or of endurance. To view treatment plans for either deficit, select 'The patient has WEAKNESS', rather than 'The patient has FATIGUE.'

Appendix A.3 Rule Modules from the Initial Prototype

The rule bases appear as they were prior to development of the second iteration prototypes.

Figure A.3-1: Diagnostic Module

```
START
FORGET KBES-MARK

: KBES-MARK ;  \ ( Bizarre programming mark to enable fresh restarts DSDS 93)

.( LOADING PLAN.TXT )

\ DIAGNOSITC RULES (sic)
RULES

IF The patient has a confirmed history of polio (determined by medical records or EMG
data) *
ANDIF The patient satisfies PPS_DIAGNOSTIC_CRITERIA *
THEN The PPS(ES) may be beneficial in the physiotherapy intervention for this   patient
*

IF The PPS(ES) may be beneficial in the physiotherapy intervention for this   patient *
ANDIF The therapist needs to review condition-specific assessment components *
THEN A thorough condition specific and general assessment facilitates treatment
planning *
ANDTHENRUN Continue1
ANDTHENRUN ASSESSMENT
ANDTHENRUN PROBLEM_SEGMENT
ANDTHENRUN PLAN2

IF The PPS(ES) may be beneficial in the physiotherapy intervention for this   patient *
ANDIFNOT The therapist needs to review condition-specific assessment components *
THEN A thorough assessment facilitates identification of impairments and disabilites *
ANDTHENRUN Continue1
ANDTHENRUN PROBLEM_SEGMENT
ANDTHENRUN PLAN2
```

IFNOT The patient has a confirmed history of polio (determined by medical records or EMG data) *
THEN Referral to a physician may be warranted *

IF You require more information about PPS(ES) *
THEN This information will assist you *
ANDTHENRUN STARTUP1

IFNOT You require more information about PPS(ES) *
THEN You may now begin treatment planning *
ANDTHENRUN STARTUP2
ANDTHENRUN PLAN2

IFNOT This information will assist you *
ANDIFNOT You may now begin treatment planning *
OR
IF Referral to a physician may be warranted *
OR
IFNOT A thorough condition specific and general assessment facilitates treatment planning *
ANDIFNOT A thorough assessment facilitates identification of impairments and disabilites *
THENHYP The PPS(ES) is not appropriate in the physiotherapy intervention for this patient *
ANDTHENRUN Continue1
ANDTHENRUN Restart1

DONE

Figure A.3-2: Problems Module

.(LOADING PROB.TXT)

START

\ PROBLEM RULES

RULES

IF The patient's knowledge of PPS must be augmented with education *
THEN The therapist can facilitate the patient's independence in condition management by empowering him with knowledge *
ANDTHENRUN PLAN6

IF The patient has PAIN *
THEN The therapist must alleviate and minimize/eliminate the causes of pain *
ANDTHENRUN PLAN5

IF The patient has FATIGUE *
THEN The therapist must determine the causes of fatigue *
ANDTHENRUN PLAN3

IF The patient has WEAKNESS *
THEN The therapist must determine the causes of weakness *
ANDTHENRUN PLAN4

IFNOT The therapist can facilitate the patient's independence in condition management by empowering him with knowledge *
ANDIFNOT The therapist must alleviate and minimize/eliminate the causes of pain *
ANDIFNOT The therapist must determine the causes of fatigue *
ANDIFNOT The therapist must determine the causes of weakness *
THEN The PPS(ES) assists in treatment planning for the disabilities associated with PPS *

IF The PPS(ES) assists in treatment planning for the disabilities associated with PPS *
THEN Weakness, fatigue, pain and insufficient knowledge about PPS(ES) are the main impairments *

IF The therapist wants to continue treatment planning for the same patient *
THEN Select a different cause of the same impairment, or another impairment *
ANDTHENRUN PLAN2

IF The therapist wants to assess a new patient *
THEN Determine whether or not the patient has PPS *
ANDTHENRUN PLAN1

IF The therapist can facilitate the patient's independence in condition management by empowering him with knowledge *
ANDIF Patient education information has been provided *
OR
IF The therapist must alleviate and minimize/eliminate the causes of pain *
ANDIF Advice has been given about minimizing or alleviating pain *
OR
IF The therapist must determine the causes of fatigue *
ANDIF A fatigue type and cause have been identified and treatment advice given *
OR
IF The therapist must determine the causes of weakness *
ANDIF Advice has been give to restore strength or endurance *
OR
IF Weakness, fatigue, pain and insufficient knowledge about PPS(ES) are the main impairments *
THEN Provide option to continue *

IF Provide option to continue *
ANDIFNOT Select a different cause of the same impairment, or another impairment *
ANDIFNOT Determine whether or not the patient has PPS *
THENHYP Thank-you for using the PPS(ES) *
ANDTHENRUN Continue1
ANDTHENRUN Restart1

DONE

Figure A.3-3: Fatigue Module

.(LOADING FATIGUE RULES)
\ FATIGUE RULES

MORERULES

IF The therapist must determine the causes of fatigue *
THEN The main types of fatigue are local, generalized and upon awakening *

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has fatigue immediately upon arising *
ANDIF The patient may be experiencing sleep apnea or hypoventilation *
THEN Referral to a respirologist/sleep lab is warranted *

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has fatigue immediately upon arising *
ANDIF The patient is experiencing musculoskeletal pain which disturbs sleep *
THEN The therapist must identify the causes of somatic PAIN *
ANDTHENRUN AM_FATIGUE

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has local fatigue (ie in muscle) which is activity sensitive *
ANDIF The patient is experiencing weakness *
THEN The therapist must determine the cause(s) of weakness *
ANDTHENRUN LOCAL_FATIGUE

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has GENERALIZED fatigue which characteristically peaks midday *
ANDIF The generalized fatigue may be due to deterioration of the reticular activating system *
THEN Referral to a psychologist may be warranted and treatment must include education *
ANDTHENRUN RAS

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has GENERALIZED fatigue which characteristically peaks midday *
ANDIF The patient is experiencing inadequate sleep *
THEN Treatment is required to promote adequate SLEEP *

IF Treatment is required to promote adequate SLEEP *
ANDIF The therapist wants to review methods to promote adequate sleep *
THEN Physiotherapy intervention may improve the quality and quantity of sleep *
ANDTHENRUN SLEEP

IF Treatment is required to promote adequate SLEEP *
ANDIFNOT The therapist wants to review methods to promote adequate sleep *
THEN Adequate sleep can reduce fatigue and pain, and facilitate muscle repair *

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has GENERALIZED fatigue which characteristically peaks midday *
ANDIF The patient is experiencing inadequate daytime rest *
THEN Treatment is required to promote adequate rest *

IF Treatment is required to promote adequate rest *
ANDIF The therapist wants to review methods to promote adequate rest *
THEN The therapist can assist the patient in determining and achieving adequate levels of rest *
ANDTHENRUN REST

IF Treatment is required to promote adequate rest *
ANDIFNOT The therapist wants to review methods to promote adequate rest *
THEN Adequate daytime rest can delay the time of evening repose, increase productivity & enhance overall quality of life *

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has GENERALIZED fatigue which characteristically peaks midday *
ANDIF The patient is deconditioned *
ORIF The patient is experiencing muscle OVERUSE *
THEN Muscle OVERUSE reduction/prevention is necessary prior to initiating an exercise program *

IF Muscle OVERUSE reduction/prevention is necessary prior to initiating an exercise program *
ANDIF The therapist wants to review measures to reduce muscle OVERUSE *
THEN There are many methods to decrease muscle overuse *
ANDTHENRUN MUSCLE_OVERUSE

IF Muscle OVERUSE reduction/prevention is necessary prior to initiating an exercise program *
ANDIFNOT The therapist wants to review measures to reduce muscle OVERUSE *
THEN ADL within fatigue and pain tolerance is advised until recouperation *

IF The main types of fatigue are local, generalized and upon awakening *
ANDIFNOT The patient has fatigue immediately upon arising *
ANDIFNOT The patient has local fatigue (ie in muscle) which is activity sensitive *
ANDIFNOT The patient has GENERALIZED fatigue which characteristically peaks midday *
THEN Fatigue upon arising, local fatigue & generalized fatigue are the three main types of fatigue included in PPS(ES) *

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has fatigue immediately upon arising *
ANDIFNOT The patient may be experiencing sleep apnea or hypoventilation *
ANDIFNOT The patient is experiencing musculoskeletal pain which disturbs sleep *
THEN Sleep disrupted by pain or apnea, and hypoventilation are the main reasons for morning fatigue *

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has local fatigue (ie in muscle) which is activity sensitive *
ANDIFNOT The patient is experiencing weakness *
THEN Weakness (either insufficient strength: overuse, disuse or both; or insufficent endurance) is the most likely cause of activity affected local fatigue *

IF The main types of fatigue are local, generalized and upon awakening *
ANDIF The patient has GENERALIZED fatigue which characteristically peaks midday *
ANDIFNOT The generalized fatigue may be due to deterioration of the reticular activating system *
ANDIFNOT The patient is experiencing inadequate sleep *
ANDIFNOT The patient is experiencing inadequate daytime rest *
ANDIFNOT The patient is deconditioned *
ANDIFNOT The patient is experiencing muscle OVERUSE *
THEN Deconditioning, muscle overuse, inadequate sleep or rest, or a dysfunctional reticular activating system are the causes of generalized fatigue included in the PPS(ES) *

IF Referral to a respirologist/sleep lab is warranted *
ORIF The therapist must identify the causes of somatic PAIN *
ORIF Sleep disrupted by pain or apnea, and hypoventilation are the main reasons for morning fatigue *
ORIF The therapist must determine the cause(s) of weakness *
ORIF Weakness (either insufficient strength: overuse, disuse or both; or insufficent endurance) is the most likely cause of activity affected local fatigue *
ORIF Referral to a psychologist may be warranted and treatment must include education *
ORIF Physiotherapy intervention may improve the quality and quantity of sleep *
ORIF Adequate sleep can reduce fatigue and pain, and facilitate muscle repair *
ORIF The therapist can assist the patient in determining and achieving adequate levels of rest *
ORIF Adequate daytime rest can delay the time of evening repose, increase productivity & enhance overall quality of life *
ORIF There are many methods to decrease muscle overuse *
ORIF ADL within fatigue and pain tolerance is advised until recouperation *
ORIF Deconditioning, muscle overuse, inadequate sleep or rest, or a dysfunctional reticular activating system are the causes of generalized fatigue included in the PPS(ES) *
ORIF Fatigue upon arising, local fatigue & generalized fatigue are the three main types of fatigue included in PPS(ES) *
THEN A fatigue type and cause have been identified and treatment advice given *
ANDTHENRUN Continue1

DONE

Figure A.3-4: Weakness Module

.(LOADING WEAKNESS RULES)

\ WEAKNESS RULES

MORERULES

IF The therapist must determine the causes of weakness *
ANDIF The weakness is due to a deficit of strength *
THEN The therapist must determine whether the cause is DISUSE, OVERUSE or both *

IF The therapist must determine whether the cause is DISUSE, OVERUSE or both *
ANDIF Muscle OVERUSE is the cause *
THEN Treatment is required to reduce muscle overuse *

IF Treatment is required to reduce muscle overuse *
ANDIF The therapist wants to review measures to reduce muscle OVERUSE *
THEN There are many methods to decrease muscle overuse *
ANDTHENRUN MUSCLE_OVERUSE

IF Treatment is required to reduce muscle overuse *
ANDIFNOT The therapist wants to review measures to reduce muscle OVERUSE *
THEN ADL within fatigue and pain tolerance is advised until recouperation *

IF The therapist must determine whether the cause is DISUSE, OVERUSE or both *
ANDIF DISUSE is the cause *
ORIF A combination of DISUSE and OVERUSE is the cause *
THEN Treatment is required to increase strength and endurance, with care to avoid exacerbating the overuse or precipitating overuse in the disused muscles *

IF Treatment is required to increase strength and endurance, with care to avoid exacerbating the overuse or precipitating overuse in the disused muscles *
THEN Treatment may include a strengthening or a conditioning program *

IF Treatment may include a strengthening or a conditioning program *
ANDIF The therapist wants to review programs based on research *
THEN Consult articles cited for complete details *
ANDTHENRUN PROGRAMS

IF Treatment may include a strengthening or a conditioning program *
ANDIFNOT The therapist wants to review programs based on research *
ANDIF The therapist wants to review salient considerations for designing conditioning and strengthening programs *
THEN Conditioning and strengthening program design will be enhanced with reference to information gleaned from the literature *
ANDTHENRUN CONDITIONING_AND_STRENGTHENING

IF Treatment may include a strengthening or a conditioning program *
ANDIFNOT The therapist wants to review programs based on research *
ANDIFNOT The therapist wants to review salient considerations for designing conditioning and strengthening programs *
THEN Care must be taken to prevent development of overuse in atrophic muscles and to prevent exacerbation in those exhibiting overuse *

IF The therapist must determine the causes of weakness *
ANDIF The weakness is due to a deficit of endurance *
THEN Treatment may include a modified conditioning program *

IF Treatment may include a modified conditioning program *
ANDIF The therapist wants to review conditioning protocols *
THEN Select an appropriate protocol and consult articles cited for more details *
ANDTHENRUN PROGRAMS

IF Treatment may include a modified conditioning program *
ANDIFNOT The therapist wants to review conditioning protocols *
ANDIF The therapist wants to review salient considerations for designing conditioning and strengthening programs *
THEN Reference information gleaned from the literature can minimize the risk to benefit ratio of an exercise program *
ANDTHENRUN CONDITIONING_AND_STRENGTHENING

IF Treatment may include a modified conditioning program *
ANDIFNOT The therapist wants to review conditioning protocols *
ANDIFNOT The therapist wants to review salient considerations for designing conditioning and strengthening programs *
THEN Conditioning programs must be designed to avoid exacerbating/precipitating symptoms *

IF The therapist must determine the causes of weakness *
ANDIF The patient is recouperating from muscle OVERUSE *
THEN Treatment is required to increase strength and endurance *

IF Treatment is required to increase strength and endurance *
ANDIF The therapist wants to review programs based on research *
THEN Summaries of protocols from research follow; consult articles for more information *
ANDTHENRUN PROGRAMS

IF Treatment is required to increase strength and endurance *
ANDIFNOT The therapist wants to review programs based on research *
ANDIFNOT The therapist wants to review salient considerations for designing conditioning and strengthening programs *
THEN Rehabilitation for those recuperating from muscle overuse must be gradual *

IF Treatment is required to increase strength and endurance *
ANDIFNOT The therapist wants to review programs based on research *
ANDIF The therapist wants to review salient considerations for designing conditioning and strengthening programs *
THEN These points will assist the therapist in designing an exercise program for the patient recouperating from muscle overuse *
ANDTHENRUN CONDITIONING_AND_STRENGTHENING

IF The therapist must determine the causes of weakness *
ANDIFNOT The weakness is due to a deficit of strength *
ANDIFNOT The weakness is due to a deficit of endurance *
ANDIFNOT The patient is recouperating from muscle OVERUSE *
THEN The three main reasons for weakness are recent recouperation from muscle overuse, a deficit of strength or a deficit of endurance *

IF The therapist must determine whether the cause is DISUSE, OVERUSE or both *
ANDIFNOT Treatment is required to reduce muscle overuse *
ANDIFNOT DISUSE is the cause *
ANDIFNOT A combination of DISUSE and OVERUSE is the cause *
THEN Overuse, disuse, or a combination of the two are the main reasons for a deficit in strength in the PPS(ES) *

IF There are many methods to decrease muscle overuse *
ORIF ADL within fatigue and pain tolerance is advised until recouperation *
ORIF Consult articles cited for complete details *
ORIF Conditioning and strengthening program design will be enhanced with reference to information gleaned from the literature *
ORIF Care must be taken to prevent development of overuse in atrophic muscles and to prevent exacerbation in those exhibiting overuse *
ORIF Overuse, disuse, or a combination of the two are the main reasons for a deficit in strength in the PPS(ES) *
ORIF Select an appropriate protocol and consult articles cited for more details *
ORIF Reference information gleaned from the literature can minimize the risk to benefit ratio of an exercise program *
ORIF Conditioning programs must be designed to avoid exacerbating/precipitating symptoms *
ORIF Summaries of protocols from research follow; consult articles for more information *
ORIF These points will assist the therapist in designing an exercise program for the patient recouperating from muscle overuse *
ORIF Rehabilitation for those recuperating from muscle overuse must be gradual *
ORIF The three main reasons for weakness are recent recouperation from muscle overuse, a deficit of strength or a deficit of endurance *
THEN Advice has been give to restore strength or endurance *

DONE

Figure A.3-5: Pain Module

.(LOADING PAIN RULES)

\ PAIN RULES

MORERULES

IF The therapist must alleviate and minimize/eliminate the causes of pain *
ANDIF The therapist wants to focus on minimizing/eliminating PAIN *
THEN The therapist must identify the cause of PAIN *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has headaches upon arising *
ANDIF The patient may be experiencing hypoventilation or apnea during sleep *
THEN Referral to a sleep lab is warranted *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has nighttime limb cramping *
ANDIF The cramping is due to sleeping posture enduced decreased circulation or radiculopathy *
THEN Sleeping posture must be improved *

IF Sleeping posture must be improved *
ANDIF The therapist wants to review methods to improve sleeping posture *
THEN Physiotherapy intervention can improve sleep by improving sleeping posture *
ANDTHENRUN SLEEPING_POSTURE

IF Sleeping posture must be improved *
ANDIFNOT The therapist wants to review methods to improve sleeping posture *
THEN Adequate sleeping posture is essential for adequate sleep *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has nighttime limb cramping *
ANDIF The cramping is due to COLD_INTOLERANCE *
THEN Treatment is required to decrease cold exposure *

IF Treatment is required to decrease cold exposure *
ANDIF The therapist wants to review methods to decrease cold exposure *
THEN Intervention can improve sleep by reducing pain *
ANDTHENRUN COLD_EXPOSURE

IF Treatment is required to decrease cold exposure *
ANDIFNOT The therapist wants to review methods to decrease cold exposure *
THEN Lifestyle modification can reduce the effect of increased sensitivy to cold *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has burning pain deep in the muscle and bone or hyperaesthesia or a crawling sensation *
ANDIF The burning PAIN is due to chronic muscle OVERUSE *
THEN Minimizing muscle OVERUSE may minimize myalgic pain *

IF Minimizing muscle OVERUSE may minimize myalgic pain *
ANDIF The therapist wants to review measures to reduce muscle OVERUSE *
THEN There are many methods to decrease muscle overuse *
ANDTHENRUN MUSCLE_OVERUSE

IF Minimizing muscle OVERUSE may minimize myalgic pain *
ANDIFNOT The therapist wants to review measures to reduce muscle OVERUSE *
THEN ADL within fatigue and pain tolerance is advised until recouperation *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has burning pain deep in the muscle and bone or hyperaesthesia or a crawling sensation *
ANDIF The patient is sleeping poorly *
THEN Adequate sleep can facilitate pain reduction *

IF Adequate sleep can facilitate pain reduction *
ANDIF The therapist wants to review methods to promote adequate sleep *
THEN Physiotherapy intervention may improve the quality and quantity of sleep *
ANDTHENRUN SLEEP

IF Adequate sleep can facilitate pain reduction *
ANDIFNOT The therapist wants to review methods to promote adequate sleep *
THEN Adequate sleep can reduce fatigue and pain, and facilitate muscle repair *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has localized joint pain *
ANDIF The patient has poor body mechanics in posture or movement *
THEN Treatment is required to improve biomechanics *

IF Treatment is required to improve biomechanics *
ANDIF The therapist wants to review methods to improve biomechanics *
THEN Intervention can enhance function and quality of life *
ANDTHENRUN BIOMECHANICS

IF Treatment is required to improve biomechanics *
ANDIFNOT The therapist wants to review methods to improve biomechanics *
THEN Improving biomechanics has the potential of decreasing localized joint and muscle pain, and may reduce muscle overuse *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has localized joint pain *
ANDIF The patient has a failing surgical joint fusion or lax ligaments *
THEN Treatment may include orthotics *
ANDTHENRUN ORTHOTICS

IF The therapist must identify the cause of PAIN *
ANDIF The patient has localized joint pain *
ANDIF The patient has contractures or deformities *
THEN Treatment is required to improve ROM *
ANDTHENRUN ROM

IF The therapist must identify the cause of PAIN *
ANDIF The patient has localized muscle pain *
ANDIF The patient is experiencing inadequate rest *
THEN Adequate rest is essential to prevent pain secondary to muscle OVERUSE *

IF Adequate rest is essential to prevent pain secondary to muscle OVERUSE *
ANDIF The therapist wants to review methods to promote adequate rest *
THEN The therapist can assist the patient in determining and achieving adequate levels of rest *
ANDTHENRUN REST

IF Adequate rest is essential to prevent pain secondary to muscle OVERUSE *
ANDIFNOT The therapist wants to review methods to promote adequate rest *
THEN Adequate daytime rest can delay the time of evening repose, increase productivity & enhance overall quality of life *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has localized muscle pain *
ANDIF The pain is located in a transplanted muscle or is due to muscle OVERUSE *
THEN Muscle OVERUSE reduction is necessary to minimize tissue damage and subsequent pain *

IF Muscle OVERUSE reduction is necessary to minimize tissue damage and subsequent pain *
ANDIF The therapist would like to review measures to reduce muscle OVERUSE *
THEN There are many ways to decrease muscle overuse *
ANDTHENRUN MUSCLE_OVERUSE

IF Muscle OVERUSE reduction is necessary to minimize tissue damage and subsequent pain *
ANDIFNOT The therapist would like to review measures to reduce muscle OVERUSE *
THEN ADL within fatigue & pain tolerance is advised until recouperation *

IF The therapist must alleviate and minimize/eliminate the causes of pain *
ANDIF The patient is experiencing pain not reduced sufficiently with physiotherapy intervention *
THEN Referral to a psychologist/psychiatrist is warranted *

IF The therapist must alleviate and minimize/eliminate the causes of pain *
ANDIF The therapist wants to focus on alleviating somatic pain *
THEN Therapy may include heat, gentle mobilisations, relaxation techniques, massage, modalities (eg.TNS) or ice (care re: cold intolerance) *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has headaches upon arising *
ANDIFNOT The patient may be experiencing hypoventilation or apnea during sleep *
THEN Referral to a physiatrist may be warranted *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has nighttime limb cramping *
ANDIFNOT The cramping is due to sleeping posture enduced decreased circulation or radiculopathy *
ANDIFNOT The cramping is due to COLD_INTOLERANCE *
THEN Referral to a physiatrist is warranted for a serum calcium evaluation or other tests *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has burning pain deep in the muscle and bone or hyperaesthesia or a crawling sensation *
ANDIFNOT The burning PAIN is due to chronic muscle OVERUSE *
ANDIFNOT The patient is sleeping poorly *
THEN Myalgic/neurogenic pain can be aggravated by muscle OVERUSE, inadequate sleep or daytime rest *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has localized joint pain *
ANDIFNOT The patient has poor body mechanics in posture or movement *
ANDIFNOT The patient has a failing surgical joint fusion or lax ligaments *
ANDIFNOT The patient has contractures or deformities *
THEN Poor biomechanics, a failing surgical joint fusion, & contractures are common late effects of polio *

IF The therapist must identify the cause of PAIN *
ANDIF The patient has localized muscle pain *
ANDIFNOT The patient is experiencing inadequate rest *
ANDIFNOT The pain is located in a transplanted muscle or is due to muscle OVERUSE *
THEN Muscle OVERUSE and inadequate rest are the two main reasons for activity sensitive localized muscle pain *

IF The therapist must identify the cause of PAIN *
ANDIFNOT The patient has headaches upon arising *
ANDIFNOT The patient has nighttime limb cramping *
ANDIFNOT The patient has burning pain deep in the muscle and bone or hyperaesthesia or a crawling sensation *
ANDIFNOT The patient has localized joint pain *
ANDIFNOT The patient has localized muscle pain *
THEN Headaches, nighttime limb cramping, deep burning pain, and pain localized to muscles or joints are common in PPS *

IF The therapist must alleviate and minimize/eliminate the causes of pain *
ANDIFNOT The therapist wants to focus on minimizing/eliminating PAIN *
ANDIFNOT The therapist wants to focus on alleviating somatic pain *
ANDIFNOT The patient is experiencing pain not reduced sufficiently with physiotherapy intervention *
THEN The PPS(ES) can assist the therapist in planning strategies to alleviate and/or to minimize/eliminate the causes of pain *

IF Referral to a sleep lab is warranted *
ORIF Referral to a physiatrist may be warranted *
ORIF Physiotherapy intervention can improve sleep by improving sleeping posture *
ORIF Adequate sleeping posture is essential for adequate sleep *
ORIF Intervention can improve sleep by reducing pain *
ORIF Lifestyle modification can reduce the effect of increased sensitivy to cold *
ORIF Referral to a physiatrist is warranted for a serum calcium evaluation or other tests *
ORIF There are many methods to decrease muscle overuse *
ORIF ADL within fatigue and pain tolerance is advised until recouperation *
ORIF Physiotherapy intervention may improve the quality and quantity of sleep *
ORIF Adequate sleep can reduce fatigue and pain, and facilitate muscle repair *
ORIF Myalgic/neurogenic pain can be aggravated by muscle OVERUSE, inadequate sleep or daytime rest *
ORIF Intervention can enhance function and quality of life *
ORIF Improving biomechanics has the potential of decreasing localized joint and muscle pain, and may reduce muscle overuse *
ORIF Treatment may include orthotics *
ORIF Treatment is required to improve ROM *
ORIF Poor biomechanics, a failing surgical joint fusion, & contractures are common late effects of polio *
ORIF The therapist can assist the patient in determining and achieving adequate levels of rest *
ORIF Adequate daytime rest can delay the time of evening repose, increase productivity & enhance overall quality of life *
ORIF There are many ways to decrease muscle overuse *
ORIF ADL within fatigue & pain tolerance is advised until recouperation *
ORIF Muscle OVERUSE and inadequate rest are the two main reasons for activity sensitive localized muscle pain *
ORIF Headaches, nighttime limb cramping, deep burning pain, and pain localized to muscles or joints are common in PPS *
ORIF Therapy may include heat, gentle mobilisations, relaxation techniques, massage, modalities (eg.TNS) or ice (care re: cold intolerance) *
ORIF Referral to a psychologist/psychiatrist is warranted *
ORIF The PPS(ES) can assist the therapist in planning strategies to alleviate and/or to minimize/eliminate the causes of pain *
THEN Advice has been given about minimizing or alleviating pain *

DONE

Figure A.3-6: Education Module

\ EDUCATION RULES
.(LOADING EDUCATION RULES)

MORERULES

IF The therapist can facilitate the patient's independence in condition management by empowering him with knowledge *
ORIF Referral to a psychologist may be warranted and treatment must include education *
ANDIF The therapist wants to review relevant components of patient education *
THEN Symptom related queries may be answered by referring to relevant sections of the PPS(ES) *
ANDTHENRUN EDUCATION

IF The therapist can facilitate the patient's independence in condition management by empowering him with knowledge *
ORIF Referral to a psychologist may be warranted and treatment must include education *
ANDIFNOT The therapist wants to review relevant components of patient education *
THEN Patient compliance may be improved with adequate education *

IF Symptom related queries may be answered by referring to relevant sections of the PPS(ES) *
ORIF Patient compliance may be improved with adequate education *
THEN Patient education information has been provided *

DONE

Appendix A.4 Example Interaction With The First Iteration Prototype

Figure A.4-1: Welcome Screen

```
                    PPS(ES)

      PHYSIOTHERAPY TREATMENT PLANNING
      ( Knowledge-Based Expert System )

                      FOR

         POST-POLIOMYELITIS SEQUELAE

         Developed by:  Myrna Donald


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                    . . . . PRESS ANY KEY TO CONTINUE
```

Figure A.4-2: Introduction Screen

```
                          PPS(ES) INTRODUCTION

 An expert system is a form of artificial intelligence. It does not
 'understand' the data nor the logic of which it is composed, nor the
 solutions it produces in response to human input.  Simplistically, it
 may be regarded as a computerized manual.

 The theory or facts and the heuristics utilized by an expert system are
 gleaned from experts or literature in a particular field of knowledge by
 a knowledge engineer.

 Expert systems are particularly beneficial in situations where an expert
 may be difficult or costly to access or a large amount of literature
 exists.  As well, they can provide an alternative to strictly didactic or
 project-directed learning formats.

 The PPS(ES) incorporates clinical experience of therapists who have worked
 with this patient population and pertinent medical research from the
 literature between 1982 and 1993.  It is not a cookbook.  Rather, it is
 a guide book designed to assist novice therapists in clinical decision
 making.  In this respect, it may be considered as a resourceful team
 member.

                                . . . . PRESS ANY KEY TO CONTINUE
```

Figure A.4-3: PPS Exclusion/Inclusion Screen

```
Is this statement true? ( y=yes, n=no, q=quit, t=trace)
                        ( d=details )

The patient has a confirmed history of polio (determined by medical records
 or EMG data)
y
  YES


Is this statement true? ( y=yes, n=no, q=quit, t=trace)
                        ( d=details )

The patient satisfies PPS_DIAGNOSTIC_CRITERIA
y
  YES


I deduce

The PPS(ES) may be beneficial in the physiotherapy intervention for this
patient
```

Figure A.4-4: Education Rule Module Screen

```
                            Type PLAN to begin
ok
plan

Is this statement true? ( y=yes, n=no, q=quit, t=trace)
                        ( d=details )

The patient's knowledge of PPS must be augmented with education
y
  YES


I deduce

The therapist can facilitate the patient's independence in condition
management by empowering him with knowledge

LOADING EDUCATION RULES

Is this statement true? ( y=yes, n=no, q=quit, t=trace)
                        ( d=details )

The therapist wants to review relevant components of patient education
```

Figure A.4-5: Recommendation and Advice Screen

```
 Poliomyelitis is an enterovirus with three immunologically distinct
 strains.  Infection may occur via the respiratory or alimentary systems.
 The majority of infected individuals do not experience any noticeable
 symptoms.  The remainder experience fever, aching and GI symptoms for an
 average period of five days.  Only one percent will develop spinal, bulbar,
 or bulbospinal symptoms.  Motor neurons in  the lateral anterior horn of
 the spinal tract may be killed or damaged, resulting in asymmetrical and
 scattered paresis or paralysis of lower>upper extremities and a loss of
 cutaneous and tendon reflexes.  Involvement of cranial nerves or of the
 medulla may result in respiratory or degluttinatory impairments.  A very
 small percentage may experience polio encephalitis.  Maximal recovery
 following the more severe affliction with polio may take a few months to
 two years.

 The neuromuscular system responds to the insult of polio by recovered and
 unaffected anterior horn cells reinnervating some but not all orphaned
 muscle fibers.  Consequently, the number of muscle fibers per motor neuron
 increases beyond the usual number, fewer muscle cells are innervated and
 some cross-innervation occurs.  Muscle fiber splitting and hypertrophy are
 other means taken to increase surviving motor unit strength.
 Transformation from Type II to Type I muscle fiber type transpires when
 functional demand exceeds system work capacity.

                                 . . . . PRESS ANY KEY TO CONTINUE
```

Appendix A.5 Evaluation Instruments

There were two three instruments used to collect feedback about the first prototype: a prototype evaluation form and a mini-system user interface test.

The prototype evaluation form was used to collect user characteristics data and feedback on the PPS(ES). Most of the prototype evaluation questions (Figure A.5-1) were open ended and covered topics related to aesthetics, content, operation and general observations. Additionally, respondents were encouraged to include recommendations on issues not specifically referred to on the questionnaire.

The section on content asked questions about the knowledge base, including robustness, granularity, explanations, transparency of the reasoning, and accuracy of the recommendations. Operation covered user friendliness, instruction by the author, and feature adequacy issues. In Aesthetics, respondents were queried about their preference in text colour and with respect to the format for rule expression. Attitudes regarding acceptance and utility of knowledge-based system applications in the domain were gathered in the General section.

System utility and friendliness in the lab setting was measured with a 'mini-test' (Figure A.5-2) to determine whether or not students were able to access all of the features (e.g. explanatory segments, 'detail' terms) and the information necessary to manage a post-polio case. Indirectly, this test may determine variances in student comprehension and interpretation of the system responses, however this was not intentional in question design and selection.

The first question referenced the module on PPS diagnostic criteria and the determination of whether or not the system was appropriate for use with the patient described. The second and third questions referenced the module on weakness. The fourth, ninth and tenth questions referenced the extensive segment on assessment and management goals. The fifth question referenced the module on pain. The sixth question referenced the weakness module and ascertained whether or not users could and would access the explanatory architectural/operational function. Question seven tapped the education module. Question eight referenced the pain module and the 'details' operational feature.

Figure A.5-1: Prototype Evaluation Form

User Data:

1. Experience

    a. What year are you in the physiotherapy program?

    b. How many years of experience have you had as a licensed therapist?

2. How much experience have you had treating patients with Post-Polio Syndrome? (Please indicate by specifying the appropriate number of patients you have treated.)

3. Mow much experience have you had treating patients with neurological disorders?
(Please indicate by specifying the appropriate number of patients you have treated.)

4. How comfortable are you using a computer?

5. Do you have experience with the following types of 'software':

    a. Applications (e.g. word processors, games, spreadsheets)

    b. Programming (e.g. Pascal, FORTRAN, Basic)

    c. Other (e.g. Data Entry)

6. Do you have experience with the following types of 'hardware':

a. IBM Compatible

b. Macintosh

c. Atari

d. Other

PPS(ES) Evaluation:

Content:

1. Do you feel that PPS(ES) is sufficiently comprehensive in disabilities and impairments inclusion?

   What recommendations would you make to improve comprehensiveness?

   Please provide any examples of other symptoms which you feel should be included and of symptoms which you feel should not be included.

2. Do you feel that wording of the statements was too complex or to simple? If so, please provide examples.

3. Do you feel that the details available for examination (i.e. the words in upper case letters were inadequately explained or that the explanations were more elaborate then necessary for your understanding level of PPS(ES)?

4. Do you feel that the options for subject review (e.g. The therapist wants to review components of the patient education, The therapist wants to review methods to improve biomechanics, The therapist wants to review treatment protocols programs) were too detailed or should be more detailed? Please provide examples.

5. Do you feel that treatment planning was logically presented, that is did you understand why one statement led to another, once the final conclusion was reached? If not, please refer to all sequences which you feel the logic is not clear.

6. How does the PPS(ES) compare to any advice of information you have been given by a supervisor on the subject of PPS? On any subject?

7. Do you concur with the advice given by the PPS(ES)? If not, please list all instances of discord and explain the reasons for disagreement.

Operation:

1. Did you find the PPS(ES) easy to use? If not please explain the reasons for difficulty and provide suggestions for improvements (e.g. the need for a list of options or a menu).

2. Was the instruction for the use during the first session adequate? If not, what would you include to improve the instructions?

3. Do you feel that it is necessary to have the option to select more information about a subject (e.g. cold tolerance prevention, considerations for strengthening and conditioning programs), or would you prefer having these run when the applicable treatment plan conclusion has been reached?

4. The original design of the PPS(ES) allowed the therapist to continue planning for different complaints for the same patient, without having to answer the questions concerning PPS diagnostic criteria, again. Do you feel that this option would improve the PPS(ES) operation? (N.B. The bug in this system is in the process of being fixed.)

5. Please make any other recommendations which you feel would assist in improving the PPS(ES) operation.

Aesthetics:

1. Do you like both the yellow and the white text?

2. Would you prefer a question to an assertion format? (For example:

   "The patient has a history of polio (confirmed by EMG or medical history)"

   Or

"Does the patient have a history of polio (confirmed by EMG or medical history)"

General:

1. Do you feel that expert systems can be useful in the field of physiotherapy? If so, how? If not, why?

2. Would you like some of the material covered in the courses offered by the School of Physiotherapy to be presented in an expert system, rather than learned through assigned projects or from straight didactics lecture?

Please use the back of these sheets, as necessary to make further comments:
As well, please list ways in which the instructor can improve the explanation of the system and instruction for its use, or any other relevant points.

Thank you for your assistance and cooperation!

Figure A.5-2: Mini-System User Interface Test

MINI-SYSTEM USER INTERFACE TEST

Please answer the following questions, using the PPS(ES).

1. Mr. Beau Jangles is a forty-five year old astronaut. As a child, he recalls having a flu-like illness which lasted a month. He has come to physiotherapy for assessment, because he is suffering from weakness and fatigue. What does the PPS(ES) recommend?

2. Mr. Smoketumuch is a fifty-five year old interior decorator who recently had EMG confirmation of previous polio infection. He recalls being hospitalized for several months as a child and being in an iron lung during part of that time. His adult years have been moderately active. Last year, however, he was forced to decrease his activity levels following a femur fracture he suffered while skiing. Since then, he's noticed a decrease in endurance level. He has come for advice on how to increase his endurance level without developing PPS. What does the PPS(ES) advise?

3. Mrs. Zeitgeist is a forty-seven year old pet groomer. Her old medical chart indicates that she had polio at the age of twenty, but fully recouperated from quadriplegia within eight months. Last March, her husband left her and her oldest child was killed in a car crash. She overate to cope with her grief, and within a few months had gained over twenty percent of her original body-weight. She states that began a rigorous exercise program to lose weight, in June. By August, she began to experience severe and marked decrease of energy by noon, and burning pain in her left leg. What does the PPS(ES) advise?

4. What does the PPS(ES) advise as a means to address patient management independence? (HINT: there are two components.)

5. What does the PPS(ES) state about surgical treatment for lax ligaments, which are causing joint pain?

6. What kind of exercise program does the research protocol of Fillyaw et al. support?

7. What is the name of the Canadian physician who has published articles stating that muscles afflicted with PPS can be differentiated from non-symptomatic muscles? (HINT: Patients may find this knowledge interesting, especially if they are considering an exercise program.)

8. List some information provided by the PPS(ES) about cold intolerance.

9. Why is Cybex testing of strength preferable to manual muscle testing in determining true strength values in polio survivors?

10. Why might quinine be prescribed for a PPS patient? What is a side-effect of this drug which may make it contra-indicated for this population? What other medications should the therapist ask about during assessment?

Appendix A.6 A Summary of Real Cases Used To Evaluate System Performance

Table A.6-1: Presenting Complaints of Cases from Halifax

Patient	Complaint
One	decreased ambulation tolerance
Two	decreased strength lower extremities bilaterally
Three	weakness left leg, pain right leg, generalized fatigue

Table A.6-2: Presenting Complaints of Cases from Toronto

Patient	Complaint
One	fatigue, back and neck pain, leg cramps
Two	frequent tripping, back and neck pain, difficulty with transfers, right hip and knee pain, anxiety concerning exercise and PPS
Three	poor posture, inadequate knowledge of exercise appropriate for PPS, decreased stability and strength of left ankle, fatigue, difficulty with transfers
Four	fibromylagia, lower extremity weakness, inadequate knowledge of exercise appropriate for PPS, fatigue

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Appendix A.8 Questionnaire

Questionnaire

Thank-you for completing the following survey concerning attitudes about and familiarity with computers. Please return the completed survey to:

Myrna Donald
c/o The Graduate Students' Association, 221 University Centre, The University of Manitoba, Winnipeg, Manitoba R3T 2N4.

EXPERIENCE

Professional/Academic:

I. Licensed Physiotherapist

1. Number of years since graduation __________ diploma/degree
2. Area of specialty (please circle all that apply)
   - Cardiorespiratory
   - Neurology
   - Musculoskeletal/Orthopaedics
   - Paediatrics
   - Geriatrics
   - Other (please specify) ______________________________
3. Employment Setting (please circle all that apply)
   - Private Practice- Acute /Rehab/ Mixed
   - Hospital Based- Acute /Rehab/ Mixed
   - Academic
   - Other (e.g. mixed, consulting, industry)

II. Student

Current Academic Level: (please circle)

Undergraduate

Master's

PhD

III. Other (please specify) ______________________________

Computer:

Please rate your level of proficiency using the following computer related hardware and software, by circling a number from zero (connoting no familiarity) to 5 (connoting proficiency).

Operating systems?

	Not At All		Some Familiarity		Proficient	
DOS	0	1	2	3	4	5
System 7 (Mac)	0	1	2	3	4	5
OS/2	0	1	2	3	4	5
UNIX	0	1	2	3	4	5
Other (please specify) ____________	0	1	2	3	4	5

Platforms?

	Not At All		Some Familiarity		Proficient	
PC	0	1	2	3	4	5
Mainframe	0	1	2	3	4	5
Workstation	0	1	2	3	4	5
Other (please specify) ____________	0	1	2	3	4	5

Communications/Information

	Not At All		Some Familiarity		Proficient	
Internet (e.g. WWW, Netscape, AirMosaic)	0	1	2	3	4	5
Email (e.g. Pine, elm)	0	1	2	3	4	5
CD ROM (e.g. Medline)	0	1	2	3	4	5
Mail Lists	0	1	2	3	4	5
Newsgroups	0	1	2	3	4	5
Other (please specify) ______________________	0	1	2	3	4	5

Applications?

	Not At All		Some Familiarity		Proficient	
Games (e.g. Doom, Magic, Solitaire)	0	1	2	3	4	5
Word Processing (e.g. WordPerfect, MS Word, MS Works)	0	1	2	3	4	5
Spreadsheets (e.g. Excel, Lotus)	0	1	2	3	4	5
Billing /Accounting (e.g. Quicken)	0	1	2	3	4	5
Citation Package (e.g. Procite)	0	1	2	3	4	5
Statistical (e.g. SAS, Statview)	0	1	2	3	4	5

Programming languages?

	Not At All		Some Familiarity		Proficient	
Pascal	0	1	2	3	4	5
FORTRAN	0	1	2	3	4	5
Basic	0	1	2	3	4	5
C/ C+/C++	0	1	2	3	4	5
Forth	0	1	2	3	4	5
dBase	0	1	2	3	4	5
Other	0	1	2	3	4	5

(please specify) ______________________________

Decision Support Systems?
(please describe):

ATTITUDES

Please use the bottom of the sheet if you require more room or want to make additional comments.

How comfortable do you feel using a computer? (please circle)

Not at all		Somewhat		Very Comfortable	
0	1	2	3	4	5

How do you feel about the use of clinical decision making aids (i.e. tools that facilitate decision making) e.g. nomograms (height to total lung capacity, skin fold site measurements as a means of approximating total body fat), formulae (220-age=maximum heart rate), etc.?

How do you feel about the use of computer clinical decision making aids?

What concerns do you have, if any regarding the use of computer clinical decision making aids?

What barriers, if any do you foresee to the implementation of computer decision support systems into the practice of physiotherapy?

What benefits do you perceive from implementation of computer decision support systems in the practice of physiotherapy?

What types of 'functionality' would be absolutely essential for inclusion with a computer clinical decision making aid, if you were to use it? (e.g. Ability to connect with Medline.)

Appendix B Second and Proposed Third Iteration Prototype Materials

Appendix B.1 Description of Team One Prototype (Sonia Narang and Murray Sneesby)

Table B.1-1: Description of Team One Prototype

Screen Title	**Contents**	**Menus***	**Buttons**
Title Screen	Title and Developers	none	Continue→ Main Menu Screen
PPS Treatment System (Main Menu)	Patient Information **B**→ Screen History of Present Illness **B**→ Screen Past Medical History **B**→ Screen Physical Examination **B**→ Screen Evaluate **B**→ Screen Exit **B**	<u>System</u> • PPS Tx System (Main Menu) Screen • Evaluate • Restart • Exit <u>Patient Information</u> • Personal Info. • Occupational • Recreational • Polio History (PMx Screen) • HPI • Physical Exam. • Meds/Tests	see **Contents**

Screen Title	Contents	Menus*	Buttons
Personal Information (Main Menu Screen as 'Patient Information' + Patient Information PD Menu) Category=PI (main)	Name **TB** Medical Number **TB** Weight **TB** Birth Date **TB** Smoking **TB** Dependents **CB** Marital Status **RB** Weight Scale **RB** Weight Status **RB** Weight Change **RB** General Information **TB**	System Patient Information	OK→Main Menu Screen
Recreation Category=PI (associated)	Activity **RB** Frequency **TB** Duration **TB** Change in Activity **RB** Reason for Change **TB**	System Patient Information	OK→ Personal Information Screen
Occupation Information Category=PI (associated)	Name **TB** Number of Breaks **TB** Average Length of **TB** Weekly Work Hours **TB** Change in Work Result **RB** Change in Work Onset **RB**	System Patient Information	OK→ Personal Information Screen
Polio History (PMHx) (Main Menu Screen + Patient Information Menu) Category=PH (main)	Age at Onset **TB** Length of Illness **TB** Time to Peak Recovery **TB** Type **RB**	System PMHx • Symptom • HPI • Personal Information	OK→Main Menu Screen
PMHx Symptoms Screen (PMHx Menu as 'Symptom') Category=PH (associated)	Symptom Name **TB** Surgery Required **T/F** Surgery Information **TB** Percent Recovery **TB** Lasting Effects **TB** General Information **TB** Aids During Illness **TB** Aids During Recovery **TB** Type of Aid **RB** Type **RB**	System Patient Information	OK→ Polio History Screen

Screen Title	Contents	Menus*	Buttons
Physical Examination (Main Menu Screen + Patient Information Menu) Category=PE (main)	Emotional **RB** Cognitive **RB** Adequate Rest **T/F** Adequate Sleep **T/F** Night Pain **T/F**	System Patient Information Physical Exam • Meds/Tests • Physical Exam	OK→Main Menu Screen
Meds/Tests Category=PE (associated)	Test Name **TB** Test Results **TB** List **TB** Currently taking **T/F**	System Patient Information Physical Exam	OK→Main Menu Screen Next Previous
History of Present Illness (HPI) Category=HPI (main)	Onset of PPS **TB** Years since residual **TB**	System Patient Information Symptoms • Pain • Fatigue • Weakness • Cold Intolerance • Headaches • HPI	OK→Main Menu Screen
Pain Category=HPI (associated)	Symptom Name **TB** Area **RB** Increased with Activity **T/F** Type **RB** Level **RB** Time **RB** PPS progression **RB** General Information **TB**	System Symptoms	OK→HPI Screen Next Previous
Fatigue Category=HPI (associated)	Symptom Name **TB** Type (location) **RB** Level (1-7) **RB** Type of Decline **RB** Degree of Decline **RB** Activity Type **RB** Duration of Activity **TB** Activity Information **TB**	System Symptoms	OK→HPI Screen Next Previous
Weakness Category=HPI (associated)	Symptom Name **TB** Area **RB** Level (1-7) **RB** Type of Decline **RB** Degree of Decline **RB**	System Symptoms	OK→HPI Screen Next Previous

Screen Title	Contents	Menus*	Buttons
Cold Intolerance Category=HPI (associated)	Symptom Name **TB** Area **RB** Level of Severity **RB** Type of Decline **RB** Adequate Clothing **T/F** Degree of Decline **RB**	System Symptoms	OK→HPI Screen Next Previous
Morning Headaches Category=HPI (associated)	Symptom Name **TB** Duration **TB** Severity **RB** Sleep Problems **CB** Type of Decline **RB** Degree of Decline **RB**	System Symptoms	OK→HPI Screen
Recommendations (Evaluate button on Main Menu Screen) Category= Rec. (main)	Treatment **TB**	System	MORE→ Main Menu Screen EXPLAIN** Restart→to Title Screen Exit→from system
Explanations Category= Rec. (associated) (Explain button on Recommendations Screen) Category= Rec. (associated)	Recommendations **TB** **T/F** Conditions Selected		OK→ Recommendations Screen MORE→ Main Menu Screen Restart→to Title Screen Exit→from system

* Menu Items and buttons connect to pages with same name, except as noted.

** Table of T/F selections for nine conditions (Muscle Overuse, Knowledge of PPS, (adequate) Breaks, Sleep Apnea, Daytime Rest (Improve), Decrease Recreation, Suggest Modalities, Entrenched Problem, Decrease Workload)

*** Category of displays: the main screen of each group is a button on the main menu screen (PPS Treatment System)

- Patient Info./Social History Screens (personal information, recreation, occupation)
- Past Medical History Screens (polio history, past medical history-symptoms)
- Physical Examination and Tests Screens (physical exam, meds/tests)
- HPI (HPI, pain, fatigue, weakness, cold intolerance, morning headaches)
- Advice (Recommendations, Explanations)

Appendix B.2 Description of Team Two Prototype (Jason Dueck and Basil Baluta)

Table B.2-1: Description of Team Two Prototype

Screen Title	Contents	Menus	Buttons
Main Menu	HPI **B** → Screen PMx **B**→ Screen SHx **B**→ Screen Test Results **B**→ Screen Exam Indications **B**→ Screen Go! **B** Show Recommendations **B**→ Screen	none	About→ title and developers screen Quit→exit Restart→ Main Menu screen
About	title and developers	none	Continue → Main Menu screen
Past Medical History (PMx)	Polio Symptoms **CB** Onset **CB** Onset Presentation **RB** Surgical 'Changes' **CB** Residual Effects **RB** Recovery Aid Condition **RB** Recovery Aids **RB** Polio Severity **RB**	none	Main Menu→Main Menu screen
Social History (SHx)	Occupational Energy Exertion Level **RB** Home Energy Exertion Level **RB** Occupational Stress **CB** Home/Recreation Physical Stress **CB**	none	Main Menu→Main Menu screen
Test Results	blank	none	Main Menu→Main Menu screen
Exam Indications	Fatigue Exam Indications **RB**	none	Main Menu→Main Menu

Screen Title	**Contents**	**Menus**	**Buttons**
History of Present Illness (HPI)	Symptom Nature **RB** Symptom (location) **CB** Symptom Duration **RB** Sleep Problem **RB**	none	Main Menu→Main Menu screen
Show Recommendations	Recommendations **TB**	none	Main Menu→Main Menu screen

Appendix B.3 Analysis of Team One Prototype

(Sonia Narang and Murray Sneesby)

1. Title Screen:
- OK
- no button to access on-line tutorial....(see point 2)
2. Instruction (operation, contents)and Introduction (i.e. PPS Differential Diagnosis screen) screens: no on-line tutorial, explanation nor instructions accessed by button or PD menu; could tie polio history responses to a) confirmation for system use (forward values), b) determining PPS development risk for the asymptomatic
3. Main Menu screen:
- All of the menu items (except Evaluate→Recommendations) in the Patient Information or System PD menus, (however the converse is not true, i.e. not all of the PI PD menu items appear on the MM screen).
- OK button label could be changed to reflect function (i.e. accept data and continue with consultation) e.g. Accept/To Main Menu (or applicable menu) to help make navigation easier
- re: PD menus, see navigation between screens (below)
4. Past Medical History (Polio History) Screen
- re: buttons, see navigation with buttons (below)
- re: PD menus, see navigation between screens (below)
- see comment number 2 (above)
5. Personal/Patient Information (Social History) Screen
- not exhaustive but definitely a good collection of items
- note: personal and patient information used interchangeably on screen titles, buttons and menus, which *may* lead to some confusion for end users
6. Recreation Screen
- need to add more text boxes for more activities but OK otherwise (OK button ties to Personal/Patient Information Screen, of which it is a logical extension)
7. Occupation Information
- OK button ties to Personal/Patient Information Screen, of which it is a logical extension
8. PMHx Screen
- on PMHx Menu as "Symptom" (*note potential user confusion with the menu titled "Symptoms" in the HPI screen)
- needs more symptom text boxes, otherwise OK
9. Physical Examination Screen
- items could be organized in way that better reflects history taking order, however items listed are good
- re: PD menus, see navigation between screens (below); however note: physical exam and Meds/Tests are lumped into the same PD menu (Physical Exam), which may be confusing, as both are listed independently under the Patient Information PD menu (perhaps this presents too many access options, as well as confusion secondary to different groupings of screens)

- Night pain d/t ?....
- need to suss out potential causes for weakness, fatigue, pain→ location, type, duration, etc. if intend to use for charting as well as for advice

10. Meds/Tests

- need more text boxes for more drugs (PPS and non-PPS specific)
- need a warning/notification/etc. re: certain drugs that is displayed in the Meds/Test box and with the recommendations; e.g. RB or CB that fires a rule to warn the PT re: assessment or treatment implications e.g pyridostigamine, fatigue and muscle relaxants, decreased respiratory rate and drugs (anesthesia) depressing respiratory function; also, perhaps a hit list of more significant medications either grouped according to function or named independently: e.g.

Drug effect/class	Drug name
analgesics	entrophen, naproxen, ibuprofen, acetaminophen
anti-inflammatory	
beta-blockers	
anti-convulsants	

OR e.g. analgesics (e.g. naprosyn, ...) T/F

11. History of Present Illness Screen

- not enough information on the screen, and end user must use PD menu to reach screens about specific symptoms; need more direction about accessing the symptom screens or the symptom information on the same screen or buttons to the symptoms to make access more intuitive e.g. Onset of symptoms **S**, years since **S**, fatigue **B**, weakness **B**, cold intolerance **B**, pain **B**, headache **B**.....; also, each symptom needs its own onset and duration text boxes for charting purposes
- could get symptom onset data from introductory screens (i.e. DDx which would gather data about the onset of the three main symptoms/complaints) and automatically fill in values
- need text box to describe progression of symptoms over time (for charting)
- could put buttons for specific PPS complaints to connect with charting areas, in addition to the extant PD menus
- **or** use this page strictly for advice/general information and have other screens for charting e.g. HPI

years since onset			
	PAIN	FATIGUE	WEAKNESS
	1.	1.	1.
	2.	2.	2.

and then in charting area, depending upon data entered will also get advice e.g. type→same as chart; if savvy user/just want advice without charting, can use the first screen and avoid charting screens (BUT, could result in conflict between selection of symptom (advice) vs. data entry of symptom (charting). Which would/should have precedence? Could have a warning message after which physiotherapist can override or make changes?)

- NB: values for certain conditions in the following symptom screens have not been linked for automatic setting wherever the condition appears, e.g. if decline is set to gradual vs. stepwise in one window, it isn't automatically set (and fixed) for the other screens in which it appears. Disadv.: conflicting data may result in inappropriate advice. Advant: unilateral setting or individualization for each symptom vs. overall trend for all symptoms (which could be placed on a general screen like HPI; type of decline can be global or specific value, i.e. general course of the sequelae/rehab or the course of a specific symptom (e.g. weakness); the two should but won't always coincide, as they could have different rates of change)

12. Pain Screen

- PPS progression should be in more general area e.g. HPI screen, however, progression of the symptom (i.e. pain) could be placed with this screen
- need to separate time and nature (frequency) of pain (two independent concepts) into two **RB**
- need either: 1) **RB**s for >1 symptom i.e. several pages of input for charting; or 2) area + type + activity level with PD menu or dialogue box; or 3) generic advice-main types of pain (burning, local, headache….) plus charting text boxes for abbreviated codes. e.g.

area	activity level	type	level
#1	yes, lots	burning	3/10
#2	yes, some	local joint	5/10
#3	no	tingling	1/10

Note: this highlights the sometimes contradictory demands of designing optimally for charting and advice.

13. Fatigue Screen

- need reference for local fatigue to strength and endurance
- am fatigue is related to sleep apnea/hypoventilation, so could have T/F button for presence/absence (or suspicion of S&S) and then recommendations associated
- for generalized "wall" fatigue, need to collect data about level, precipitating activity, duration, onset and time of day usually occurs (am, pm, aft, variable, etc.) with text box for more precise descriptions needed, mitigating factors, activity diary data…., maybe behavior over time….

14. Weakness Screen

- same need to **chart** for >1 muscle group/individual muscle for name, grad of strength, etc., but Adv.: having more abstract areas (e.g. u/e, back) can link to recommendations without having to enter all of the details

15. Cold Intolerance Screen

- perhaps does not require a separate screen, could be grouped with pain or placed with headache for space and # of link considerations, but re: navigation, individual screen for each symptom is appealing

16. Headaches Screen

- as with cold intolerance, could be placed with other symptoms to minimize space and linking, but separate page appealing in terms of grouping relevant material

17. Recommendations Screen (MORE)

- "surface" explanations i.e. reminder of T/F selections (but not other data upon which recommendations *might* be made)

- not linked directly to a particular recommendation, i.e. if >1 recommendation, cannot ascertain which value has triggered each piece of advice
- at least one T/F condition is not a display of direct entries made by the user; i.e. muscle overuse is concluded from other data entered (burning pain, pain with activity, inadequate sleep or rest); reasoning/K used to make this conclusion is not clear;
- however, very good synopsis of the **key** data
- could re-format as

condition	**T/F**	treatment plans

18. Navigation within a screen:

- scroll bars allow viewing of all areas even when screen size does not accommodate the entire screen of information
- no scroll bars for those whose window size will not accommodate the entire screen of information ????

19. Navigation between screens

- combination of buttons and PD menus
- Buttons:
    - Next and Previous in symptom screens refer to other symptom screens and the HPI screen; if not all information for a symptom fits on one screen, could also use these buttons to connect with next page or have a continued page for a given symptom;
    - consistent reference point for OK buttons is the main screen of a category or the main screen for the entire system e.g. OK links to the Polio History Screen from the PMHx symptom screen; OK links from the recreation screen and the occupational information screens to the personal/patient information screen (of which they are a logical extension)
- PD Menus
    - The Patient Information PD menu does not include **symptoms**. These can be reached only by first going to the HPI screen, which may not appeal to the savvy user
    - PMHx menu does not includes (HPI, personal information, symptom) but not the other patient information items, which *may* be confusing to the user
    - Symptom (PMHx) and Symptoms (HPI) **may** cause confusion or have an adverse effect on navigation

Could use.... menu items that lead to a more detailed PD menu or a fly-out menu: e.g.

HPI....	**Physical Exam....**
symptom	meds
personal information	physical exam
recreation	
occupation	
meds/tests	etc.

to keep items grouped according to the history category (reflected by the Main Menu screen buttons). And to decrease confusion due to moving in circles from Main Menu to HPI to particular symptom to HPI to ....

- Other navigation clues/cues:
    - using different colours for the RB and CB for different symptoms is a nice touch as it can make it easier to remember where you are if you've been interrupted or to emphasize that you have moved to another area
- Features/Functionality/Facilities:
    - Lacks Save to file, Print session, compare session values, etc.
    - Current Knowledge base lacks heuristics to progress patient (e.g. mock example: if patient's strength value improved 90% since admission, then increase resistance by 50%....), however this may not be necessary, as physiotherapist basic education includes protocols for strengthening and PPS patient is no different except as noted in the declarative segments....

Appendix B.4 Analysis of Team Two Prototype (Jason Dueck and Basil Baluta)

1. Title Screen: no title screen with developers' names, etc., however, have an About button that links to screen with this information.
   Adv.: frequent users aren't bothered with the redundant and nonessential
   Disadv: infrequent users won't necessarily look at the About info! And are thrown into the system without any introduction
2. Instruction and Introduction (i.e. PPS Differential Diagnosis screen)screens: no tutorial, explanation nor instructions accessed by button or PD menu
3. Main Menu Screen:

- all history sections + advice as buttons;
- Restart button → Main Menu screen;
- About button → title info;
- Quit - out of the system
- Go! Button is needed to solve glitch that interferes with recommendation access
  Adv.: everything you need that is related to this level of organization is on one screen
  Disadv: if you know where you want to go, you may have to reach your destination by traversing unwanted screens

4. Past Medical History Screen:

- # of errors in grouping concepts/items e.g.
  - onset → should be 'type' and exclude respiratory (covered by 'bulbar')
  - symptom severity→needs to be connected with area/specific symptom OR changed to overall severity OR could have both (see next point)
  - onset presentation→should be 'polio symptom severity' (paresis & paralysis reflect this measure), omit scoliosis (which is a residual effect, and not a measure of severity at onset of the acute illness)
  - residual effect of surgery needs to be assoicated with specific procdures/locations (because there can be more than one of each that is applicable)
  - recovery aids condition→needs to be associated with recovery aid

<u>Using Slots and Table Format</u>

<u>Recovery Aid</u>	<u>Condition</u>	
	<u>OK</u>	<u>Not OK</u>
<u>one</u>	x	
<u>two</u>		x
<u>three</u>	x	

<u>Or using T/F Buttons and Slots</u>

Recovery Aid	OK/Not OK	Comment and Name/Type
One	OK	New in 1994/ elbow crutches
Two	Not OK	Needs need arm piece/wheelchair

5. Social History screen:
- not enough information, e.g. nothing about weight, smoking, dependents, etc.
- could have graph to show change over time in energy or stress levels, etc. this could be associated with locations, perhaps

6. Test Results Screen:
- may/not be necessary, perhaps have as an optional screen mainly for charting (with text boxes for additional information) and *maybe* linked to rules e.g. EMG→enervation rate abnormal→ Recommendation: caution re: exercise

7. Exam Indications Screen:
- RB for fatigue values means either/or when in real world all could be occurring simultaneously
- different approach than T/F buttons approach taken by S&M
- both approaches essentially rely on the therapist to decide if the condition exists that then to select it from a list or to confirm or deny its presence (or confirm its absence or presence)

8. HPI Screen:
- RB makes symptom choice exclusivity that is not real world e.g. could (and probably do) have weakness and fatigue.
- symptom duration→ should be 'symptom behavior' for value choices listed and perhaps could change to CB or place activity related values in separate RB
- need to be able to link symptom with location and duration etc.
- need to be able to select more >1 symptom and associated cause at one time; in this system, >1 recommendation only via RB that are not directly related to the symptoms e.g. recovery aid condition

  Adv.: charting drives the recommendations

  Disadv: reasoning behind the recommendation is not transparent; opacity due to lack of link to symptom-transparency due to link with specific deficit; but, doesn't demonstrate how deficit and symptoms are related (is this necessary (?), or could the organization be based on this approach? Partial argument is that the connections are necessary to raise the system from the level of technician support to therapist support i.e. technician does as told and doesn't have to think about the underlying factors or reasoning vs. therapist who benefits from knowing the reasoning, as carryover to other situations and other combinations of conditions (i.e. factors or values)

9. Recommendations Screen:
- no option to see or review key selections
- the advice is very brief and no comments connect it with the selections made for the case

- no title is given to each recommendation to link with it with the general name of a symptom or the associated reasoning, either of which would help when >1 recommendation given

10. Navigation within a screen:

- no scroll bars for those whose window size will not accommodate the entire screen of information

11. Navigation between screens:

- is exclusively by buttons;
- there are no PD menus,
- the only button on each of the screens other than the Main Menu screen returns the user to the Main Menu screen

    Adv.: very difficult to become lost in the system; all 'system' operations are on the same and only one screen (i.e. restart, quit, about)

    Disadv. savvy users will want to go directly to screens of interest without having to return to the Main Menu screen between each screen of interest and there are no buttons or PD menus to accomplish this

Appendix B.5 Team Two Prototype Screen Examples

Figure B.5-1: Main Menu of Team Two Prototype

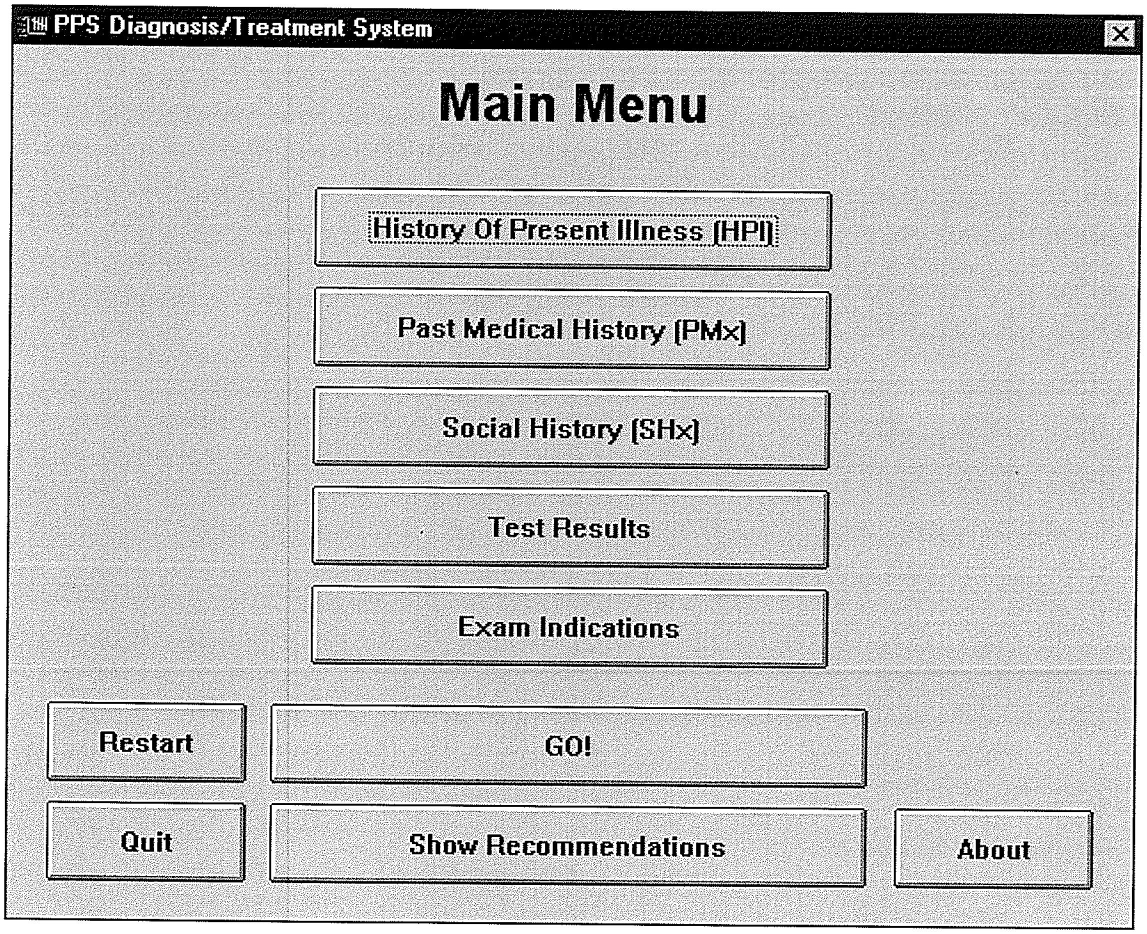


Figure B.5-2: History Screen of Team Two Prototype

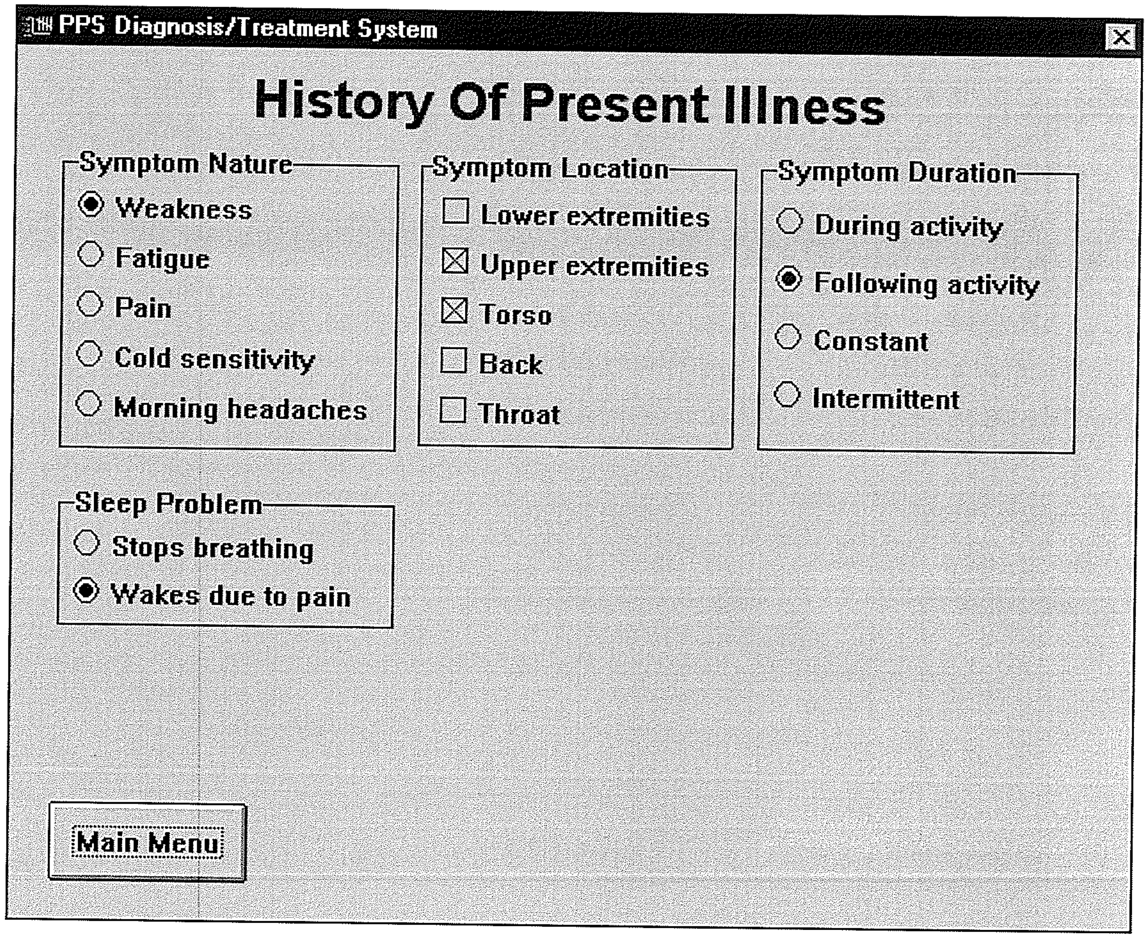
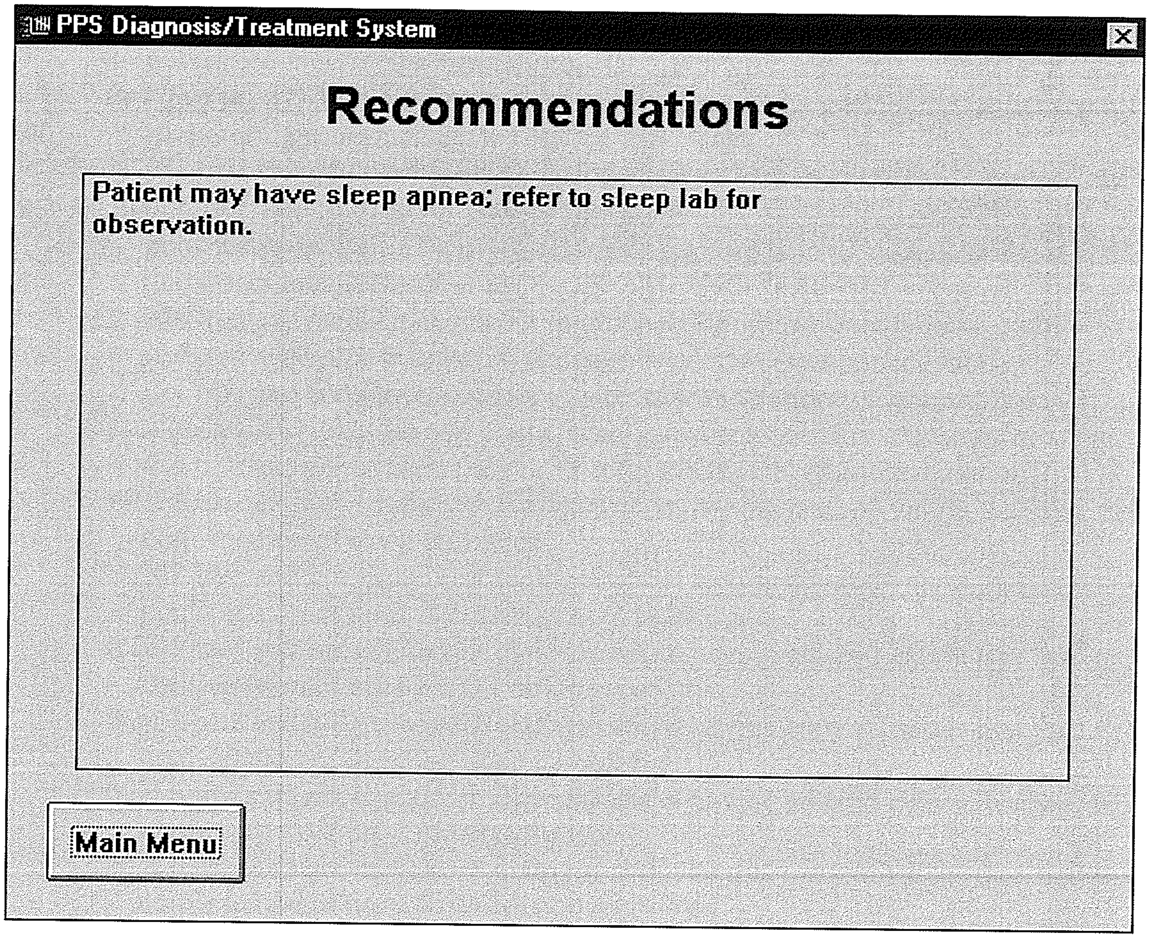


Figure B.5-3: Recommendation Screen of Team Two Prototype



Appendix B.6 Rules/Demons from the Team Two Prototype

1. sleep problems (am headache c/s snoring apnea, insomnia) → sleep problems confirmed and (recommendation)
2. smoke/drugs/EtOH/Poor diet → inadequate knowledge of PPS, "suggest patient read literature" (recommendation)
3. if 2 true → and not explain → dialogue about having entered values that lead to the confirmation of need for patient education
4. poor rest/pain with ↑ activity/aching or burning pain → muscle overuse confirmed and (recommendation)
5. if 4 true and inadequate rest → improve daytime rest (recommendation)
6. if 4 true and work overuse → decrease workload (recommendation)
7. if 4 true and recreation overuse → decrease recreation (recommendation)
8. night pain → overuse and pain controlled with modalities (recommendation)
9. if 4 true and general/am fatigue → refer to OT, etc. (recommendation)
10. if 1 true and not explain → dialogue about having entered values that lead to the confirmation of sleep problems
11. if 8 true and not explain → dialogue about having entered values that lead to the confirmation of need for modalities to reduce pain
12. if 9 true and not explain → dialogue about having entered values that lead to the confirmation of need for OT or other consult
13. if 1 true and not explain → dialogue about having entered values that lead to the confirmation of need for sleep lab referral
14. if 5 true and not explain → dialogue about having entered values that lead to the confirmation of need for daytime rest
15. if 6 true and not explain → dialogue about having entered values that lead to the confirmation of need for decreased work load
16. if 7 true and not explain → dialogue about having entered values that lead to the confirmation of need to decrease recreational activities

Appendix B.7 Rules For the Proposed Third Iteration Implementation

Note that each table contains the rule sets for each of the three modules.

Table B.7-1: Module One: **Differential Diagnosis**

Antecedent (if)	**Consequent (then)**
not confirmed polio	may not be polio + refer to physician for confirmation
not stable for specified period	not PPS by definition +may be active polio or another disease + refer to physician
not new pain/weakness/fatigue	absence of the main complaints suggest that the complaints may be secondary to another problem + if the symptoms are not relatively new, they may be due to another problem + refer to physician

Table B.7-2: Module Two: **Admonishments /Alerts**

Antecedent (if)	**Consequent (then)**
dependants > 0	note effect of dependents on activity demands
weight status -obese	note effect of obesity on activity levels and energy demands, exercise precautions....
recreational/fitness > 0	note effect of occupational activities on activity levels and energy demands....
occupational activities	note effect of recreation and fitness regimes on activity levels and energy demands....
smoking >0	note effect of smoking on conditioning and fatigue + advise patient regarding the possible risks for pulmonary dysfunction due to PPS (see **education segment** for details)
alcohol consumption >0	note effect on respiratory system and educate patient about possible risks for serious respiratory dysfunction due to PPS (see **education segment** for details)
surgical intervention ≠0	note effect on joint and strength integrity when prescribing exercise

Antecedent (if)	Consequent (then)
other illness (e.g. IIDM, RA, asthma)	when prescribing exercise, note the possible contraindications/precautions due to concomitant illness/injury
other injury (e.g. fracture, burn, strain)	when prescribing exercise, note the possible contraindications/precautions due to concomitant illness/injury
ADL aids current status < adequate	note that aids must be reviewed and improved *
orthotics current status < adequate	note when prescribing exercise that condition of orthotics must be improved *
mobility aids current status < adequate	note that condition of mobility aids must be improved *
medications = depressants(examples)	note adverse effect of depressants and analgesics on respiratory system
medications = analgesics (examples)	note adverse effect of depressants and analgesics on respiratory system
medications = pyridostigamine	note potential beneficial effect of this drug on strength when reassessing this factor and progressing exercise
medications = quinine	note potential beneficial effect of this drug on strength when reassessing this factor and progressing exercise

Antecedent (if)	**Consequent (then)**
emotional status = low	consider referral to psychological counseling when patient's affect is low
functional status = inadequate	consider consult with occupational therapy for intervention
all pain choices in main complaints screen	use thermal modalities (ice, hot packs, US, etc.) with care due to potential for decreased sensation and altered circulation

* denotes reminder function versus heuristic recommendation per se

Table B.7-3: Module Three:**Treatment Heuristics**

PPS Knowledge Inadequate	Educate the patient about his condition. + Refer to the educational segment, MORE #.
Generalized Pain-Muscle Overuse	Reduce muscle overuse. + Use modalities to alleviate pain. + See MORE #.
Generalized Pain-Inadequate Sleep	Reduce factors negatively impacting on sleep. + See MORE recommendation #. + Use modalities to alleviate pain. + Improve sleep hygiene and posture as required. +See MORE #.
Localized Joint Pain-Poor Biomechanics	Improve biomechanics. + See MORE #.
Localized Joint Pain-Lax Ligaments	Consider orthotics and strengthening the muscles about the joint... + See MORE #.
Localized Joint Pain-Contractures	Consider serial casting and dynamic stretching. + See MORE #.
Localized Joint Pain-Inadequate Orthotics/Aids	Repair or replace aids. + See MORE #.
Localized Muscle Pain-Inadequate Rest	Educate patient regarding rest. + Send note to employer and insurance agent supporting need for rest on the job. + See MORE #.

Localized Muscle Pain-Muscle Overuse	Attempt to reduce muscle overuse. See MORE #.
Pain unaltered with physiotherapy intervention (including acupuncture)	Refer to a pain clinic, physiatrist, psychiatrist or psychologist.
Fatigue upon awakening-sleep apnea/hypoventilation	Refer to a sleep laboratory or respirologist.
Fatigue upon awakening-Musculoskeletal Pain	Attempt to reduce the factors contributing to the pain. + See MORE # for advice concerning muscle overuse. + Assess sleep posture and adequacy of sleeping platform. + See MORE #.
Fatigue upon awakening-Sleeping Hygiene	Educate the patient regarding good sleep hygiene practices. + See MORE #.
Local Fatigue (deconditioning/muscle overuse)	Prescribe an appropriate conditioning program. + See MORE # for examples. + Consider modifying energy demands. + See MORE # for conservation of energy techniques.
Generalized Fatigue-Inadequate Rest	Educate patient regarding methods to attain adequate rest. + Send note to employer and insurance agent supporting need for rest on the job. + See MORE #.

Generalized Fatigue-Inadequate Sleep	Attempt to reduce the factors contributing to the poor quality or quantity of sleep. + Educate the patient regarding good sleep hygiene practices and the importance of adequate sleep. + See MORE #.
Generalized Fatigue-Muscle Overuse	Reduce muscle overuse. + See MORE #.
Generalized Fatigue-Deconditioning	Prescribe an endurance program. + See MORE #. + Consider educating the patient regarding energy conservation techniques to enhance function until improved level of conditioning has been achieved. + See MORE #.
Weakness (deficit of strength) secondary to disuse.	Prescribe an exercise program. + See MORE #. Review general guidelines to tailor program, MORE #. + Watch for development of muscle overuse.
Weakness (deficit of strength) secondary to overuse or a combination of disuse and overuse.	Prescribe an exercise program. + See MORE #. Review general guidelines to tailor program, MORE #. + Watch for development/exacerbation of muscle overuse.

Decreased endurance secondary to poor conditioning or muscle overuse.	Prescribe an exercise program to improve conditioning. + See MORE #. + Review general guidelines to tailor program, MORE recommendation #. + Refer to MORE # when patient has muscle overuse.

Appendix B.8 Description of the Proposed Third Iteration Prototype Design

Screen Title	**Contents**	**PD Menus***	**Buttons**
Title Screen Category= Intro.	Title and Developers	none	Continue→ Introductory Screen
Introductory Screen Category= Intro.	On-line Tutorial…. **B** → Screen PPS Diagnostic Criteria Confirmation Checklist (for new consultations)…. **B**→ Screen Open Saved Session….→**B** (dialogue box)	<u>System</u> • Quit • Open/New…. • Save Session • Print Chart…. • Help • Compare….	Quit→exit
On-line tutorial Category= Intro.	Tutorial • general instructions • instruction with case study	<u>System</u>	Quit→exit Continue→ Introductory Screen
PPS Diagnostic Criteria Confirmation Checklist Category= Dx	Confirmed history of PPS **T/F** 15-20 years functional stability **T/F** Onset of new pain/fatigue/weakness **T/F**	<u>System</u>	Quit→save? → exit Main→ Main Menu Screen

Screen Title	Contents	PD Menus*	Buttons
Main Menu Category= Hx (Main)	Patient Demographics…. **B**→ Screen Past Medical History…. **B**→ Screen History of Present Illness…. **B**→ Screen Social History…. **B**→ Screen Tests…. **B**→ Screen Recommendations…. **B**→ Screen	<u>System</u> <u>History Menus</u> • Main Menu • Patient Demographics • Past Medical History • History of Present Illness…. • Social History • Tests (EMG….) • Treatment Record <u>Advisor</u> • Definitions • Recommendation s • MORE recommendations • References	Quit→save? → exit
Patient Demographics Category= Hx (Main)	Name **TB** Medical Number **TB** Date of Birth **TB** Age **TB** Gender **RB** Visit Date **TB** General Information **TB** Marital Status **TB**	<u>System</u> <u>History Menus</u> <u>Advisor</u>	Quit→save? → exit Main→Main Menu Screen

Screen Title	Contents	PD Menus*	Buttons
Social History Category= Hx (Main)	Smoking Behavior (non/former/ppd) **TB** Dependents-Type (enter #) **TB** Marital Status **RB** Weight **TB** Weight Behavior (inc./dec./stab.) **RB** Weight Status (Norm./under/over) **RB** Alcohol Consumption **RB** Recreational/Fitness Activities (Intensity/Freq./Dura./Status) **CB &TB** Occupational Activities (Intensity/Freq./Dura./Status) **CB&TB** Volunteer/Other Activities **TB** Financial Status **TB** Comments **TB**	System History Menus Advisor	Quit→save? → exit Main→Main Menu Screen
Past Medical History (Polio and Other Illness/Injury) Category= Hx (Main)	Age at Onset **TB** Length of Illness **TB** Age at Peak Recovery **TB** Functional Status at Peak Recovery **TB** Type **RB** Severity **RB** Areas affected (L/E, U/E, spine, right, left) **CB** Surgical Intervention **TB** ADL aids since **TB** Orthotics since **TB** Mobility aids since **TB** Activity level since **TB** Strength level since **TB** Other illness (e.g. IDDM, RA, asthma) **TB** Other injury (e.g. fracture, burn, strain) **TB**	System History Menus Advisor	Quit→save? → exit Main→Main Menu Screen
Tests (e.g. EMG, MRI) Category= Hx (Main)	Test Name **TB** Test Results **TB** Test Date **TB** Comments **TB**	System History Menus Advisor	Quit→save? → exit Main→Main Menu

Screen Title	Contents	PD Menus*	Buttons
History of Present Illness (HPI) Category= Hx (Main)	Onset of PPS Complaints **TB** Years since peak recovery **TB** General pattern of decline **TB** ADL aids current **TB** & Status **RB** Orthotics current **TB** & Status **RB** Mobility aids current **TB** & Status **RB** Medications (key groups c specific e.g.) **RB** Other Medications **TB** Illicit drug/herbal remedies/etc. **TB** Emotional Status **RB** Cognitive Status **RB** Fasciculations **T/F** Functional Status • ambulation **RB** • transfers **RB** • mobility **RB** • ADL **RB** Knowledge of PPS adequate **T/F** Main complaints ….**B** Non-PPS complaints/comments…. **B**	<u>System</u> <u>History Menus</u> <u>Advisor</u>	Quit→save? → exit Main→Main Menu
Non-PPS complaints Category= Hx (Main)	Illness **TB** Injury **TB**	<u>System</u> <u>History Menus</u> <u>Advisor</u>	Quit→save? → exit Main→Main Menu
Main Complaints Category= Hx (Main)	Pain complaints **CB** Fatigue complaints **CB** Weakness complaints **CB** Morning Headaches **T/F** Cold Intolerance **T/F** Pain details…. **B** Fatigue details…. **B** Weakness details…. **B** Other complaints/details…. **B**	<u>System</u> <u>History Menus</u> <u>Advisor</u>	Quit→save? → exit Main→Main Menu

Screen Title	Contents	PD Menus*	Buttons

Pain Details
Category= Hx
(Details)
	Local Joint Pain
	• Lax Ligaments
	    • Joints Affected **TB** (Right/Left/ROM/ Orthotic Type &Condition/Status /Behavior/ Level)
	• Contractures **TB**
	    • Joints Affected (Right/Left/ Degrees/Status/ ROM/Level)
	• Biomechanical dysfunction **TB** (description and status)
	• Activity details
	• Decreases pain? **TB**
	• Increases pain? **TB**
	
	Local Muscular Pain **TB**
	• Muscles Affected (Right/Left/Activity Related/Status/Level/Beha vior)
	• Activity details **TB**
	• Decreases pain? **TB**
	• Increases Pain? **TB**
	
	Burning Pain
	• Onset **TB**
	• Duration/Behavior **TB**
	• Location **TB**
	• Activity Related **T/F**
	• Activity Details **TB**
	• Level **RB** or **TB**
	• Decreases pain? **TB**
	• Increases pain? **TB**
	
	Unbearable/Unremitting Pain **T/F**
	
	General Information **TB**
		System
		History Menus
		Advisor
			Quit→save? → exit
			Main→Main Menu

Screen Title	Contents	PD Menus*	Buttons
Fatigue Details Category= Hx (Details)	Onset **TB** Antecedent events **TB** Time from event to fatigue dev. **TB** Course **TB** Alleviates? **TB** Increases? **TB** Musculoskeletal Pain **TB** (if not noted in Pain details screen; e.g. location, type, level, duration, increases, decreases, status) Local Weakness/Muscle Overuse/Deconditioning **TB** (if not noted in Weakness details screen; e.g. location, level…) Daytime Rest • Visit Date **TB** (automatic from demo. screen) • Amount **TB** • Frequency **TB** • Adequate? **T/F** Sleep Pattern • Visit Date **TB** (automatic from demo. screen) • Amount **TB** • Adequate? **T/F** Sleeping Posture **TB** (description, status) Sleeping Platform **TB** (description, status) Activity Log Highlights **TB**	<u>System</u> <u>History Menus</u> <u>Advisor</u>	Quit→save? → exit Main→Main Menu

Screen Title	Contents	PD Menus*	Buttons

Weakness Details Category= Hx (Details)	Strength (Grades 0-5/velocity, etc.)
	Area (e.g. hip-flexors) **CB** & **TB**
	Comments (e.g. specific muscle tests) **TB**
	Endurance
	• Borg perceived exertion (0-22)
	• Incline (degrees)
	• HR (beats/min)
	• RR (breaths/min)
	• Mode
	    • Treadmill, Running Cycle ergo meter, UBE **RB**
	    • other **TB**
	• Duration **TB**
	• General Comments **TB**
		<u>System</u>
		<u>History Menus</u>
		<u>Advisor</u>
			Quit→save? → exit
			Main→Main Menu

Cold Intolerance Category= Hx	Area **RB** Precipitating Events **TB** Level of Severity **RB** Adequate Clothing **T/F** Comments **TB**	<u>System</u> <u>History Menus</u> <u>Advisor</u>	Quit→save? → exit Main→Main Menu
Morning Headaches Category= Hx	Duration **TB** Severity **RB** Sleep Apnea/Hypoventilation suspected? **T/F** Neck Problems **T/F**	<u>System</u> <u>History Menus</u> <u>Advisor</u>	Quit→save? → exit Main→Main Menu
Other complaints/details Category= Hx (Details)	Other complaints **TB** Other details **TB** Sensory Status **TB** Swallowing Status **TB** Respiratory/CV Status **TB** Deformities **TB** Posture **TB**	<u>System</u> <u>History Menus</u> <u>Advisor</u>	Quit→save? → exit Main→Main Menu

Screen Title	Contents	PD Menus*	Buttons
Recommendatio ns Category= Recs (main)	Treatment Advice ** **TB**	System History Menus Advisor	Quit→save? → exit Main→Main Menu Explain....→ Recap of key selections Treatment Record....→ Treatment Record
Treatment Record Category= Recs (associated)	Visit Date **TB** Problem Name/Number **TB** Treatment Administered **TB**	System History Menus Advisor	Quit→save? → exit Main→Main Menu

General *Menu Items and Buttons connect to screens with the same name, except the continue button in the first few screen and the explain button in the last few screens.

Rules

1. PPS Diagnostic Criteria Confirmation Checklist→ explanations as to why the patient cannot have PPS, by definition
2. Recommendations→

- each treatment advice segment is headed with an applicable title, e.g. Strength Training for Disuse Atrophy to indicate on an abstract level which selections resulted in this advice being triggered
- brief advice is augmented with lengthier segments that can be accessed by a button or hypertext link.

3. Alerts: tailor made advice for each case.

Screens

Introductory

The PPS Case Management Assistant is for use only with patients who have satisfied the PPS differential diagnosis criteria. To find out if your patient satisfies these criteria, or to use the application as a case based instructional tool select the button labeled 'PPS Diagnostic Criteria Confirmation Checklist'. If you have already used the application for this patient, enter the patient's identity number to access associated files.

PD Menus

System

Print chart

- all visits → all session notes
- specific visit (enter visit date)→ all session notes for that date
- recommendations/explanations only (enter visit date)
- comparisons

Advisor

MORE recommendations → a file containing the longer advice segments, or an hypertext table of contents with the treatment advice segments named and numbered. This method of presentation is preferable to displaying the entire segment. Navigation through lengthy or numerous segments is probably best done in segments, because this user group typically is interrupted frequently and is diverse in experience (therefore some therapists may not be naïve with respect to a particular piece of advice and won't need the entire advice segment displayed).

Note: Do not require an Explain menu option for this implementation due to the manner in which the advice information is triggered and presented. The main complaints screen associates the complaints with the possible causes or contributing factors. When the recommendation is shown, a title describing the purpose of the segment is given that indicates the reason for this advice being given. E.g. Energy conservation for muscle overuse contributing to fatigue, pain or weakness.

History Menus

History of Present Illness

- Main complaints
- Pain Details
- Weakness Details
- Fatigue Details
- Other Complaints/Details
- Non-PPS complaints/comments

Buttons

Quit→save?→exit

- acts as a fail safe for situations that are common in the clinic e.g. 1) naïve or distracted user forgets to save; 2) application left open and other user wants to close it/shut down the system;
- could be made optional, i.e. possible for end user to disable automatic save.

Explain→

- recaps all of the key selections made that have triggered the recommendations.

Appendix B.9 Proposed Third Iteration Prototype Screen Examples

Figure B.9-1: Introduction Screen

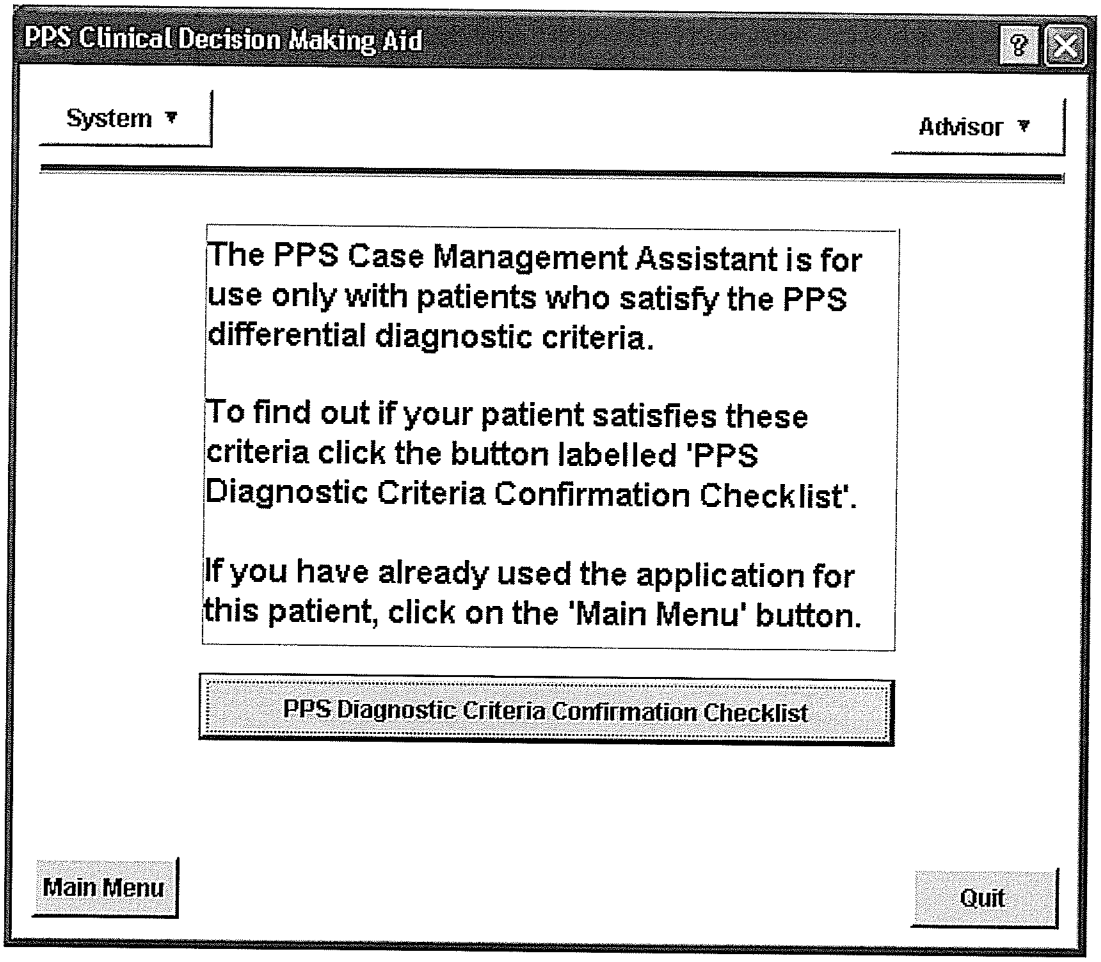


Figure B.9-2: PPS: Diagnostic Criteria Confirmation Checklist Screen

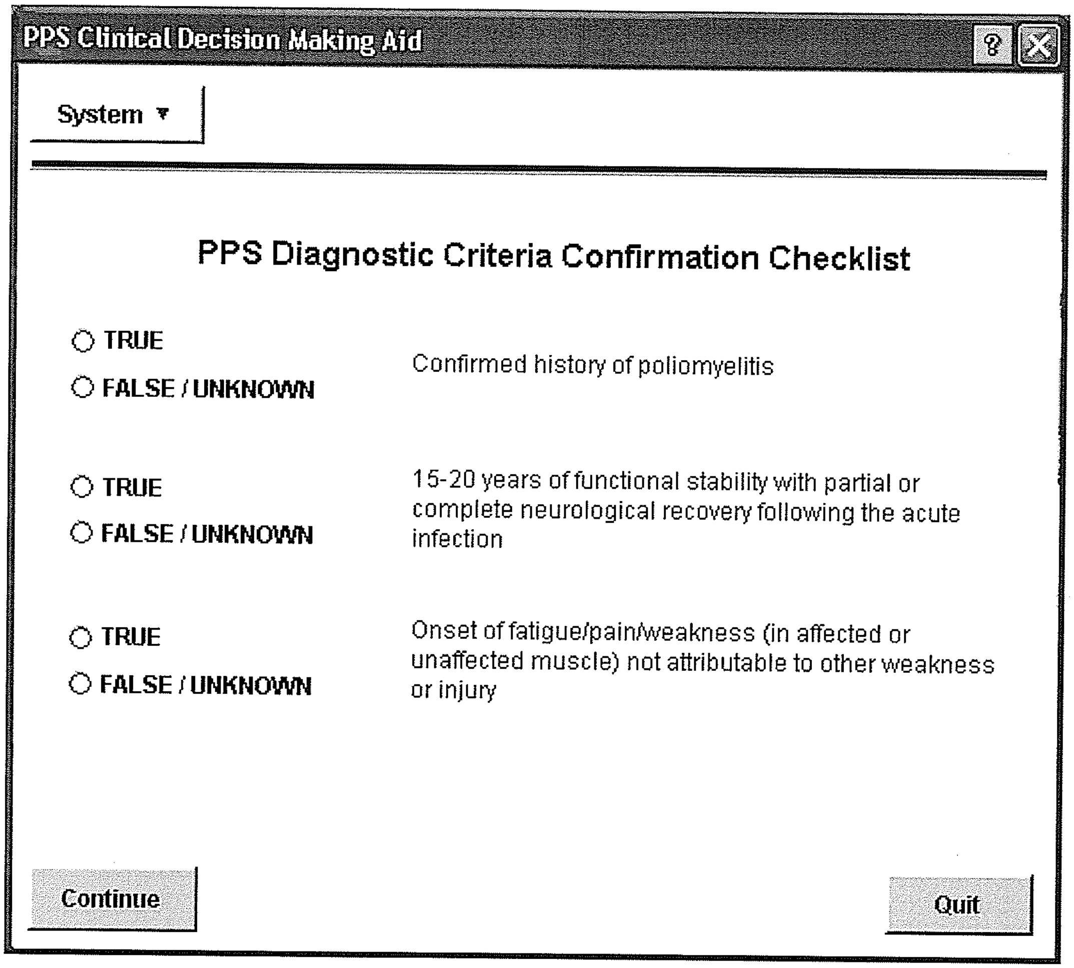


Figure B.9-3: Main Menu Screen

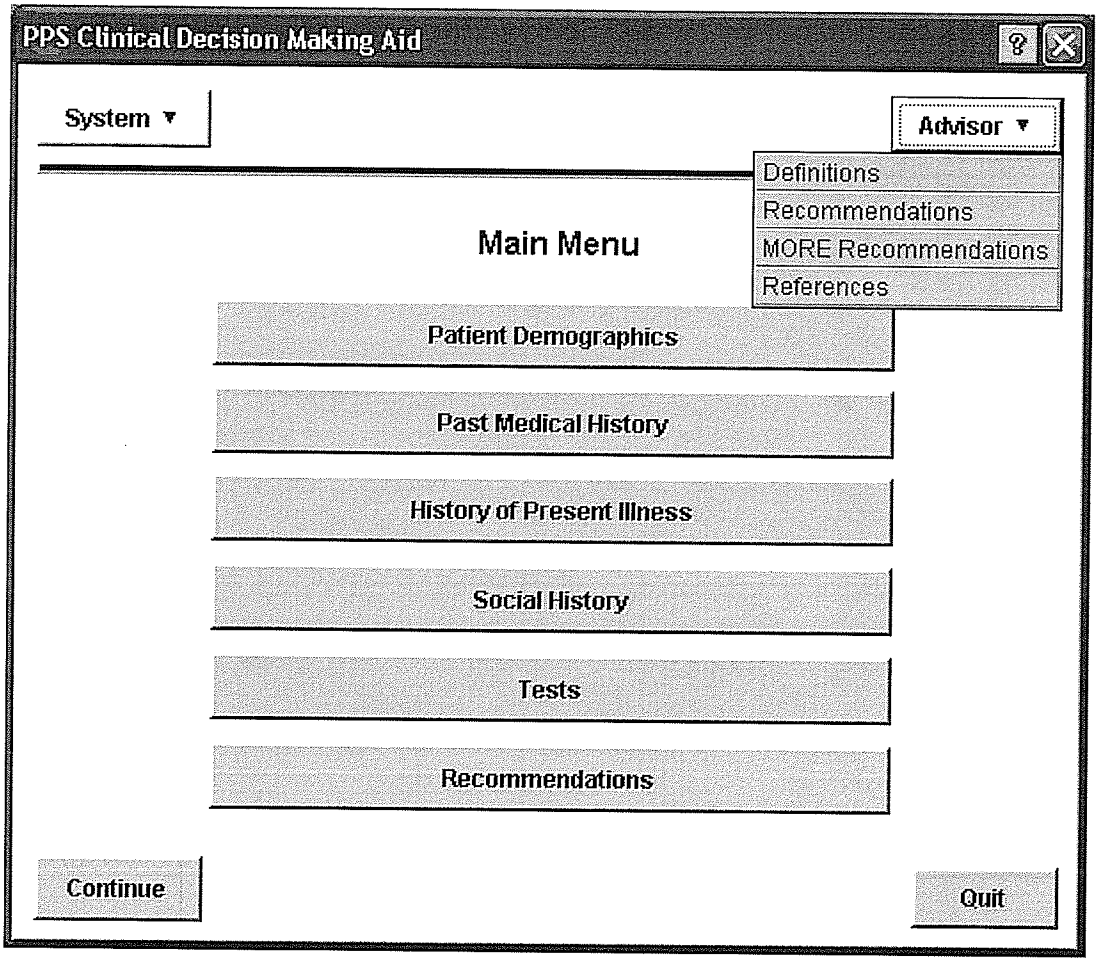


Figure B.9-4: Patient Demographics Screen

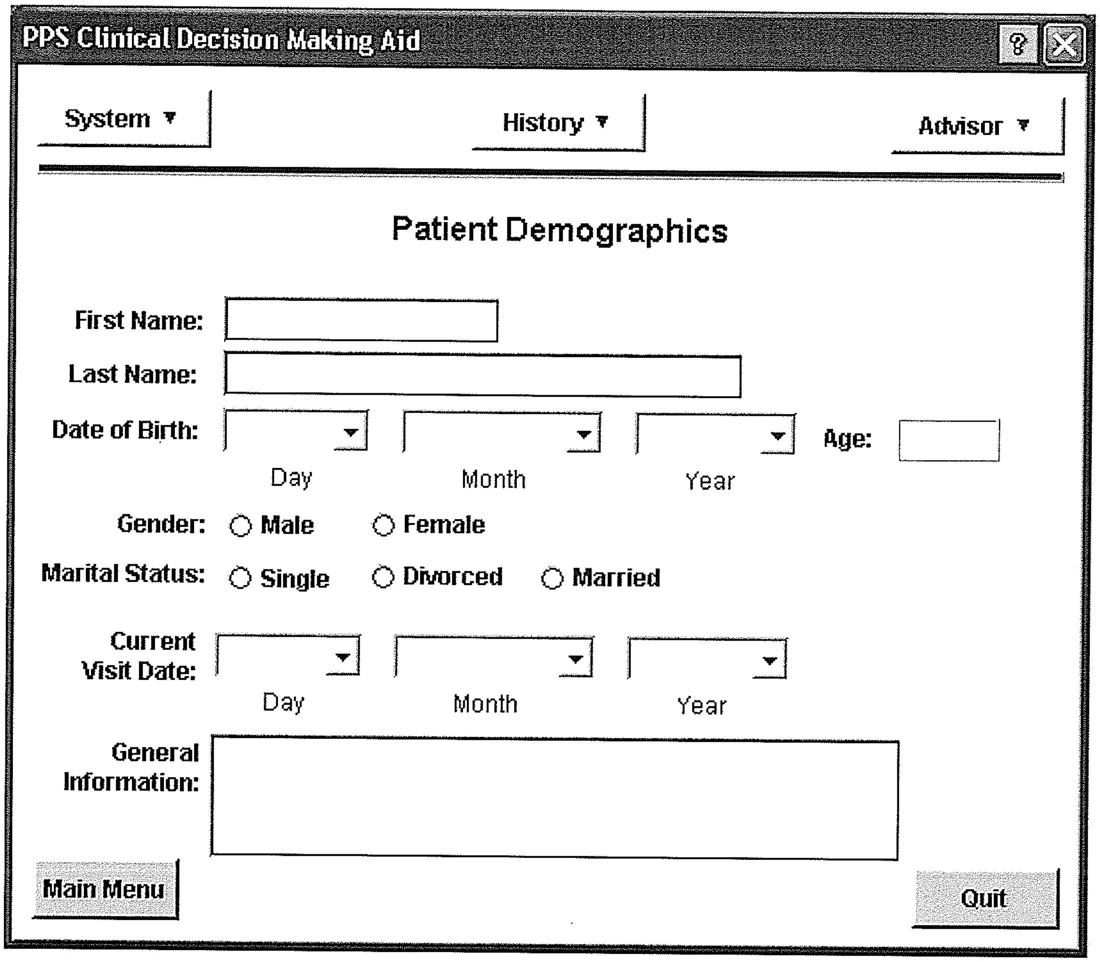


Figure B.9-5: Social History Screen

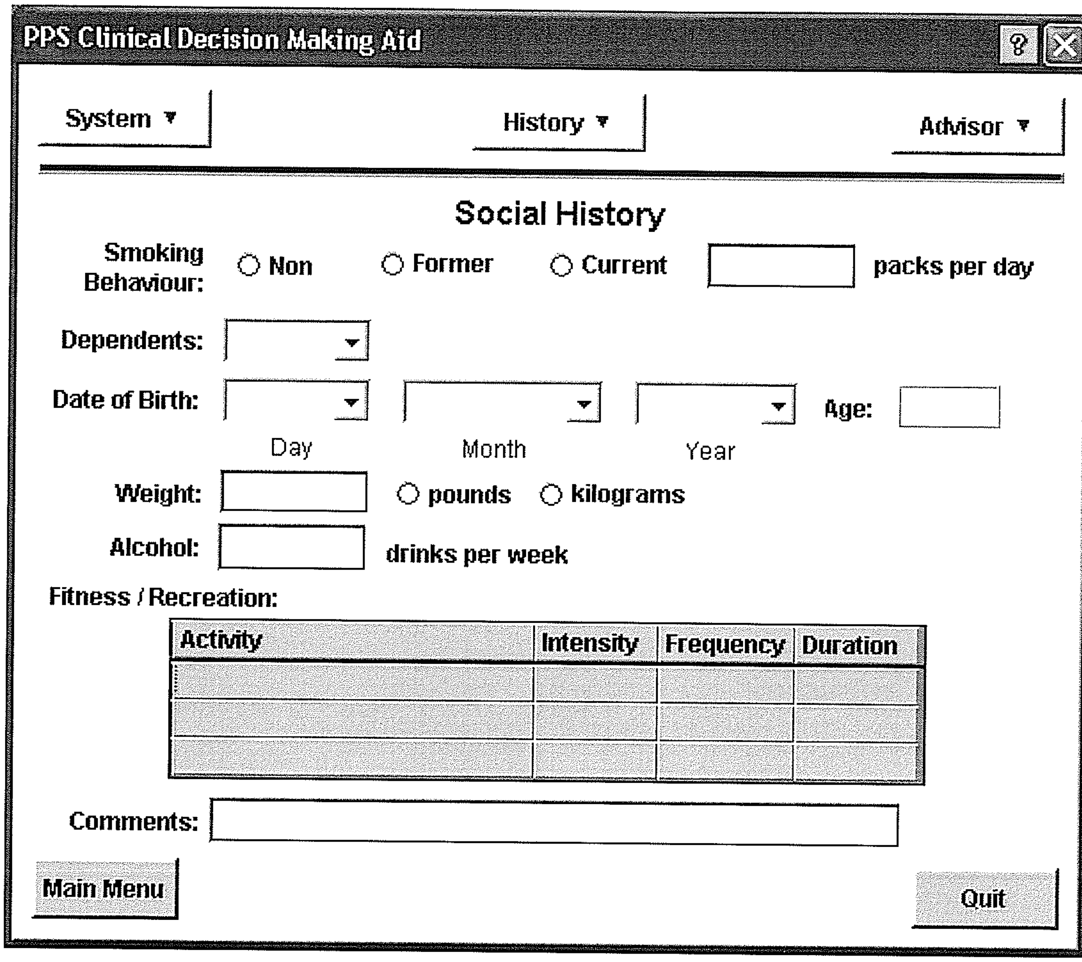


Figure B.9-6: Past Medical History - Polio Screen

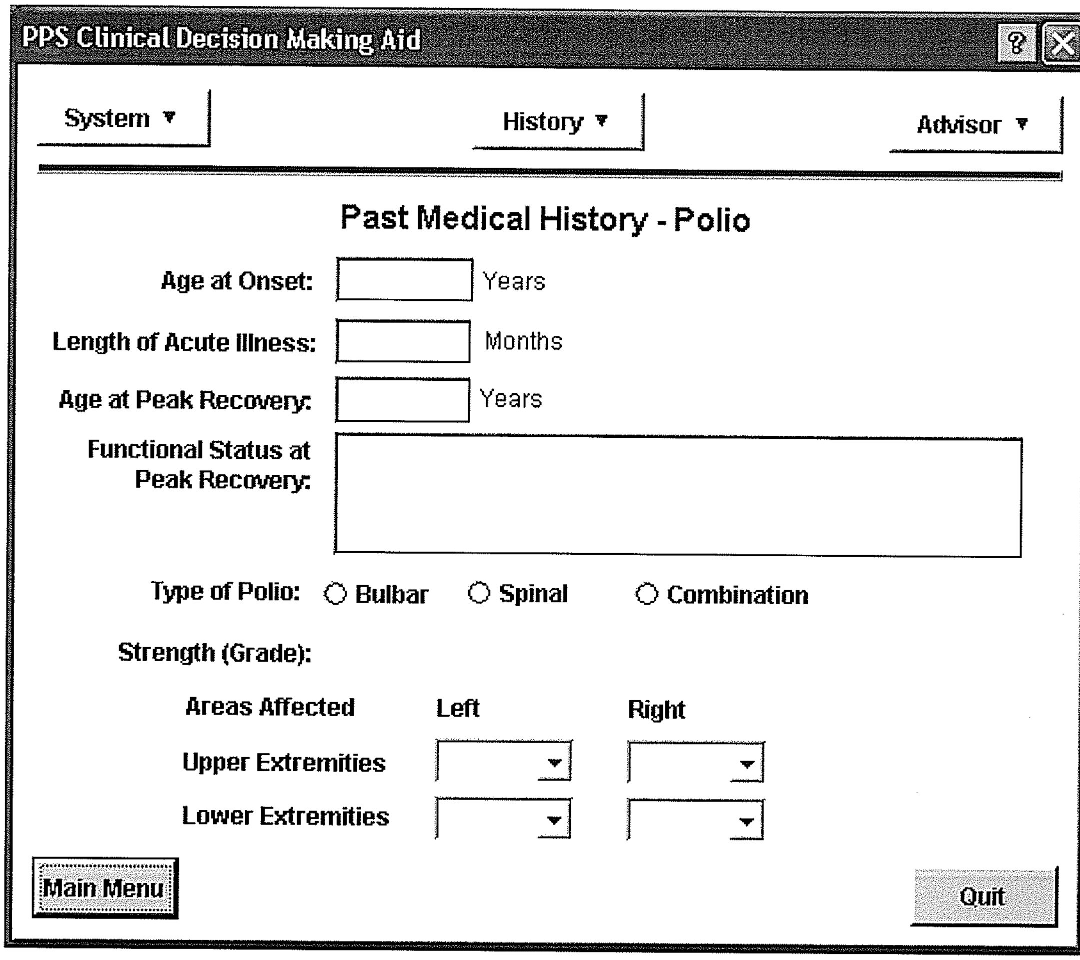


Figure B.9-7: History of Present Illness Screen

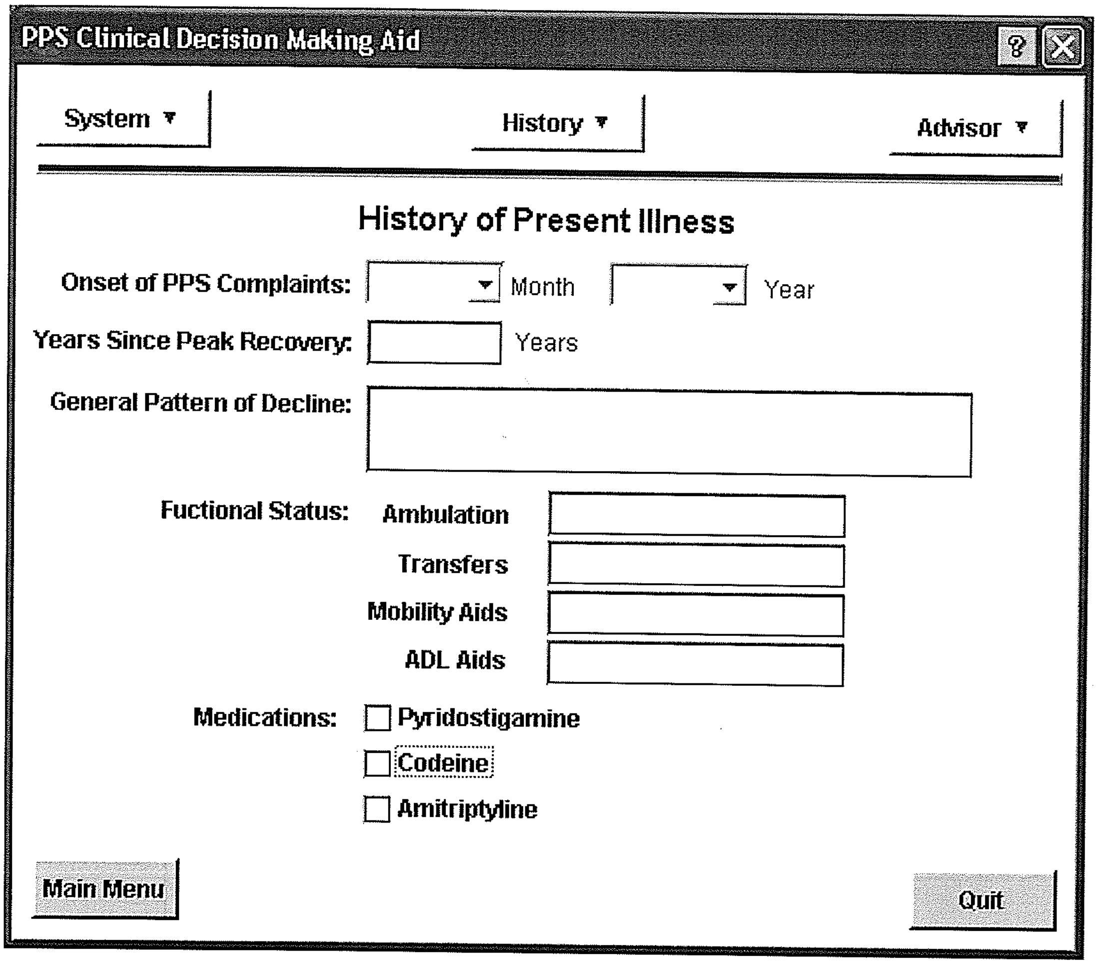


Figure B.9-8: History of Present Illness 2 Screen

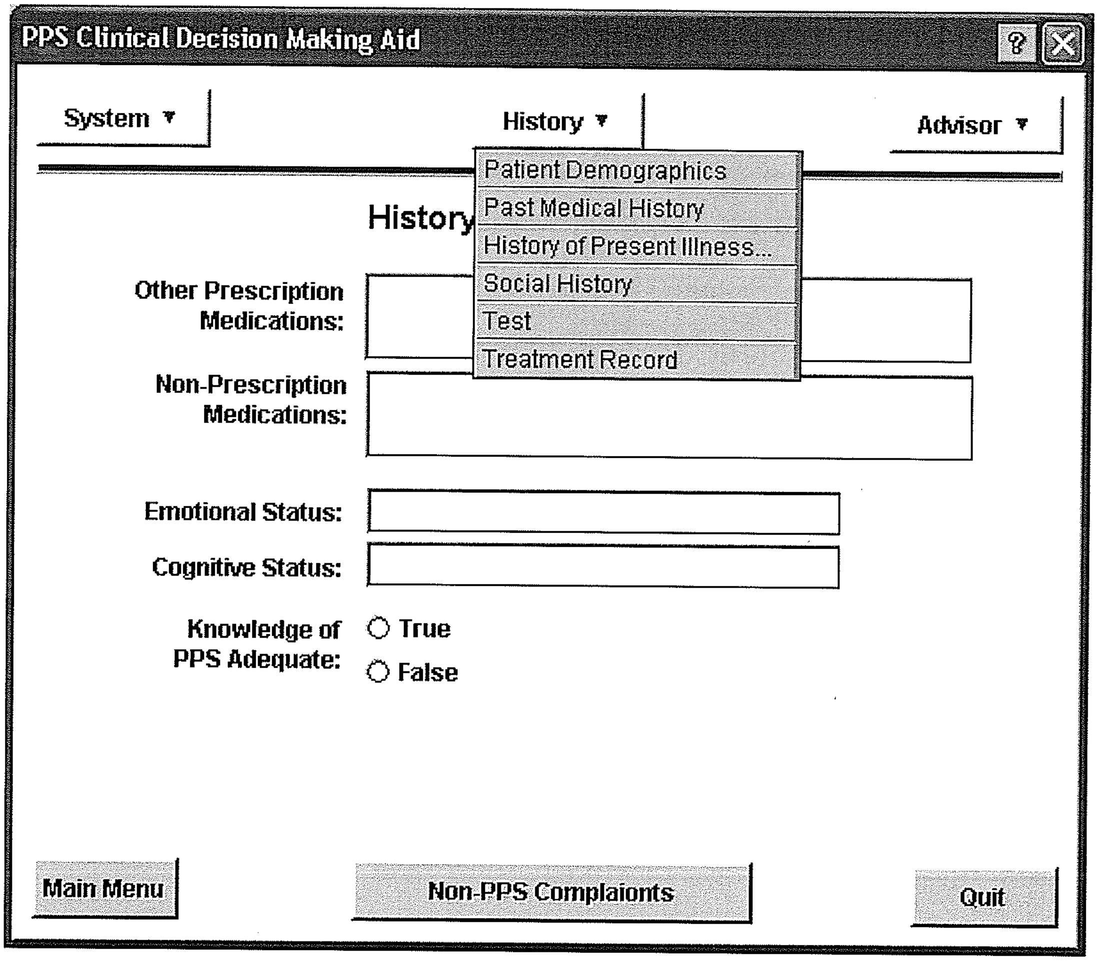


Figure B.9-9: History of Present Illness – Main Complaints Screen

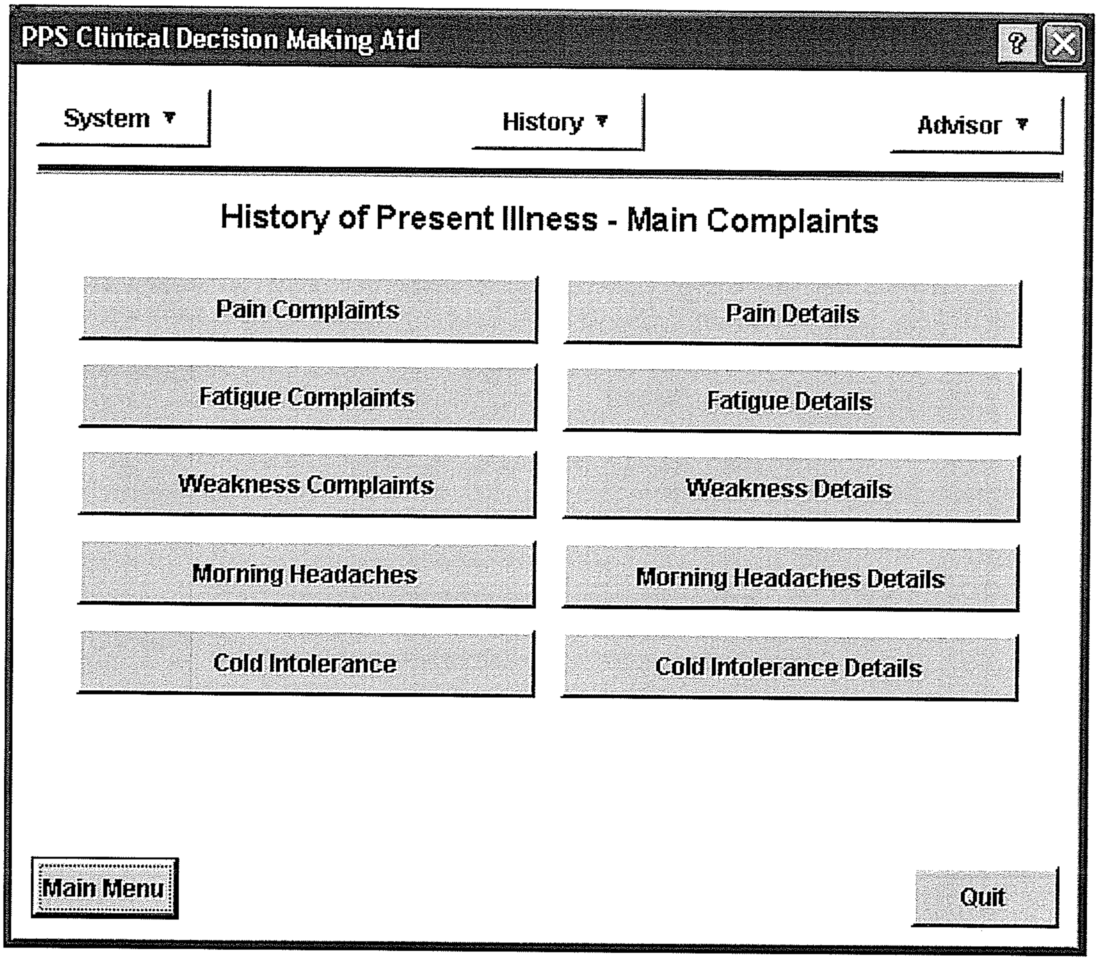


Figure B.9-10: Treatment Recommendations Screen

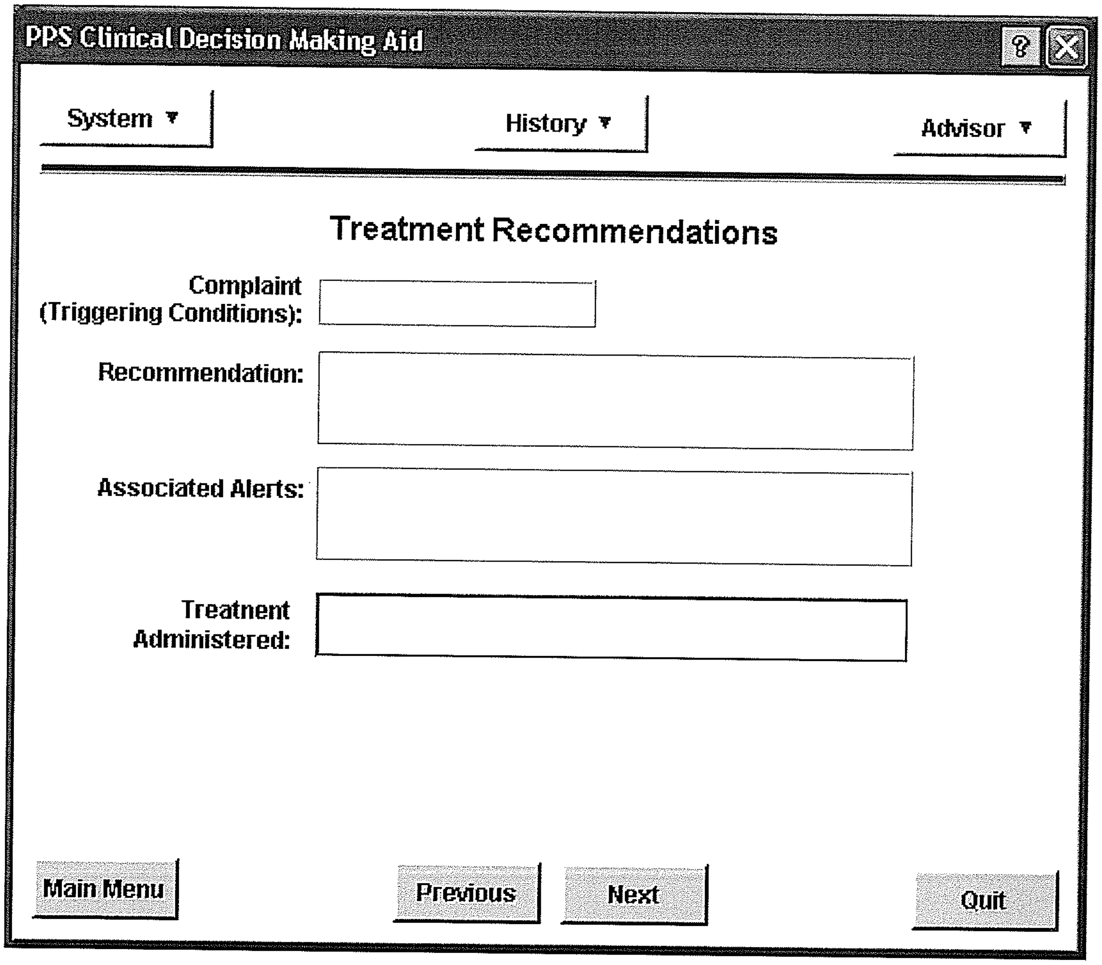


Figure B.9-11: PPS Diagnostic Criteria Confirmation Checklist Screen

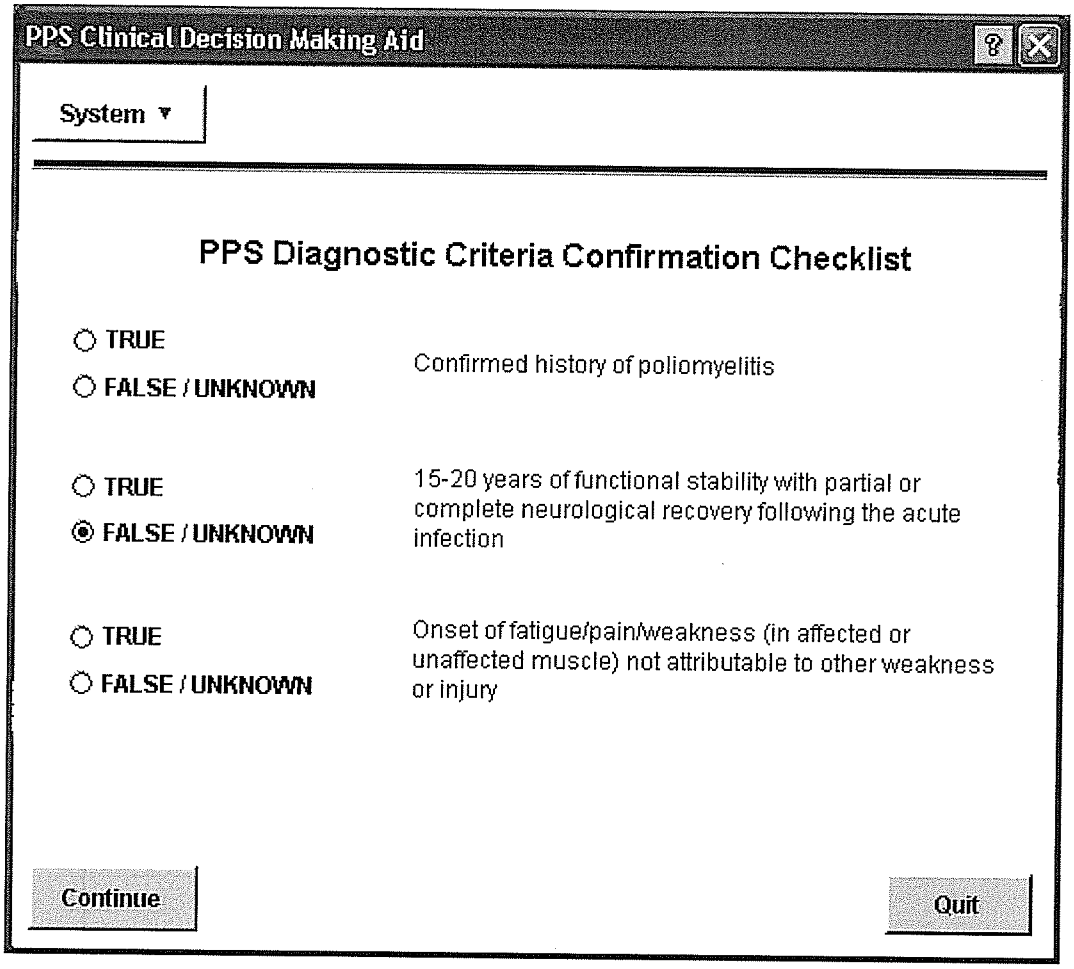
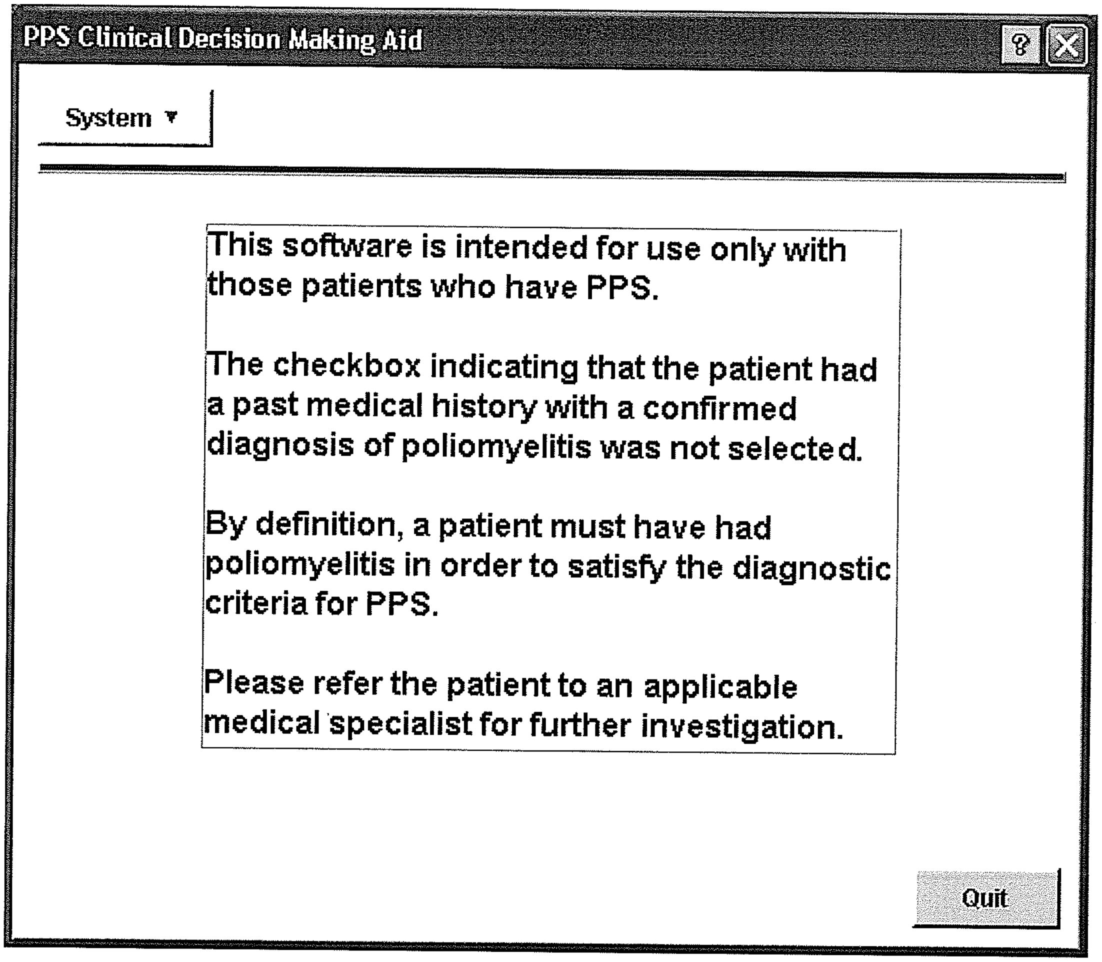


Figure B.9-12: Interaction Screen



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