Royal Hospital for
Neuro-disability

Refining the Wheelchair Prescription Process

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by

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ABSTRACT

Wheelchair prescription is a highly involved process that is unique to each individual. There are many aspects to consider when making a prescription, ranging from environmental needs to the physical needs of the patient. This report, prepared for the Royal Hospital for Neuro-disability, takes an in depth look at the current prescription process. We examine ways in which the RHNd can make the prescription process more standardised and efficient, and explore how an expert system could be beneficial.

EXECUTIVE SUMMARY

The Royal Hospital for Neuro-disability (RHNd) treats patients that suffer from neurological disease and central nervous system damage. These disabilities may cause abnormal muscle reflexes, poor muscle tone, and postural problems. Patients who develop these life long disorders require assistive devices to facilitate everyday life. At the RHNd, all but one patient require wheelchairs to fulfil their therapeutic needs. Consequently, wheelchair prescription plays an integral role in the treatment provided at the hospital. Wheelchair prescription is a complex task because the clinician must not only consider the patient's physical disorder, but also take into account funding, future placement (environment), and the needs of the primary care provider. The vast array of wheelchairs and adaptations available further complicates prescription. The RHNd would like to bring some order to this complexity by identifying rules and relationships that exist in wheelchair prescription with the implementation of an expert system. The goal of this project is to identify the inefficiencies that currently exist in the prescription process and to define the essential qualities of an ideal expert system for the RHNd.

Since our recommendations need to address the specific needs of the RHNd, we conducted shadowing sessions, interviews, follow-up questionnaires, and an expert system trial with the clinic staff. From the interviews and shadowing sessions, we outlined the prescription process and identified the major sources of inefficiency at the hospital. We incorporated this information into a flowchart of the prescription process and highlighted the problem areas. We geared the follow-up questionnaire towards extracting information on the prescription of specific wheelchairs. This data, coupled with information from wheelchair manuals, allowed us to complete spreadsheets of the wheelchair specifications and a flowchart of their prescription. In addition, we evaluated Nigel Shapcott's Computer Aided Wheelchair Prescription System (CAWPS) prototype with select staff members. From these trials we were able to clarify the staff's expert system expectations; we incorporated this information, along with data from the interviews, into a recommendation of what type of system would be most appropriate for their needs.

Through our research we discovered that no functioning expert system specifically for wheelchair prescription currently exists. Therefore, the RHNd requires a custom designed system that will address its specific needs. We have found that an expert system must contribute to the production of a more thorough and efficient wheelchair prescription. In addition, the system must play an integral role in remedying the identified inefficiencies. Most importantly, the RHNd must have the ability to update the expert system constantly with the advancements in wheelchair technology and prescription methods.

Based on these expert system requirements we have identified two types of appropriate expert systems, namely rule-based and neural network systems. Developers have designed both types to accommodate changes in the rule base. The downfall of the rule-based system is that the developers must identify the rules before the system can function, and we have discovered that there are no clear-cut rules in wheelchair prescription. The neural network type system can learn such rules by pattern recognition, but only tests will reveal how efficient the rule development will be with the complex variables of wheelchair prescription. Therefore, we feel that the RHNd should trial a specific system before it makes a concrete decision.

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I. INTRODUCTION

The treatment of neurological diseases is a tremendous undertaking because in most cases a definite cure has yet to be discovered. Treatment is a highly involved process that requires monitored long-term care and rehabilitation, usually done on an in-patient basis. Nevertheless, facilities that provide neurological treatment must be highly organised and efficient in their treatment methods, especially if they treat a variety of diseases.

The Royal Hospital for Neuro-disability (RHNd) is a leading treatment centre in England. It was founded in 1854 by the Reverend Dr. Andrew Reed and was formerly known as the "Hospital for Incurables." In the years since its founding, the RHNd has made great strides and seeks to better the lives of the severely disabled. Consequently, the establishment is constantly looking for ways to better their therapeutic methods. To address the needs of wheelchair prescription, the RHNd's Department of Biomedical Engineering has developed Wheelchair Clinic. Essentially, Wheelchair Clinic is a team of occupational therapists, physiotherapists, nurses, and seating technicians, who meet with the patient and/or the patient's relatives to provide recommendations and advice for wheelchair prescription. The ultimate goal of the team is to match the patient to a wheelchair that suits his or her "physical, environmental, and functional needs"(Wheelchair Clinic Organisation Procedure, 1998). To accomplish this end, the Department of Biomedical Engineering is always searching for innovative ways to improve upon the clinic. Recently, they have developed a computer program that utilises a polar graph which is a circular graph to organise data. It allows for the visualisation of the patient status before and after wheelchair prescription.

With the continual advancement of wheelchair technology, the prescription of an appropriate wheelchair for a physically disabled individual has become a more complicated task. There are hundreds of wheelchair models and adaptations available and essentially, the clinician can modify every aspect of the wheelchair to fit the individual patient's need. Both consumers and professionals are overwhelmed by the increasing amount of options that are available (Taylor & Trefler, 1991). With twelve percent of Britain's 400,000 wheelchair users having complex wheelchair needs, there exists a significant possibility for wheelchair prescription mistakes (Silcox, 1995). The Department of Biomedical Engineering is finding wheelchair prescription to be a highly involved process, and desires simplification with a more efficient expert system. Specifically, an expert system is an organised deductive program to arrive at a solution by using available information ("Expert Systems Come of Age," 1998).

This project addresses the need for an expert system. We analysed the current prescription method in order to identify inefficiencies that the new system should improve. The Department of Biomedical Engineering is open to suggestions for the implementation of an existing system or the design of a custom model. Consequently, an in depth study of current expert systems in the United States revealed systems which could help in the developmental needs of an expert system for the RHNd. To prepare us for a custom design, we also explored the different types of expert systems and their general development. We gave added consideration to the specific requirements of neurological diseases treated at the RHNd, and to wheelchair prescription in general.

The RHNd requires an expert system that is more efficient and expedient in wheelchair prescription than their current manual method. The ideal expert system will match a patient to an appropriate wheelchair and significantly reduce the chance of overlooking critical pieces of information. A more organised method reduces the chance of error and therefore is a great benefit to the patient and the hospital. If it is effective in organising the patient data and facilitates proper decision making, an expert system has the potential to allow the hospital to provide overall better treatment for patients that require wheelchairs. It was our goal in this project to define the essential qualities of an ideal expert system. No such existing system meets these standards, so the RHNd can design one from our suggestions.

Since our recommendations must address the specific needs of Wheelchair Clinic we conducted shadowing sessions, interviews, and a prototype test with the clinic staff. We extracted information from the clinician staff to define the expert system requirements. To accomplish this objective, we shadowed actual prescriptions to identify the specific steps the clinic staff takes to make their wheelchair recommendations. Also, we conducted interviews with select members of the clinical staff to classify the guidelines and reasoning used in matching a patient to a specific wheelchair. Finally, by allowing the staff to test a prototype system from the United States we evaluated the feasibility of such a system for the RHNd. After analysing the information collected by these three methods we developed our expert system recommendations.

We measured the potential success of an expert system by its fulfilment of a number of criteria. The system must improve the overall quality of wheelchair prescription in Wheelchair Clinic. Also, it must be feasible within any cost constraints established by the RHNd. Most importantly, the system must remedy the inefficiencies in the current system. A proposed expert system must therefore fulfil these requirements.

II. LITERATURE REVIEW

NEUROLOGICAL DISORDERS

The Royal Hospital for Neuro-disability (RHNd) specialises in the treatment of patients with neurological disorders. Therefore, we based our research in wheelchair prescription around a basic understanding of neurological disorders treated at RHNd. We focused on Multiple Sclerosis (MS) and Muscular Dystrophy (MD) because they are two commonly treated neurological disorders. The majority of the patients at the Royal Hospital have suffered from severe central nervous system injuries. Since this encompasses a large variety of disabilities, it is unrealistic for us to investigate each one. However, our research into MS and MD should provide a basic understanding of central nervous system disorders.

The National Institute of Neurological Disorders and Stroke provided information regarding the common disorders treated at the RHNd. We found information on over 100 neurological disorders, including multiple sclerosis and muscular dystrophy. Both MS and MD are life long disorders, although some physical therapy treatment and oral medication is available to lessen the effects of the disorders (National Institute of Neurological Disorders and Stroke, 1996). The people suffering from these disorders have slow deterioration of their muscles. It is important to make their living conditions, including mobility, both convenient and individually specific to suit each patient's particular need.

Multiple sclerosis is a central nervous system disorder that affects an estimated 250,000 to 300,000 people in the United States. It affects young adults between the ages of 20 and 40, and is more prominent among whites than among other races and occurs more in women than men (National Institute of Neurological Disorders and Stroke, 1996). The information provided insight into how the disorder manifests itself, what treatments are available, what causes MS, and what researchers are currently doing.

MS is an autoimmune disease causing the immune system to attack itself instead of fighting off foreign invaders. The immune system does not recognise myelin, a nerve insulator, as part of the body (National Institute of Neurological Disorders and Stroke, 1996). As a result, the immune system begins to attack the myelin as it would a foreign invader. Destruction of myelin slows or blocks transmission of neurological messages, which results in the loss of function and ultimately disables the afflicted person (National Institute of Neurological Disorders and Stroke, 1996).

Muscular dystrophy, unlike multiple sclerosis, is one of a group of proven genetic diseases. Specifically, muscular dystrophy is characterised by progressive weakness and degeneration of the muscles which control movement (National Institute of Neurological Disorders and Stroke, 1996). Muscular dystrophy affects people of all ages although myotonic MD is commonly found among adults. Myotonia is the delayed relaxation of the muscle after a strong contraction which occurs in myotonic MD (National Institute of Neurological Disorders and Stroke, 1996).

Both of the diseases discussed cause severe muscle disability. In all central nervous system disorders and injuries, each person's body reacts differently to the damage. The central nervous system, which includes the brain and the spinal cord, has the responsibility for issuing nerve impulses and analysing sensory data. Central nervous system disorders can range in severity from patient to patient, even within the same disorder. Consequently, it is difficult to conclude on the impact a central nervous system disorder will have on an individual. In addition, the disorder may progress, further disabling the patient. For instance, after a stroke most of the damage to the brain occurs in the hours or days after the event (Rosenthal, Griffith, Bond, & Miller, 1983). Also, brain damage and disease can cause a patient to live in a persistent vegetative state. In this condition, patients are in a state where they lack awareness of their surroundings and possess severe positioning problems. Neurological damage causes abnormal primitive reflexes, which result in a pathological increase in muscle tone and poor posture of the trunk and extremities (Shaw, 1986). Patients who develop these life long disorders and impairments require assistive devices to facilitate everyday activities. Consequently, these devices play a key role in the disease therapy.

WHEELCHAIRS AND PRESCRIPTION

In order to understand how an expert system can improve upon the wheelchair prescription for the neurologically disabled patients, it is necessary to investigate the overall process and the result, which is the prescribed wheelchair. To grasp the dynamic process of wheelchair prescription, we will first discuss the evolution of the wheelchair and its direct effect on prescription. Also, an exploration of the current relationship between the clinician and the wheelchair user will provide insight into the need for efficiency.

Wheelchair History

Tracing the history of wheelchair advancement reveals that as seating systems (wheelchairs) become more individualised, they become more complex. In the early 1500s, the handicapped were transported in wooden carts (Cook & Hussey, 1995). Even as late as 1946, World War II veterans were sharing wheelchairs and using pillows as cushions. At that time, both the medical patients and the physicians lacked the knowledge and training to order wheelchairs that provided a correct fit. Generic wheelchairs were the only types that were easily accessible. As a result, bruised arms and other injuries were common among wheelchair users (Nicosia & Philips, 1990).

In the 1970s, the desire for better fitting, higher performance wheelchairs for handicapped athletes led to innovations in the wheelchair. This transition led to the development of the more rigid boxed-framed wheelchairs and lighter composite materials being utilised in construction. The same concept of desiring more from a wheelchair led to the recent development of the electric powered wheelchair. Clinicians hope that the newly found interest in powered wheelchair sport will precipitate further design development (Warren, 1990).

Over the last twenty years wheelchair technology has dramatically advanced, resulting in a tremendous number of wheelchair types and modifications. There are so many makes and models available that prescription can be a confusing and overwhelming task (Taylor & Trefler, 1991). Though these technological advances currently allow the handicapped to function and more fully participate in everyday activities, the resulting influx of new models and accessories has greatly complicated wheelchair prescription. Clinicians must take into consideration a great deal more information today than when generic wheelchairs were prescribed for everyone (Ragnarsson, 1990). With the continual advancements made in wheelchair technology, clinicians find it difficult to simply keep current (Ozer, 1990).

Wheelchair Overview

Today, clinicians consider wheelchairs not only as propelling structures, but also as supporting aids (Cook & Hussey, 1995). There are a variety of frame types that range from conventional lightweight aluminium frames to heavy duty strengthened types for larger individuals. The basic components include armrests, a seat, a backrest, a push handbrake, the rigging (legrests and footplates), casters (two small wheels), a frame with crossbar, a tipping lever, two large wheels, and handrims. The frames come in different sizes to fit an individual because a precise fit is required for proper use (MacFarland & Wilson, 1986).

When prescribing basic frame styles the clinician must consider the mobility needs of the user. These mobility needs are usually assessed in three categories: dependent mobility, independent manual mobility, and independent power mobility (Warren, 1990). Dependent mobility wheelchairs include transport chairs and strollers that the attendants can propel. Typically, they are called "indoor chairs," and have two large front wheels and casters in the back. Clinicians prescribe these wheelchairs as a secondary lightweight system, which is easy to transport for individuals incapable of independently propelling a wheelchair (MacFarland &Wilson, 1986). The "traditional" or "universal" chairs with two large back wheels with handrims and small casters in the front are called independent manual mobility chairs (Delisa & Greenberg, 1982). The patients who typically use these chairs have enough strength to propel the chair independently for extended periods of time. If a user has difficulty manually propelling a wheelchair, he can use an independent power mobility chair. These chairs are basically motorised derivatives of the universal chair (Cook & Hussey, 1995).

For those patients who require manual propulsion frames, prescription depends on the support needs of the user. For the most part, the different styles are simply modifications of the universal type to fulfil the varying supportive requirements (Cook & Hussey, 1995). The universal wheelchair includes an "X"-shaped frame for easy folding and a sling made of flexible material that stretches across horizontally for seating (hammock seating) (MacFarland & Wilson, 1986). It is limited in its therapeutic usefulness because it provides very little overall support, and the user tends to slide forward into a slumped position. Another model that uses the hammock seating is the ultra-light, or sport model, that has a shorter box-like frame composed of composite materials for greater flexibility and manoeuvrability (Ragnarsson, 1990).

Hence, these models only benefit people who have good upper body strength because they provide minimal pelvic and back support (Cook & Hussey, 1995).

Since clinicians prescribe chairs that can recline for therapeutic purposes, different body angles can reduce pressures on affected areas and allow for correct muscle tone development (Warren, 1990). There are two types of chairs that allow for this change in body positioning, the reclining model and the tilt-in-space model. The reclining model allows the seat's back angle to be changed and the tilt-in-space model allows for all seating angles to be pre-set, so that the chair reclines as a single unit (Cook & Hussey, 1995). To accommodate amputees, clinicians prescribe chairs in which the rear wheels are moved back slightly for increased stability (Delisa & Greenberg, 1982). Also, for those patients who have good leg strength, clinicians prescribe foot drive models that are lowered and contain adaptive riggings (MacFarland & Wilson, 1986). To accommodate growth, there are chairs that allow for the frame size to be changed by various methods (Cook & Hussey, 1995). Thus, slight modifications in the universal model allow developers to address a variety of other supportive needs.

Power driven wheelchairs are the most technologically advanced wheelchair type and can accommodate a variety of disabilities. Typically, clinicians recommend motorised wheelchairs for patients with severe neuro-musculoskeletal disabilities or poor muscle endurance (Ragnarsson, 1990). The type of power drive train is again determined by the needs of the patient. If a patient has moderate postural control and wishes to travel outdoors over different terrain, then the powerful direct drive models are ideal. In these direct drive models, the motor is connected directly to the rear wheel, and the chair is shaped much like a scooter (Warren, 1990). For those patients who have to manoeuvre around tight spaces or require better support, there are standard style wheelchairs, which have a shorter mobility base and reclining options (Axelson & Minkel, 1994). These models are usually belt-driven, which allows for the motor to be positioned away from the wheel (connected by the belt) and generally provide a smoother ride. Essentially, the standard belt driven styles provide for more therapeutic options and comfort, while the rugged direct drive models allow for additional speed and power (Cook & Hussey, 1995).

The RHNd mainly prescribes six wheelchairs for its patients' specialised needs. These include the Shadow, the Cirrus, the Putney Alternate Position (PAP), the Carters Recliner, the Action 2000, and the 8L/9L/Apollo. The Shadow is a base that includes tilt-in-space and is the RHNd's primary chair for matrix seating. Matrix seating is a customised seating system that clinicians prescribe for severe postural problems. The Cirrus has a reclining back and is the RHNd's primary tilt-in-space model, but it can not accommodate matrix seating. Two of the other wheelchairs, the PAP and the Carters Recliner, can accommodate matrix seating. The PAP is also a tilt-in-space model while the Carters Recliner only has a reclining back. Another reclining chair is the Action 2000, which is a lightweight, small-sized chair. The Action 2000 also comes without a reclining back, like the other standard chairs. The 8L/9L is a sturdier standard chair for larger patients. The last chair, the Apollo, is the motorised version of the 8L/9L. We supply more information on the specifications of these wheelchairs in the appendices (see Appendices B and C).

Just as there are a variety of wheelchair types, there are a multitude of methods to control the motorised movement. The method of control depends on which bodily movements the individual can provide (Warren, 1990). Most common is the four-direction joystick, which can be positioned for hand, chin, foot, or head use. There is also a scanning system that rotates between positions with a blinking light and a button that can be pushed when the desired direction is lit (Cook & Hussey, 1995). Another more advanced control method is a sip and puff system in which the speed and direction can be controlled by the amount of blowing and inhaling into a sensor. There are even voice-activated systems (Warren, 1990). For patients with tremors, there are averaging systems available that ignore rapid short movements and only respond to deliberate long movements (Cook & Hussey, 1995). Each of these control methods can be further categorised to lateral or momentary control. A lateral control will be turned on by the push of a button, and remain turned on until the button is pushed again; a momentary control is only activated when pressure is constantly applied to the button (Cook & Hussey, 1995). In the most advanced models, remote controls can be incorporated into the joystick apparatus to control devices not attached to the wheelchair. The type of control prescribed depends on the goals and the needs of the patient (Warren, 1990).

Another highly individualised component of wheelchairs is the cushion the user directly sits upon. Its purpose is to provide an effective base from which the individual can function from (Ferguson–Pell, 1990). In addition, the cushion is important in the distribution of pressure. Foam is generally the material used, but gel-filled, air-filled, and water-filled cushions are also prescribed. Hybrid cushions, consisting of foam and gel combinations, can provide superior comfort and shape. They provide maximum support by moulding to the patient's shape and propping the patient in a specific position. The most advanced cushion type is the alternating pressure cushion, in which different areas of the cushion raise and lower to constantly change pressure areas, reducing bed sores or pressure related inflammations (Cook & Hussey, 1995). Again, there is not one ideal cushion type; what is adequate for one patient may be detrimental to another. When prescribing a cushion type, the stress on soft tissue, stability provided, frictional properties, moisture and heat accumulation, and durability must be taken into consideration (Ferguson-Pell, 1990). Also, the cushion and wheelchair frame must be considered together so one does not hinder the effect of the other (Ragnarsson, 1990).

Wheelchair Prescription

Essentially every component of the wheelchair, from the armrests to the wheels, can be modified to the needs of an individual. With so many components to take into consideration, wheelchair prescription has become quite complex (Taylor & Trefler, 1991). Accordingly, it is necessary to evaluate the needs of the patient to find the best fit and most therapeutic wheelchair possible (Ozer, 1990). Furthermore, researchers have discovered that often physicians alone do not have the expertise to properly prescribe wheelchairs, especially for severe disabilities. Consequently, they may prescribe wheelchairs that hinder rather than facilitate the patients' ability to function (Delisa & Greenburg, 1982). Considering the wealth of information that must be analysed in wheelchair prescription, clinicians admit that it is very possible to overlook key variables. For example, a clinician may miss the fact that the patient has a very narrow hallway leading to his bedroom and prescribe a chair that has two long of a base for the narrow turn (Ellis & Rabideau, 1997). Therefore, many therapists feel that an evaluation team of physiotherapists, occupational therapists, and technical experts is essential to address the multitude of concerns during prescription (Bergen & Colangelo, 1982).

The actual prescription process is multi-faceted and requires an interaction between the patient and the clinicians to determine the right chair for the disability. Therapists agree that for proper prescription, the focus should be centred on the patient's needs and goals and not the appeal of glamorous new technology (Taylor &

Trefler, 1991). Individualisation is an important aspect of prescription, because people with the same disability may function very differently (Ragnarsson, 1991). The goal of prescription is to find the chairs that will accommodate the patients' disabilities, and allow them to carry out activities that are important to them. To accomplish this feat, prescription is carried out in two main steps: the gathering of a patient profile, and the subsequent matching of that profile to a specific wheelchair type (Berhman, 1990). The consumer profile must encompass both the physical needs and the functional goals of the patient to pinpoint wheelchair selection. For a first time wheelchair user, additional product demonstrations and trials may be required. Also, severely disabled patients usually require a more thorough seating and positioning evaluation to identify proper therapeutic position and accessories (Ellis & Rabideau, 1997).

To individualise prescription, the clinician must first assess the patient's specific physical needs to find the proper "fit" between patient and wheelchair (Ozer, 1990). A medical report must be attained that includes the patient's size and weight, disability and date of onset, and prognosis. The clinician uses this physical information to determine the proper seat width, seat depth, seat height, horizontal position, back height, back width, back angle, armrest height, footrest length, and footrest angle (Brubaken, 1990). Also, it is important to obtain an assessment of his or her physical and sensory skills that include range of motion, motor control, strength, vision, and perception. Finally, functional skills, which include the patient's ability to transfer and propel the wheelchair, must be considered (Cook & Hussey, 1995). These assessments enable the clinician to identify the basic wheelchair type and accessories the patient requires (Ragnarsson, 1990).

The wheelchair also serves to increase a person's ability to function effectively and efficiently in his or her environment (Ozer, 1990). Consequently, the clinician must interact with the patient to identify his or her specific goals and preferences (Behrman, 1990). Interviews with wheelchair users have revealed that they feel the clients' interests and goals should be the main focus in the prescription process (Rushmore, 1997). The patient's goals may include desired activities, environments, preferences, transportation, reliability, durability, and cost. These aspects are often determined from questionnaires and direct communication with the patient (Berhman, 1990). Also, the identification of problems and benefits from previous wheelchair use can narrow the patient's preferences (Ellis & Rabideau, 1997). It is essential to evaluate these areas in order to determine the patient's specific goals and needs before initiating the search for a matching wheelchair. A thorough exploration of the patient's unique situation will define and ease the process of wheelchair selection (Ozer, 1990).

For patients who need the wheelchair to facilitate or correct muscle and skeletal irregularities, the required therapeutic seating posture must be an additional priority before selection. Neurological disease patients often suffer from irregular muscle tone, muscle weakness, abnormal reflex patterns, and possibly even skeletal deformities. Researchers have shown that poor positioning in the chair may precipitate abnormal spine curvature, pelvic misshape, or bed sores (Cook & Hussey, 1995). However, proper positioning can help to normalise tone, decrease irregular reflexes, decrease deformities, increase stability, and maximise functional abilities (Bergen & Colangelo, 1982). The major determination in the seating position is the postural control of the individual. If the person has good control then a system can be prescribed primarily for mobility and comfort. On the contrary, if one or both hands are needed to prop up the body, additional pelvic support is required to free up the hands for functional activities. A system that provides total body support is required when the patient totally lacks the ability to support him or herself (Cook & Hussey, 1995).

Therefore, postural control defines the amount of support required for maximum function.

Once the clinicians determine the patient's postural control, the individual can be fitted in a seating simulator to evaluate the positioning and cushioning requirements. Clinicians believe that accurate positioning can only be accomplished by evaluating the patient in the seated position (Taylor & Trefler, 1991). Once the patient is in the proper sitting simulator, clinicians can determine the required sitting position for different activities. Usually, clinicians work on positioning the pelvis to establish correct weight distribution, and then move to the legs and feet (Taylor & Trefler, 1991). Once the lower extremities are in place, the clinicians position the trunk (the area from the stomach to the chest) along the midline of the chair (Bergen & Colangelo, 1982). Next, the clinicians properly position the head and neck to inhibit abnormal reflexes and maximise visual skills. Finally, the clinicians situate the arms so they do not disrupt head and neck alignment. Also, the arms must be kept from hanging over the sides of the wheelchair which can lead to injury (Cook & Hussey, 1995). Once the clinicians angle the body, they assess the need for restraints and padding requirements from the positioning. Next, the search for a wheelchair recommendation that meets the seating needs and user preferences begins (Delisa & Greenberg, 1990).

This final step in prescription, matching a specific wheelchair to the patient's need, is typically the most difficult task (Berhman, 1990). The wheelchair will essentially become part of the user, and must facilitate his or her daily activities and goals. For this reason, the proper prescription is key and the "comfort, proper fit, and ease of use" can affect the overall quality of the user's life (Nicosia & Philips, 1990). Currently, this matching process is completed manually which requires searching catalogues for chairs with appropriate components. This method has proved inefficient and a more organised system is needed. The recent development of the wheelchair standards by the American National Standards Institute (ANSI) and the Rehabilitative Engineering Society of North America (RESNA) in the United States and by the European Committee for Standardisation require manufactures to keep wheelchair quality high (Axelson & Mclauren, 1990). However, clinicians ultimately need a simplified method to classify wheelchairs according to the deficiencies they accommodate. Researchers suggest that an expert system can address this need by providing a uniform prescription method (Garand & Shapcott, 1996). This project will identify the qualities that need to be included in such a system for wheelchair prescription at the RHNd.

EXPERT SYSTEMS

An expert system is a computer program that uses expert knowledge to attain high levels of performance in a narrow problem area. These programs typically represent knowledge symbolically, examine and explain their reasoning processes, and address problem areas that require years of special training and education for humans to master (Waterman, 1986).

History of Expert Systems

The history of expert systems is very young. In the 1960s the goal was to find general methods for problem solving, and to use them to create general-purpose programs. An example of this type of expert system is its ability to prove theorems (Waterman, 1983). The next focus for expert systems was finding general methods for representation and search methods. These methods would be used to create specialised programs for computer understanding (Jackson, 1990). Expert systems are currently used as extensive, high quality systems with knowledge about distinct problems. The ultimate goal of an expert system is to create a program that will mimic the expert's reasoning in solving a problem, and also reduce human error with a uniform method.

Expert System Overview

An expert system is a program that uses available information, analytical reasoning, and deduction to suggest solutions to problems in a particular discipline ("Expert Systems Come of Age," 1998). Gathering available information with accuracy and completeness is crucial to expert system development, since it is the foundation of the expert system. Analytical reasoning is a problem solving technique used when the alternatives to a solution must be examined ("Expert Systems Come of Age," 1998). The deduction of an expert system is the process of deriving conclusions based on factual information as well as certain assumptions. An expert system must always explain the causes and the rationale behind the conclusion. Therefore, any conclusion made by the expert system must justify its step-wise reasoning. The system is also able to provide advisory and troubleshooting capabilities (Advani, Gudmunson, & Hopkins, 1995). An expert system is ultimately designed to assist less expert staff who would be unsure or unable to give an unaided diagnosis.

There are many different ways of deriving an expert system. It may use case based reasoning, rule-based reasoning, decision trees, or decision tables (Advani, Gudmunson, & Hopkins, 1995; Dugard, File, & Houston, 1993). An expert system based on cases is developed using a random sample of previously diagnosed cases (File, Dugard, & Houston, 1993). This type of reasoning system has the potential to be biased toward more commonly occurring cases. Therefore, it has the potential of diagnosing rare cases incorrectly. However, a rule-based expert system is a set of expert defined rules. This system also allows the computer to assign probability factors to each rule, and can then identify which diagnosis best matches the customer's problem (Advani, Gudmunson, & Hopkins, 1995). These factors (e.g. weights) are assigned to each rule, and as each question is asked, the statistical weights help decide the probability of each event. An expert system can use a decision tree based algorithm, which provides solutions in a flowchart format. However, a downfall to this algorithm is that a specific ordering of the questions asked is necessary (Advani, Gudmunson, & Hopkins, 1995). Yet another type of expert system is the decision table. In this table the list of indicating factors are rearranged in every possible scenario, allowing diagnoses of each individual question (File, Dugard, & Houston, 1993). Each type of expert system has its own advantages and disadvantages. The type of algorithm used in each case must support the type of work that is being done. The one disadvantage for all of the systems is that the knowledge contained within an expert system is constantly evolving, implying that the system must be constantly refined and updated (Advani, Gudmunson, & Hopkins, 1995).

Another type of expert system develops rules of its own. This type of a system is a neural network based on the biological workings of the nervous system. These systems attempt to mimic the interconnections and workings of the neurones of the nervous system (Peretto, 1992). Individually, nerve cells are simple and imperfect in their impulse processing, but working collectively they accomplish complex functions. This is how developers design neural networks. They are made of many simple processors connected to each other by memory variables that automatically adjust as users input new data. The programmers connect the processors in parallel; they connect them in a specific structure so that the system can modify itself in connection strength and processing parameters. The network processes information that the user inputs by pattern recognition or data compression.

Designers classify neural networks by their architecture, that is, by what components the designers connect to other components, and by their learning rules, that is, by what parameters change and how. A neural network is a good candidate for wheelchair prescription because the network learns and develops complex rules on its own by recognising patterns (Cooper & Reilly, 1990). With the high degree of variability in wheelchair prescription, clinicians have difficulty defining clear-cut rules. A neural network approach would eliminate the need for clinicians to clarify the rules. However, only test with actual data will reveal how efficiently the system can develop such rules (Peretto, 1992).

For wheelchair prescription, ARTMAP type neural networks seem most appropriate. ARTMAP is a type of self-organising neural network. Its developers designed the system to be capable of fast and stable learning, hypothesis testing, and output according to input patterns. This enables ARTMAP to pick up rare events or conditions and categorise them into its system without dismissing them. The system utilises fuzzy logic to calibrate confidence levels and develop sets of IF-THEN rules. The rules evolve as users expose the program to new data sets. Users can extract these IF-THEN rules from the system at any stage during the system's learning process (Carpenter & Grossberg, 1989). This would be an important feature if developers used the system for wheelchair prescription. Clinicians may already know some of the rules, but others may be combinations of many variables that clinicians could analyse and incorporate into practice. Developers have specifically designed ARTMAP systems to make predictions among non-stationary circumstances (Carpenter & Grossberg, 1989). Therefore, we feel that this type of neural network may be ideal for the evolving process of wheelchair prescription.

Basic Characteristics of an Expert System

Every expert system must have the basic characteristics of expertise, symbolic reasoning, depth, and self-knowledge (Waterman, 1983). Each system efficiently uses reason to exhibit expert performance at a high level of skill. The system must use symbolic reasoning, which represents the thought process of a human. This is very important because the human mind goes through many steps in making decisions, some of which are very complex. Using symbolic reasoning allows the system to work more like the human thought process, which simplifies the algorithm. The depth of a program needs difficult problem domains to solve problems using a set of complex rules. The last part of an expert system, self-knowledge, involves the ability of the system to examine its own reasoning and explain its operations. This allows the operator to understand the reasoning behind each conclusion.

Some expert systems use fuzzy logic to allow the system to make more complex human-like decisions. Fuzzy logic is a multi-valued logic that allows intermediate values to be defined between conventional evaluations (Bauer, Nouak & Winkler, 1996). In other words, conventional (Boolean) logic is defined as strict binary decisions which have completely true or false truth values, whereas fuzzy logic allows for partial truth. Instead of true and false solutions, it is possible to have degrees of truth defined on a continuous interval from false to true, or numerically, from zero to one. In this way, fuzzy logic allows for computer programmers to program computers in a more human way of thinking (Bauer, Nouak & Winkler, 1996).

Fuzzy logic has many applications and benefits, which include programming an expert system. Benefits of using fuzzy logic as opposed to using conventional logic include simplified and reduced development cycle and ease of implementation. In addition, fuzzy logic can provide a more user-friendly and efficient performance (Bond, 1994). It would be beneficial to use fuzzy logic to program an expert system for wheelchair prescription because wheelchair prescription is not a defined and rigid process; each prescription is unique to the individual. The rules involved in wheelchair prescription are highly complex and dependent on multiple variables. Fuzzy logic offers a comparable way to represent these rules when programming.

Steven A. Garand and Nigel Shapcott of the University of Pittsburgh have attempted to develop a computer-based expert system for the prescription of wheelchairs. The developers designed the Computer Aided Wheelchair Prescription System (CAWPS) as a standard prescription process. Ideally, it will aid the clinician in determining the most appropriate combination of wheelchair features that best match the user's goals. The developers claim that it makes prescription more time-efficient by its generation of written reports and its quick access to "current, accurate, and standardised" wheelchair information (Garand & Shapcott, 1996). Unfortunately the developers ran out of funding and were unable to finish the program. If finished, the program would use algorithms to deduce appropriate wheelchairs in three steps. First, the program would prompt the user to answer questions that will establish the client's goals. Next, from these goals the program would develop an ideal model wheelchair that is represented in graphical format. Finally, the program would use a systematic approach derived from the ANSI/RESNA wheelchair standards and opinions from leading experts to rate existing wheelchairs on their similarity to the model chair. The program would display results in a graphical format which could be printed (Garand & Shapcott, 1996). Recently, the developers have attempted to add digital video to help clarify the contents of the goal specific questions (Walker & Shapcott, 1997). Currently the program is only able to ask the questions geared at the client's goals and organise the answers into a report. The system can not actually match a patient need to a wheelchair. Research suggests that the CAWPS program is the only wheelchair prescription expert system available at this time (Garand & Shapcott, 1996). Therefore, the project includes a test of this system at the RHNd.

Knowledge Acquisition

An expert system is created to think and use knowledge like an expert would concerning a specific task. There are many crucial factors that go into solving a problem, making it difficult to transform the criteria for decision making into a program.

One of the most important aspects of developing an expert system is knowledge acquisition (Kidd, 1987). Knowledge acquisition is the process of extracting information from the expert, and translating it into a program or guidelines for the expert system's problem solving base. The success of an expert system is dependent on the knowledge acquisition stage of expert system development (Prerau, 1990). If the information obtained from the expert is incorrect or incomplete than the expert system will not have evaluated all of the appropriate criteria for solving the problem, and will produce the wrong solution.

David Prerau (1990) uses the example of waiting at a red light in a car as a simple illustration of knowledge acquisition. Prerau presents the possible dialog that the expert and the knowledge engineer may have under the circumstances of knowledge acquisition. In one instance the knowledge engineer asks the expert to describe the decision making process once the light turns green. The expert replies that he would accelerate forward. The knowledge engineer must further inquire about restrictions that would prevent the expert from accelerating forward. Some examples of restrictions may be if there is a left-hand turn only sign, if a pedestrian is crossing the road, or if a roadblock is up. This simple example highlights the many considerations one may have when making a simple decision (Prerau, 1990).

Knowledge acquisition is a complex stage in the development of an expert system and there are many different approaches to this process. One approach used by Thomas Gruber (1987) is to separate knowledge into two categories: strategic knowledge and substantive knowledge. Strategic knowledge is knowledge used to make a decision when the future effects of the decision are unknown, which differs from substantive knowledge where the outcome is defined and definite. Substantive knowledge is based on rules. For example, an IF-THEN statement would be substantive knowledge. The knowledge is subdivided in order to eliminate representation mismatch, which is the difference that occurs between the knowledge expressed by the expert and the representation of knowledge allowed by computers (Gruber, 1987). The difficulty arises when the expert tries to formulate his strategic knowledge in an acceptable format for use in an expert system (Gruber, 1987).

Some general guidelines for knowledge acquisition were proposed by Prerau (1990) regarding knowledge acquisition meetings. The meetings should be held in the expert's domain before and after observing the expert perform the specific task. This is so questions can be asked about the task before observation and then again after the observation. The expert should be easily accessible, be able to provide uninterrupted meetings, and be able to articulate the actual process in understandable terms for the observer (Prerau, 1990).

The process of knowledge acquisition begins with the expert describing a general overview of the task (Prerau, 1990). The general overview allows the knowledge engineer to become familiar with the work involved. The expert should then break the task into subtasks that are described thoroughly with precision (Prerau, 1990). The task as a whole should not be tackled in one meeting, but instead be broken up into subtasks that are addressed at different meetings.

Throughout knowledge acquisition, information extracted from the expert should be documented when found and continuously cited throughout the process (Prerau, 1990). Documentation is the primary tool used in the development of an expert system, so it may be helpful to have other experts verify the process and the terminology used (Prerau, 1990). The documentation provides clear descriptions of the procedures with lengthy titles for the subtasks and is updated continuously throughout the knowledge acquisition process (Prerau, 1990). The information obtained in knowledge acquisition should not only simulate the expert's thought process but complement the expert, because human reasoning does have weaknesses (Kidd, 1987).

Acquiring knowledge is a lengthy and involved process, but there are software tools available to aid in knowledge acquisition. Depending on the domain of the expert system and the problem solving method being used there are a variety of knowledge acquisition tools. A hierarchy of application task categories is represented by Kitto and Boose (1987) which allows for easy determination of the acquisition tool that is appropriate given the type of knowledge based reasoning.

Expert System Implementation

The next topic of research is devoted to how people would react to the expert system for wheelchair prescription. This topic focuses on the organisations that provide political support for the disabled, special interest groups, and the people who have to use the expert system. How will these groups react to the new system and what kind of impact will their reaction have on the use of the expert system? First, we will discuss the topic of interest groups, in particular the interest groups of Great

Britain.

Wilson (1990) discusses the relationship between interest groups in the United Kingdom and politicians, and why this relationship is beneficial for both groups. The government in Great Britain generally consults interest groups and special organisations about policies, even though they are not required to do so under the law (Wilson, 1990). In the United Kingdom, resources are not available to politicians that allow them to educate themselves on policy proposals, so the politicians rely on the interest groups to help evaluate the policy proposals.

Not only do the interest groups inform the politicians but they also add "legitimacy to government policies" which are approved by the interest groups themselves (Wilson, 1990). This allows for the government to avoid any unfavourable action that could result from an uninformed decision. This relationship is beneficial for both groups, the interest groups possess the knowledge to implement working policies and the politicians hold the power to enforce the policies.

An expert system for wheelchair prescription would help to make the process for patients with neurological disorders more convenient and accurate for them. If the system proves successful, interest groups would support such a system because of its invaluable aid to the people affected by disabilities. If this were the case then the interest groups may be able to push for further development. However, an expert system cannot be implemented if the people who need to use the system choose not to use it because it is complicated.

Once an expert system is implemented, how will people who have to use it in their job react to it? The management in the Florida Department of Motor Vehicles implemented an expert system for use in determining the appropriate disciplinary actions for a variety of employee offences. This example suggests several "lessons" that are useful to keep in mind when designing and implementing an expert system that replaces human decision making. The findings suggest that support of the expert system by the senior management in the agency was a crucial factor for determining the use of the expert system (Berry, Berry & Foster, 1998). In addition, when designing the expert system, the user must be kept in mind. Since there is some apprehension when any new computer system is implemented, the system must be user friendly (Berry, Berry & Foster, 1998). The authors are suggesting that people will be more likely to use the system if it is easy to use, and they are introduced to it in an informative way. A key tactic used to increase acceptance of the expert system is to involve the individuals who will use the system in the designing process through feedback from those individuals (Berry, Berry & Foster, 1998).

CONCLUSIONS

An expert system could prove very useful to the prescription of wheelchairs to patients with neuro-disabilities. There are an increasing number of wheelchairs available on the market today, all with a variety of accessories that make each one unique. This allows the recipient of the wheelchair to choose one that is ideal for his or her specific needs. Choosing a wheelchair proves to be very difficult due to two important factors, the first of which is the number of available wheelchairs (Shapcott, 1997). As new models of wheelchairs enter into the already large database, it becomes increasingly difficult to find the perfect model for each user. This brings on the second problem, which is the possibility of prescribing a patient the wrong wheelchair (Shapcott, 1997). This incorrect diagnosis could be potentially harmful to the recipient, because there is a substantial possibility of damage resulting from a poor assessment (Silcox, 1995).

The number of people in unsuitable wheelchairs indicates that standards of wheelchair assessment, prescription and advice are inadequate. Twelve percent of the Britain's 400,000 wheelchair users have special seating needs, which results in a large number of wheelchair prescription mistakes (Silcox, 1995). An expert system could help to simplify wheelchair prescription and enable clinicians to be more responsive to the patient's other needs (Pasternack, 1998).

SUMMARY AND APPLICATIONS OF PRELIMINARY RESEARCH

The preliminary research consists of three main topics of interest: neurological disorders, wheelchairs and wheelchair prescription, and expert systems. The purpose of the preliminary research was to gain understanding of each of the three topics listed. The research topics equipped us to evaluate the expert system needs for wheelchair prescription at the RHNd.

Since the RHNd treats patients with neuro-disabilities, the first topic under investigation was neurological disorders. The study conducted on neurological disorders provided information on how the disorders effect a person afflicted. It focused on Muscular Dystrophy (MD) and Multiple Sclerosis (MS) because they are two of the most commonly treated disorders at the hospital. In researching MD and MS, we wanted to know why wheelchair prescription was particularly important to patients with neurological disorders. We found that neurological disorders slowly deteriorate patients' ability to control their muscles, resulting in a slow loss of function and mobility. Patients who are afflicted by a neurological disorder need to be constantly re-evaluated, since their condition changes slowly throughout their lives. Consequently, every few years they may need a different or updated wheelchair, which means they need to have a wheelchair prescribed on a regular basis that fits their current needs. The task of wheelchair prescription can be made more accurate and convenient by an expert system, which will improve the quality of life for patients with neurological disorders.

Our second topic of research focused on wheelchairs and wheelchair prescription. The wheelchair aspect of the research was to explore the different types of wheelchairs that are currently available. It is also important to understand why so many different types of wheelchairs exist. This enables us to see why wheelchair prescription is such a lengthy and specialised process. The information obtained from our research aided us in defining the basic criteria of wheelchair prescription to find out what factors make a wheelchair unique to each individual. We found many different types of wheelchairs for patients with neurological disorders. In addition, there are many features designed and made specifically for an individual. With such a variety of wheelchairs available, the process of prescribing the correct wheelchair for an individual has become quite complex.

We investigated wheelchair prescription because we wanted to learn how people currently prescribe wheelchairs in the absence of an expert system. It is important to locate the difficulty in the wheelchair prescription process so we can determine the appropriate function for an expert system within the process. In addition, an expert system can also simplify the process of wheelchair prescription. We know the criteria experts use to prescribe wheelchairs and used the established criteria for application in an expert system.

Finally, the research focused on expert systems. The importance of expert systems to our project lies within the problem statement. For this reason, we needed to know what expert systems are and how they are developed. Secondly, we needed to know if there are any existing expert systems for wheelchair prescription. There are many types of expert systems with a multitude of applications. To gain a general understanding of expert systems we investigated the basic characteristics and uses of such systems. We found that there are three main types of reasoning an expert system may use. It may use case based reasoning, rule-based reasoning, and decision trees or decision tables. Another approach is using neural networks to design an expert system. A neural network is a type of system that develops its own rules based on its own pattern recognition. Also, we have investigated a method of computer programming that will comparably be able to represent the complex and undefined rules of wheelchair prescription. This method is fuzzy logic, which is a superset of Boolean logic that uses a continuous range of truth-values allowing for partial truth to exist.

The search progressed further into the development of an expert system, including knowledge acquisition and representation. Knowledge acquisition deals with the problem of extracting knowledge from the expert and translating it into a systematic process that will be used by a computer program. Knowledge representation deals with the problem of taking the knowledge acquired and finding a computer language that will be suitable for representing the task. There are many strategies for solving the problems involved with knowledge acquisition and knowledge representation; the solution depends on the type of decision making process required for the task.

From our research on existing expert systems for wheelchair prescription, we have located an expert system prototype specifically for wheelchair prescription developed by Nigel Shapcott of the University of Pittsburgh. He has developed a computer-based expert system prototype (CAWPS) for wheelchair prescription. Shapcott's prototype is the only computer-based system presently found that has the potential to make an actual wheelchair recommendation (Garand & Shapcott, 1996). Although a paper-based assessment form is what the RHNd currently use, this system is not sophisticated enough to match the patient's need to a specific wheelchair type. A paper-based system may be appropriate, but we would like to eliminate most of the human error involved in such a system.

III. METHODOLOGY

OBJECTIVE

The objective of our project was to simplify the highly involved process of wheelchair prescription by taking the initial steps in the development of an expert system and making recommendations for future development. To accomplish this task we analysed the current system in use at the Royal Hospital for Neuro-disability by shadowing the prescription process. We also interviewed the clinicians at the hospital to get their opinions on wheelchair prescription, which helped us to determine exactly what an expert system must be able to provide. We have already researched the current expert systems in the United States and determined that no existing expert systems fulfil the needs of the hospital. From this research we found it necessary to recommend to the RHNd the need for a custom designed expert system.

PROCEDURE

We have shadowed Wheelchair Clinic, interviewed clinicians, and tested a prototype system, to identify the expert system needs of wheelchair prescription for neuro-disability patients at the RHNd. First, we gained a basic overview of Wheelchair Clinic to see how the clinic functions as a whole. Then we shadowed actual prescriptions to get a better understanding of the decision-making process involved in prescribing wheelchairs. While we gained a general understanding of how the clinic and the prescription process works, we interviewed the staff involved in prescription to identify the general rules clinicians use when they prescribe wheelchairs and the inefficiencies in the process. Lastly we tested Nigel Shapcott's CAWPS program and received the Wheelchair Clinic team's feedback on it. Each of these methods provided us with a better understanding of the prescription process and aided in our recommendation of an appropriate expert system for the RHNd.

Process at RHNd

Upon arrival at the RHNd, we became acquainted with the staff of the Wheelchair Clinic and began to set up formal interview times for the following week. In setting up the interviews we used purposive sampling, in which researchers use their special knowledge to select subjects who represent the population being studied (Berg, 1998). In addition, we used reference sampling so that we could interview the key clinicians involved in the prescription process and produce a more accurate set of guidelines (Berg, 1998). In the interviews, we asked for a basic overview of their current procedures for prescribing wheelchairs to patients. It was necessary for us to become familiar with their current procedures in order for us to determine the type of expert system that will best suit their needs. In addition, shadowing helped us understand the wheelchair prescription process, by seeing what they are doing and why they are doing it. Again, we used a purposive sampling technique in the shadowing of the prescription process. We also took into account the major aspects of the patient assessment form that they use to help determine the proper wheelchair for each patient. We then followed up on the results of the interviews and shadowing sessions with secondary questions we administered in the form of a questionnaire.

Interviewing

In interviewing clinicians, our task was to determine what an expert system must be able to provide. We conducted interviews with all members of Wheelchair Clinic, occupational therapists, physiotherapists, and seating technicians. We used reference sampling with the members of Wheelchair Clinic by asking them to refer us to other clinicians that they felt were pertinent to the prescription process. These staff members help each of the patients and their families find a wheelchair that suits the physical, environmental, and functional needs of the patient. The interviews allowed the staff to give any input on the expert system as a whole and helped us to determine the most important steps in the prescription process. Since our goal was to determine exactly what the expert system must be able to provide, we established what each clinician sees as the most important steps in the prescription process.

We designed the interview to obtain a verbalisation of the prescription process from the clinician so that we could produce an accurate outline of the prescription process. We interviewed in teams of two, and recorded each interview with a tape recorder. The second team member took written field notes. We asked the clinicians what they felt were the most important steps in the prescription process, and to indicate any areas they would like simplified. Finally, we left a portion of the interview open for the clinicians to offer any input on topics they felt were relevant or that we overlooked in the interview. Again we rewrote our observations directly following the interview to insure accuracy.

In our analysis, we conducted a visual comparison to look for similar perspectives on the improvement of the prescription process. We analysed this information by creating a flowchart of their procedures that is representative of both the information obtained from the interviews and the shadowing sessions (see Appendix E).

Questionnaire

We conducted follow-up interviews, in the form of a questionnaire. We changed the format of the interviews to allow the clinicians more time to answer each question thoroughly. We chose the clinicians by using purposive sampling based on their responses from the interviews. These questions were more specific in nature; they dealt with the prescription of only six types of wheelchairs. The chairs chosen for the questionnaire were the Shadow (Matrix seating), the Cirrus, the PAP, the Carters Recliner, the Action 2000, and the 8L/9L/Apollo. Specifically, the technical staff chose the chairs because they are the most commonly prescribed chairs by Wheelchair Clinic and the chairs can accommodate a varying severity of muscle deformity.

We designed the questionnaire to accommodate the prescription of the six wheelchairs chosen by the technicians. Each of the six chairs provide different levels of postural support and satisfy the needs of different physical deformities. These deformities range in complexity from partial function control to complete loss of function. For example, the matrix-base seating system will support a patient that has no function control. In particular, the matrix-base seating offers the most complete support for any patient. However, matrix-base seating is very expensive and therapists must justify the patient's need for prescription to the funding authorities. Often, a less expensive chair can provide adequate support. Therefore, the therapists only prescribe matrix seating for patients with severe physical deformities.

In the preliminary interviews, we discovered two prime aspects of wheelchair prescription that we used as the basis for our questionnaire. The first aspect concerns adaptation compatibility with a wheelchair type. Each wheelchair type is only compatible with certain adaptations. For example, matrix seating fits the Shadow, Carters Recliner, and PAP frames. Therefore, we can eliminate the three remaining chairs, the 8L/9L/Apollo, Cirrus, and Action 2000, because they are not compatible with the matrix seating system. (We indicate all compatible adaptations for each chair in Appendix B.) The list of adaptations helped us to determine correct questions for the questionnaire.

The second prime aspect of wheelchair prescription is that therapists choose the seating mechanism first by the patient's physical and postural needs. We discovered from our preliminary interviews that the physical and postural needs of the patient are the primary concern in prescription. The therapist will never compromise these needs in a prescription. Therefore, we first asked questions concerning the physical and postural reasons for prescription and then asked for secondary factors that affect prescription. Such secondary factors include funding, environmental, and primary care provider needs.

We divided the questionnaire into sections based on the supportive properties of the seating mechanism. We began the questionnaire with a group of questions about the seating system that provides the most postural support, the matrix. Within this section, we first asked questions concerning the physical and postural reasons for prescribing or not prescribing the seating mechanism and wheelchair frame. Then we asked questions concerning the secondary reasons for prescription. In this way, we were able to identify the wheelchair frames that are compatible with the seating mechanism that offered proper physical and postural support. We further narrowed the selection of appropriate chairs by
assessing their ability to fulfil the secondary needs of the patient. We used the information obtained from the questionnaire to create some basic rules for prescribing the six chosen wheelchairs.

Shadowing

Once we obtained a basic understanding of Wheelchair Clinic's current procedures, we began to shadow wheelchair prescriptions. Shadowing involved observing the members of Wheelchair Clinic develop a wheelchair prescription for a patient, while noting the criteria that the clinician uses to make his or her determination. Shadowing allowed us to make our own interpretation of their prescription process, instead of relying only on the information they told us.

Shadowing provided an opportunity to observe each clinician's decision-making process, which helped us to recommend an expert system we felt was appropriate. Ultimately, we created a flowchart and a set of guidelines of their procedures that is representative of the information we obtained from both the interviews and the shadowing sessions.

In shadowing the prescription process we took notes using four of Berg's (1998) five strategies for recalling data. We chose to omit the fifth strategy, which is to limit the time spent in the setting because it is necessary for us to be present for the whole prescription process. During the shadowing sessions, we first recorded key words and phrases used by the clinicians to describe the prescription process. Since key words and phrases trigger the memory, they lessened the effects of memory erosion (Berg, 1998). Second, we took notes that indicated the sequential order of events during the observation. By taking notes in sequential order we increased our ability to recall each detail of the process (Berg, 1998). Our third and fourth steps required us to rewrite all observations directly after the shadowing session and to avoid interaction with other members of the project team before recording our observations. This decreased any bias that may have occurred during discussion with other members of the team. This method ensured that we accurately recorded our observations.

Testing Existing Systems

One of the main objectives of this project was to review the wheelchair prescription aids and any existing expert systems developed in the U.S. After searching for such systems we were able to find one such computer-based program and several paper-based and computer-based prescription aids. However, we found that only one expert system actually exists for wheelchair prescription. The Computer Aided Wheelchair Prescription System (CAWPS) developed by Nigel Shapcott and

Steven Garand is the only system that has the potential to match a patient profile to a specific wheelchair type (Garand & Shapcott, 1996). Paper-based and computer-based prescription aids exist, but they only provide a framework for gathering and organising patient information. Since the Wheelchair Clinic staff does not know exactly what they require in an expert system, we brought both types of systems with us to London. From our initial assessment of these systems it does not seem likely that any will fulfil all the special needs of Wheelchair Clinic, because the RHNd deals specifically with patients with neurological disease. The systems we brought over were too generalised for the hospital's patients. For this reason, we introduced the CAWPS program to the clinic staff and allowed them to test it out and voice their opinions. We felt that a purposive sampling technique was best for this method. Again with this technique, we desired explicit information from specific people, so we did not use randomisation to select respondents (Berg, 1998). We needed to find out the clinic's impression of the prototype, so we asked the clinicians directly for their feedback.

Paper-based assessment forms are essentially forms that aid in data retrieval and organisation. They are designed to integrate data from the medical, therapeutic, functional, and environmental aspects of a user's life and act as guides for the clinician to develop a clear action plan. They simply organise the information obtained from a patient assessment. Wheelchair Clinic already uses such forms, so a brief review by the staff should be sufficient to evaluate the forms. Due to time constraints, we were only able to show the paper based assessment forms that we brought from the United States to our liaison Dr. Cousins. However, Wheelchair Clinic was in the process of refining a new assessment form, created by primary members of the Biomedical Engineering department. We were able to observe their focus group meeting in which they discussed the pros and cons of the new form. We took notes during this meeting and then we recorded full field notes directly after the meeting. We synthesised the field notes from the session into a list of the improvements suggested by the group members during the meetings. By providing us with information on their own assessment form, the staff's analysis helped us determine what must be included in an expert system.

The CAWPS computer program not only organises the patient information, but also has the potential to match it to an ideal wheelchair model. Since this program is more complex than the paper-based systems, there are more aspects of the computer-based system that we can analyse. Initially, we introduced the system to the staff collectively and explained to them what it does and how it works. We then allowed them to try out the prototype in our presence. During the trial period, we found out what the staff particularly liked and disliked about the system and we incorporated this feedback into our final recommendations. We found from the trial period that the system is not feasible in Wheelchair Clinic, but there is still valuable data to be learned from the expert system.

Both the paper-based and computer-based systems have pros and cons. In fact a combination of the two systems may be the ideal choice for the RHNd. Consequently, an analysis of each model helped us determine what type of system will best fulfil the specific needs of the Wheelchair Clinic team.

Analysis

Once we collected the data from the prescription shadowing sessions, the clinician interviews, the questionnaire, and the existing system trial, we determined the components of an ideal expert system for Wheelchair Clinic. Since we used four different methods to determine the needs and preferences of the clinic team, we feel that we acquired an accurate perception of this ideal system. This triangulation, or use of multiple methods, helped to eliminate bias (Berg, 1998). Also, we used each method to find the qualities that an ideal expert system must possess. We then determined which qualities were the most crucial to the clinic by assessing which needs clinicians stressed repeatedly in the shadowing sessions, interviews, and the prototype test. From this analysis, we determined that none of the existing systems fulfilled the needs of Wheelchair Clinic. Then, we defined additional requirements of a custom system and what type of expert system can best address these special needs. Also, we determined at what point in the prescription process the implementation of such a system would be most appropriate. In addition, we suggested that the system address the concerns raised in the clinician interviews. Finally, we drew conclusions about what we felt an ideal system must be able to do. Before we offered our solutions to the RHNd we reviewed the information gathered to ensure we had resolved any incongruencies in our recommendations. Consequently, we presented the data and analysis clearly and accurately so the clinic can reference the material when making future decisions.

IV. DATA AND ANALYSIS

INTERVIEWS

We have collected data on the inefficiencies in the prescription process and the qualities that the RHNd requires in an expert system through interviews, shadowing sessions, and evaluating existing expert systems. We began our data collection by interviewing key members of the staff involved in the wheelchair prescription process. We conducted one wave of purposive preliminary interviews using reference sampling to choose our respondents. Simultaneously, we shadowed Wheelchair Clinic to obtain data on the interactions between the technicians and the therapists in the wheelchair prescription process. Next, we used the results of the preliminary interviews to create a questionnaire that we distributed to the respondents most active in the wheelchair prescription process. Also, we introduced the existing expert system to the staff and attended the focus group meeting concerning the assessment form. Then, we evaluated the qualities that the staff found beneficial and those which were a hindrance. The qualities helped to determine the appropriate types of expert system for the RHNd.

We conducted preliminary interviews with occupational therapists, physiotherapists, technical staff, the Wheelchair Clinic team, a social worker, a neurologist, and a psychologist. We identified the different roles and knowledge that each person contributed to the process of prescribing wheelchairs. The physician administers a neurological evaluation to new patients before the wheelchair prescription process can begin. The social workers primarily deal with the patients in the rehabilitation wards and act as a link between the family of the patient and the hospital. Then the psychologists evaluate the patient's cognitive ability. The occupational therapists and physiotherapists work closely together to assess the patient's postural and physical needs. Then, the therapists use trial wheelchairs and adaptations to determine the most appropriate wheelchair that provides the correct postural support. Based upon the physical assessment and trials, the therapists bring the patient to Wheelchair Clinic and present their findings to the team of specialists. The clinicians then decide if they agree with the therapists' recommendations or if they have any further trial suggestions not considered by the therapists. The technical staff is involved in designing and constructing the special adaptations to the wheelchair.

Two out of the three group members conducted the interviews; one group member would ask questions while the other recorded observations. We recorded and transcribed the information directly following the interview. We analysed the information gathered from the preliminary interviews, looking for common responses. We performed a content analysis, by extracting the core response to the question asked and then entering it onto a spreadsheet. The result was a matrix charting the core responses given by the staff. Then, we highlighted the primary and secondary responses to view the most common answers given by the clinicians. The spreadsheet and interview questions appear in Appendix D. From this spreadsheet, we were able to uncover some of the existing inefficiencies and the basic principles involved in wheelchair prescription. We also used the content analysis to organise a flow chart depicting the prescription process (see Appendix E). In addition, our spreadsheet revealed the common agreements and disagreements among staff.

We discovered that the primary considerations when prescribing a wheelchair are the physical and postural support needs of the patient. A therapist's main objectives are to prevent any further progression of deformity and to avoid pressure sores. The therapist can achieve this objective by providing proper support and positioning for the patient in the wheelchair. This is a crucial factor for patients of the

RHNd because irregular muscle tone and skeletal deformities are commonly associated with neurological disorders. Secondary considerations in wheelchair prescription are the functional and environmental needs of the patient. Functional needs include the ability of the patient to manoeuvre the wheelchair and the practicality of the chair as a form of transportation. Environmental needs include the size of the wheelchair, the weight of the wheelchair, and ease of operation. Environmental needs result from the restriction imposed upon the patient to operate the wheelchair due the environment. Such restrictions would include the width of the doorways or the hallways in the patient's home. These secondary needs are important when deciding on the type of wheelchair because the chair must be compatible with the patient's life style in order to serve as an aid to the patient. The current assessment form used at the RHNd to aid in wheelchair prescription incorporates these primary and secondary considerations.

We also found three main considerations that are not presently on the assessment form but the clinicians include in their decision making process during wheelchair prescription. These considerations include the primary care provider's needs, the funding issues, and the future placement of the patient. It is essential to consider the primary care provider's needs because he or she will be the main facilitator of the wheelchair. For example, if the wheelchair is difficult to operate or if the wheelchair is too heavy then the primary care provider will not be able to provide suitable care for the patient while in the wheelchair. For instance, the primary care provider may not be able adjust the settings on the wheelchair for proper positioning or may not be able to push and stop a heavy wheelchair. Funding is an important issue involved in the prescription process because without enough funding the patient will not be able to have the prescribed wheelchair. If clinicians prescribe a certain wheelchair and funding is not a consideration, the hospital may have to search for funding from private organisations, which is often a long and difficult process. Often the clinicians prescribe a wheelchair without considering the future placement of the patient, which is due to the fact that future placement is unknown to the patient and family. However, future placement can affect the prescription, because a wheelchair must be suitable for the patient's environment. Specifically, an indoor wheelchair would be inappropriate if an individual was eventually going to be travelling outdoors.

Our interviews uncovered two main sources of inefficiency in the prescription process. The first is that beyond the assessment form, the clinicians at the RHNd do not use an organised approach for wheelchair prescription. The clinicians use the assessment form as a guide for extracting the vital patient information needed for a proper prescription. The clinicians agree that the assessment must begin with positioning the trunk of the patient. However, after that point the clinicians begin to disagree about the next step. The clinicians can either move up or down the patient's body positioning the patient in the seat. An organised approach to the process would allow for a more time efficient and standardised prescription.

The second inefficiency concerns the wheelchair loan system at the hospital. Part of the assessment is to test the patient in the recommended wheelchair to see if the chair will meet the postural needs of the user. The clinicians borrow the trial chairs from the hospital's loan supply. The loan system is inefficient because the supply is limited with respect to the types and number of available chairs, and use of the trial chairs is not monitored. The clinicians find it time consuming to locate the chairs and to wait for the chair to become available for trial. Also, if the hospital does not have an appropriate chair in their loan stock it takes weeks to get a trial chair from an outside wheelchair service. Some clinicians believe that a seating simulator would help to alleviate some of the problems with the loan chair system by providing the therapist with vital information on positioning and accurate measurements. Specifically, a seating simulator is an instrument that finds a patient's ideal wheelchair specifications and adaptations by positioning him seated in the simulator. The seating simulator would not eliminate wheelchair trials but it would decrease the time spent on evaluating unsuitable wheelchairs.

Our preliminary interviews indicate that the clinicians involved with the physical and postural assessment of the patient rely on the Biomedical Engineering department to keep informed about available wheelchair technology. Consequently, this creates a knowledge gap between the physical aspect and technological aspect of wheelchair prescription. The physiotherapists and occupational therapists work closely with the patient completing the assessment form and conducting wheelchair trials. Members of the technical staff work closely with the wheelchairs, so they know the available technology and the compatible adaptations. Therefore, the therapists know what the patient needs the wheelchair to provide physically, and the technical staff know what each chair can provide for the patient. The problem arises with communication between the two groups. The only formal interaction between the therapists and the technicians occurs at Wheelchair Clinic.

From the interview questions, we have found that the staff at the hospital feels that an expert system will be a beneficial aid to the prescription process. However, the staff also voiced concerns about the implementation of an expert system. Some clinicians feel that the use of an expert system should only be as a tool that would serve as a guide to assure a correct prescription. Others feel it should be a quality control device used to confirm the clinicians' judgement. In both cases, the clinicians are concerned with the expert system taking the place of the therapist's judgement. The main concern with an expert system is that it needs to make the process more efficient and does not further complicate the patient assessment.

QUESTIONNAIRES

The information and feedback we obtained from our preliminary interviews suggested that we should change the format of our data collection. We developed a more precise questionnaire to identify the circumstances in which clinicians prescribed certain wheelchairs. The questionnaire allowed the clinicians more time to think about the questions and to answer thoroughly. The technical staff selected six commonly prescribed wheelchairs to narrow the knowledge base. The chairs selected consist of the Shadow (Matrix based), the Cirrus, the PAP, the Carters Recliner, the Action 2000, and the 8L/9L/Apollo. Then, we chose ten out of the twenty interview candidates to complete the questionnaire based on their experience and knowledge of the prescription process. The preliminary interviews asked general questions to indicate the role and position each person held in the prescription process. We were able to determine from the preliminary interviews which clinicians had a thorough understanding of the process. We selected the candidates based on the completeness of their interviews. If respondents were unable to answer any interview question concerning the prescription process, we eliminated them from the questionnaire selection. From the remaining clinicians, we then selected an equal number of physiotherapists, occupational therapists, and technical staff members to complete the questionnaire.

We distributed the questionnaire to ten staff members and allowed each person one week to complete it. We received eight out of the ten questionnaires to analyse. From these questionnaires, we defined the reasons for prescription of different seating mechanisms. We began with the physical and postural reasons given by the therapists. Every reason stated by the therapists in our questionnaire is valid because each one of the therapists currently uses this reasoning when prescribing wheelchairs. Therefore, we included each reason stated on the questionnaire as a valid reason for prescription. Unfortunately, this fact posed a problem with analysis. We decided to list all reasons for prescription in Appendix F, however, we will only discuss the most commonly agreed upon reason in the analysis. Consequently, we have decided that the reasons that most clinicians agree upon are the most clearly accurate.

The first question concerned the postural reasons for prescribing Matrix seating. The results of our questionnaire indicated that seven out of the eight therapists prescribe a Matrix seating system when the patient is rated "unplaceable" on a Chailey seating scale. This means that the patient is unable to support himself in an upright position and resist gravity. The second question asked for postural reasons for prescribing the tilt-in-space seating mechanism. Six out of the eight therapists agreed that they prescribe a tilt-in-space when the patient requires forward positioning for a stand transfer. In addition, the tilt-in-space offers dynamic seating which allows for upper limb activity, orientation, and resting. The next question regarded reasons for prescription of the reclining back seating mechanism. Four of the eight therapists agreed that they prescribe the reclining back seating system when only one seating position is necessary but relief from gravity is required. The last question based on the seating mechanism referred to the standard wheelchair seat. Six out of the eight respondents answered that they would prescribe a standard seating mechanism when the patient is active and can remain balanced in the sitting position unsupported for long periods of time.

We based the next section of questions on propelling mechanisms. The propelling mechanism depends on a patient's physical and cognitive ability. However, in some cases it may depend on the primary care giver's needs. We began this section with a question on the prescription of self-propulsion. The physical reason given by three out of the eight therapists for prescription of self-propulsion is when the patient has good upper-limb strength and function in joints, arms, and hands. The second question probed for the physical reasons for prescribing power control. Two out of the eight therapists prescribed power control when the patient has control of their environment, demonstrates independence, and possesses motor control. The last question in this section dealt with power assist. Power assist is a motorised aid to help the caregiver propel the wheelchair. The only physical reason for prescribing power assist, given by one therapist, is when the patient is only able to self propel short distances and easily fatigues. However, six out of the eight therapists responded that they would prescribe power assist if the home environment were hilly or sloped.

We also included in each section other considerations involved in prescription. This section allowed the therapists an opportunity to state reasons other than physical that might affect the prescription. One consideration was the prescription of foam carve as an alternative to the matrix seating system. Seven out of the eight therapists would prescribe foam carve because it is cheaper and less labour intensive than the matrix seating. However, one clinician stated that she would rather prescribe matrix seating because it is more adaptable than foam carve. Another consideration, for prescribing power control, is when the patient's sight and special awareness are intact. Three out of the eight respondents agreed that they would not prescribe power control if the patient's sight and spatial awareness were impaired.

The remaining considerations in wheelchair prescription involve the wheelchair frames. We represented these considerations as positive and negative factors for prescribing each wheelchair. We subdivided both positive and negative sections into physical, environmental, funding, and primary care provider elements of prescription.

Again, in this analysis it is important to note that the primary concerns of the therapists are to fulfil the patient's physical and postural needs. We display the results of this analysis in Appendix F.

The first wheelchair we analysed is the Shadow, which can accommodate the matrix seating system. From the questionnaire, therapists indicated a negative physical aspect of the Shadow is that it does not have a split back. Environmentally, the wheelchair may be too heavy or bulky, which may result in difficult transport. In addition, the wheelchair may be too heavy for the primary care provider to manoeuvre. The wheelchair is expensive but if the therapists can physically justify the patient's need for the wheelchair then the wheelchair service will fund it. Moreover, the wheelchair is more effective over a period of time than comparable bases, which may help to justify prescription. However, the Shadow wheelchair is usually the base of choice for matrix seating. Also, the wheelchair has adjustable height push handles and power control adaptations that make pushing the chair in the reclined position easier.

The second wheelchair we took into consideration is the Cirrus. The Cirrus wheelchair cannot be prescribed for patients over 5'10'' because it will not provide adequate seat depth and width. A negative environmental feature of the wheelchair is that it is large and requires turning space that many houses and buildings cannot accommodate. This may pose a problem if the patient's primary environment has narrow corridors. In addition, the wheelchair is expensive and the health authorities may not approve funding because the Carters Recliner is comparable in function but approximately £1000 less in cost. Another factor that may influence the clinician's prescription is that family members may alter the tilt-in-space mechanism which could lead to safety issues. Although, the tilt-in-space mechanism is the same feature that therapists frequently use as the reason for prescribing the Cirrus over the Carters

Recliner.

The third wheelchair we considered is the PAP. The PAP does not physically supply much lateral or sacral support for the patient. However, the wheelchair does have a removable back for better positioning of the patient. The wheelchair is only for indoor use and most wheelchair services will not supply funding for it. Furthermore, the wheelchair is heavy and bulky and may be difficult for the primary care provider to push. The wheelchair has the ability to accommodate matrix seating and is less expensive than the Shadow. Therefore, clinicians may prescribe the PAP instead of the Shadow.

The Carters Recliner, the fourth chair that we analysed, provides reclining options but does not have a tilt-in-space mechanism, which some clinicians would prefer in order to change the position of the reclined patient. The wheelchair is large and makes transport difficult because of its high headrest. In addition, the wheelchair is heavy to push for the primary care provider. However, the wheelchair is both easier to manoeuvre, and lighter in weight, than the Shadow. In addition, the chair can accommodate matrix seating and wheelchair services may request the Carters Recliner over the Shadow if funding is severely restricted.

The fifth wheelchair we considered in the questionnaire analysis is the Action 2000. The Action 2000 has a low back and does not provide enough support for the patient in the recline position. Furthermore, the wheelchair is not sturdy for difficult terrain and the push handles are not adjustable. This may make pushing by shorter or older people difficult. However, the wheelchair does have small removable armrests that facilitate transfer. The primary care provider and patient may prefer this wheelchair instead of the Carters Recliner because of its aesthetically pleasing appearance.

The sixth wheelchair is a standard style base available in a manual and motorised version. The 8L/9L are standard manual wheelchairs, which are sometimes too heavy to self propel and are not easy to manoeuvre in small environments. These wheelchairs are still the same price as more fashionable models and are heavier than other models. However, clinicians often prescribe the 8L when the patient can self propel and has good upper-body strength because it has a strong base and sturdy frame. The motorised version, the Apollo, is not an outdoor chair and the movement of the wheelchair may affect its stability.

From the analysis of the questionnaire, we were able to determine some basic principles for prescription of the six wheelchairs selected. From the basic principles we created a flowchart showing the decision-making process clinicians use (see Appendix G). The results are only preliminary and may require modification. If the hospital would like to develop more rules for prescription, we suggest that the hospital hold focus groups.

SHADOWING SESSIONS

In shadowing Wheelchair Clinic, we observed the interaction between the ward therapists and the clinic team when the clinicians are attempting to make a wheelchair prescription. We were able to gain an understanding of what actually occurs at the sessions and how Wheelchair Clinic ties into the prescription process. Through our shadowing sessions we identified four major factors that the clinicians must consider in order to make a suitable and efficient wheelchair selection. In addition, we were able to distinguish where some of the inefficiencies and problems occur during prescription. These observations were included into a flowchart of the prescription process (see Appendix E). Shadowing allowed us to gain an unbiased perception of the prescription process at the RHNd.

Wheelchair Clinic is essentially a forum for the ward therapists to present their progress with wheelchair trials and address any problems with senior therapists and the wheelchair technical staff. The ward occupational therapist and physiotherapist complete a physical assessment and usually wheelchair trials before attending clinic. The therapists provide the clinic team with the results of the assessment and the trials in the assessment form. The clinic team briefly reviews these forms fifteen minutes before clinic. At the start of the clinic session the ward therapist presents a brief history of the patient, discusses problems, and comments on the wheelchair trials. Then we observed that the clinic team asks questions of the therapists that are primarily concerned first with the physical supportive needs, and then funding and primary care provider needs. Next, the therapists bring the patient into clinic to view the patient in the seated position and further assess his or her needs. After further discussion the clinic team makes a recommendation which commonly is a request for further wheelchair trials or a prescription. From these observations, we have discovered that the ward therapists conduct the assessment of the patient's needs and the matching of those needs to a specific wheelchair type. Wheelchair Clinic primarily serves as a quality control advising session where the senior therapists and technical staff discuss problems and funding issues.

The actual discussion during Wheelchair Clinic depends on the objectives, the wheelchair trials, and the problems encountered by the ward therapists, but the clinicians consistently discuss physical factors. We have perceived from the shadowing sessions that the main priority in wheelchair prescription at the RHNd is the physical needs of the patient. We observed the members of Wheelchair Clinic probing the ward therapists about the patient's condition to ensure that the therapist has taken the appropriate measures to prevent further deterioration and provide adequate support.

Whenever a member of Wheelchair Clinic suggests a new wheelchair, the clinic team first discusses if the chair can fulfil the patient's postural support needs. In addition, when presenting the wheelchair trials the ward therapist always discusses how well the trial chairs meet the patient's physical needs. For example, one therapist discussed how the trial equipment was ineffective in controlling a patient's muscle spasms. Thus, the focus of the clinic depends on the progress the ward therapist has made, but the issue of postural support is always a primary concern.

Another major consideration is the funding aspect of the wheelchair equipment. The clinic team is always concerned about what type of funding the patient has, so it can determine how thorough it has to be in its justification of the equipment it prescribes. If the patient is funded by an outside wheelchair service, the clinic team has to make sure they justify every aspect of the chair they prescribe by specifically citing the patient's physical needs and future progression. Moreover, if the patient only has a set amount of funding, the team must seek additional sources of money for expensive equipment. Therefore, we have found that funding directly relates to the patient's physical needs when trying to find a suitable wheelchair. Unless the patient has an abundant amount of funding, the clinic must determine the least expensive wheelchair that can fulfil the patient's supportive needs.

We have also recognised that the environmental factors and the primary caregiver's needs are secondary considerations. During Wheelchair Clinic we noted that the clinic team consistently probed the ward therapists about the patient's family needs and the intended environmental use. These include such things as the ability of the primary care provider to manoeuvre the wheelchair, and wheelchair access to a patient's home. It is important information if the patient's caregiver is going to take the patient away from the hospital for any period of time. We observed that the presence of the patient's primary caregiver was also important to extract this information. Often the clinicians ask the family member about any access restrictions and their transport abilities. The clinicians also provide the family member an opportunity to voice his or her concerns about the patient and the wheelchair trials. However, in one case the family member seemed to be intimidated and overwhelmed by the Wheelchair Clinic. For this reason, it may be better to address family concerns in the initial assessment rather then having the family member attend the actual clinic.

Through our passive observations at Wheelchair Clinic, we have been able to identify areas where the clinicians encounter problems. There exists a knowledge gap between the ward therapists and the available technology. The ward therapists simply do not know enough about the wheelchairs available to determine consistently which wheelchairs are most appropriate for trial. The senior therapists expressed multiple times in clinic that the ward therapists need to be more informed about the specifications of the wheelchairs available and which adaptations are compatible with which wheelchairs. It seems that if the ward therapists had easier access to this information it would eliminate multiple Wheelchair Clinic sessions. The therapist could determine if some chairs are inappropriate because of size restrictions or incompatible adaptations before actually going through an unneeded wheelchair trial. The therapists also expressed concerns about the loan chair system. During the shadowing sessions we discovered that there is very little organisation with the loan chair supply. The technical staff admitted that even they did not know what loan chairs are available at a specific time. As a result, ward therapists are often unable to conduct thorough wheelchair trials due to the limited supply and organisation of the loan chairs.

An additional inefficiency we observed occurs when the therapist representing the patient in Wheelchair Clinic is unfamiliar with the patient. This commonly occurs because the therapists that conduct the assessments on the patients rotate wards every six months. At one clinic, the therapist had just recently acquired the patient and seemed to have very little knowledge about the patient's condition and wheelchair trials. The session was very inefficient and the members of Wheelchair Clinic were unable to get much accomplished. We observed that the ward therapist must have conducted a thorough assessment and wheelchair trials in order for the clinic to run smoothly and make progress towards prescription.

EVALUATION OF EXPERT SYSTEM AND PRESCRIPTION AIDS

After conducting our initial literature review and further research upon our arrival in London, we determined that no functioning expert system for wheelchair prescription currently exists. The one expert system we acquired from Nigel Shapcott which he specifically developed for wheelchair prescription is unfinished. We did, however, continue according to our methodology and evaluate Shapcott's Computer Aided Wheelchair Prescription System (CAWPS) with the members of Wheelchair Clinic. As expected the program could not fulfil the needs of RHNd, but the trials did allow the staff to communicate further what they desire in an expert system. In addition, we identified some other computer systems that are not expert systems, but that may be useful in streamlining the prescription process.

From our evaluations with the assistance of the technical staff and the members of Wheelchair Clinic, it became evident that the only available expert system prototype specifically for wheelchair prescription, Nigel Shapcott's CAWPS program, is unsuitable. However, the respondents expressed that the program did offer some positive features. A few members commented that the point and click aspect of the program was quite easy to use. In addition, they found that the majority of the questions were good for developing a patient profile. Furthermore, the technical staff stated that the warning explanations and the reference sections were quite useful. After viewing the program, the staff realised that creating an expert system for wheelchair prescription is a tremendous task and agreed that the CAWPS program was a satisfactory initial attempt.

The evaluators discovered further problems with the format of the CAWPS' decision tree questions. The staff has concerns about the program's illogical sequencing of questions. All members who evaluated the system dislike the fact that the system jumps from questions concerning physical aspects to questions concerning environmental aspects. They also feel that the system asks the same questions repeatedly. Specifically, the program asks additional questions about the patient's ability to propel a wheelchair when the user had already indicated that the patient could not be self-propelled. Again, after the user had indicated "unknown" for the patient's visual status, the CAWPS program asks further questions about the patient's vision. The clinicians sampling the program were confused as to why the program kept asking the same illogical questions. We discovered another small glitch when the program asks a question concerning future status. It states to "choose all answers that apply," but the program only allows the user to choose one answer. These problems seem to stem from errors in the decision tree design of the program.

The time consumption of the program was another major problem that the clinic team found. The team felt that the program asks questions irrelevant to the specialised environment of the RHNd. For example, the team commented that it was bothersome to answer questions about secondary and tertiary forms of transportation when most patients at the hospital only use one form of transport. The program did not even provide the RHNd's primary source of patient transport, the ambulance, as an option. In addition, the clinicians commented that many of the questions are irrelevant, because the system's reasoning differs from the reasoning used at the RHNd. For instance, the program infers that removable footplates are only important for environmental reasons, such as determining if a wheelchair can fit into restricted environments. In contrast, at the RHNd the clinicians might well prescribe the footplates for a therapeutic purpose, specifically, pressure relief. Furthermore, the clinicians had trouble understanding the terminology in the CAWPS program, because the developers geared the program towards use in the United States. To remedy the need for such questions the clinicians suggested that it would be easier to use a computerised version of their assessment form to input the information. This would insure that the system would only require information necessary to make a thorough wheelchair prescription at the RHNd.

The clinicians expressed that they would like to be able to view and alter the rules and relationships in the system, and the CAWPS program simply does not allow this. The reviewers commented that they would have to update the rules of a system for wheelchair prescription because the reasoning in wheelchair prescription is very unstructured and the wheelchair technology is continually expanding. Consequently, the clinicians feel that a rule-based expert system would be more appropriate for their needs than a decision tree system like the CAWPS program. The unfinished CAWPS program has demonstrated the difficulty in developing a universal system for use in all facets of wheelchair prescription, but the design of a system that only incorporates the wheelchair options available and relevant to the RHNd may be an easier process. From this system evaluation we determined that an expert system would need to be adapted to the specialised treatment and wheelchairs provided at the RHNd.

We discovered two other computer-based systems for wheelchair prescription after speaking to a reference who was involved with computer systems in the medical field. Specifically, these programs are Rehab Anywhere and RehabCentral. These programs are not expert systems, but developers created the systems to streamline the prescription process. Rehab Anywhere is a system that allows an institution to put its assessment form and commonly used wheelchairs into a database. This allows the user to have quick access to patient information and wheelchair specifications. Another feature of Rehab Anywhere is its teleconferencing abilities, which allow a clinician to perform an assessment on site away from the computer, while another clinician transcribes the data into the system (ARTSCO, 1999).

The other system, RehabCentral, is a web-based system in which a clinician enters patient information into the RehabCentral standardised assessment forms. Essentially, the system is a database for storing patient information on the web. It also contains reference information on common procedures in prescription and wheelchairs that are available in the United States (RehabCentral, 1999). The RehabCentral program may not be appropriate for the RHNd because it is against the National Health Services laws on confidentiality to release patient information onto the web. Developers have geared both programs toward use in the American market so they would require customisation to the RHNd assessment process and wheelchairs. Again, neither of these programs are expert systems, but they may be able to provide the RHNd further organisation of patient and wheelchair information in a database format.

We gained valuable information from Wheelchair Clinic's focus group meeting, in which the clinicians discussed a new wheelchair assessment form. We discovered that the staff would like the assessment form to be on the hospital network. A major concern was the number of pages the assessment form must be to accommodate the information. The clinicians decided that a computerised version would simplify the form. They would like to contract a computer programmer who could develop a database system, in Microsoft Access, of the assessment form. Clinicians also mentioned that they could include help boxes, in the computerised form, to inform the ward therapists of the implications of the information. They would, therefore, be creating their own computer–based prescription aid to streamline the prescription process. Therefore, a paper based expert system would not be appropriate for the RHNd because it already feels overwhelmed by the paperwork in the current assessment form.

The staff also had some concerns about the actual content of the assessment form. The staff decided that it would be important to add more questions to help determine the status of the patient. These added questions would allow the ward therapist to determine if the patient was stable, deteriorating, or improving with a more standardised measure. In addition, the clinicians determined that they should also include the power wheelchair assessment into the wheelchair assessment form. Another important topic of discussion was the incorporation of the patient's physical measurements on the assessment form. The staff feels that this information would be useful in prescription and decided it would need a standard form of measurement. To remedy this need for standardisation, the clinicians suggested the use of a seating simulator. Furthermore, the staff discussed how one could input the standardised measurements from the seating simulator into an expert system. One member suggested processing the information directly into the expert system from the seating simulator electronically.

From this focus group, we were able to gain a better understanding of the long-term goals of the therapists' computer use within the prescription process. If they are successful in developing a network database from a computerised version of their wheelchair assessment form, they could apply it as the front end of an expert system.

The assessment form could be the initial source the expert system uses to gather information for the prescription of a wheelchair. Therefore, the expert system component of the process would have to incorporate the wheelchairs available and match the information from the assessment form to an appropriate wheelchair.

V. CONCLUSION

INEFFICIENCIES OF THE PRESCRIPTION PROCESS

Through our analysis of the wheelchair prescription process at the Royal Hospital for Neuro-disability, we have found four main sources of inefficiency. These inefficiencies are the main contributors to inappropriate wheelchair trials and prescriptions. The first inefficiency is the knowledge gap between the technicians of the Wheelchair Clinic and the therapists conducting wheelchair assessments. The second inefficiency is that the clinicians need to give more consideration to the primary care provider's needs and the future placement of the patient during the wheelchair assessment process. The third contributing factor is the difficulty of information transfer during the ward therapist turnover that occurs every six months. The fourth area of inefficiency in the wheelchair prescription process is the limited availability and disorganisation of loan chair system. Addressing these issues can make the prescription process more efficient and allow the Wheelchair Clinic to make better use of its time.

By interviewing key members involved in the wheelchair prescription process and shadowing Wheelchair Clinic, we found a knowledge gap between the technicians of the Wheelchair Clinic and the therapists conducting the patient's wheelchair assessment. The therapists involved in the wheelchair prescription process had many concerns, one of which was that the specifications of each wheelchair are unknown to the ward therapists. This makes the individualised prescription of a wheelchair very difficult. Another concern is that the ward therapists are unaware of the available adaptations for each chair. For example, if the clinician decides on a specific wheelchair base to meet the patient's postural needs, the chair must also allow for each adaptation to provide for the patient's postural and functional needs. If the therapist adaptation to provide for the patient's postural and functional needs. If the therapist does not know which adaptations fit on each chair, the therapist could possibly prescribe the wrong wheelchair. As a result, Wheelchair Clinic might waste valuable time and resources. Another concern is that the therapists do not have a consistent way of finding out about new wheelchairs. This poses a problem when new technology comes out that could benefit a particular patient. To try to solve these problems the technical staff suggested that we analyse the six most commonly prescribed wheelchairs at the RHNd. These chairs consist of the Shadow (Matrix based), the Cirrus, the PAP, the Carters Recliner, the Action 2000, and the 8L/9L/Apollo. From this list of chairs, we made a spreadsheet of the dimensions of each wheelchair (see Appendix C), as well as the adaptations that each wheelchair base can accommodate (see Appendix B). We also designed a flowchart expert system model for the prescription of the six chairs that we based on the information gained from our questionnaire (see Appendix G). This will help each of the therapists in deciding which wheelchair is best for their patients, as well aiding in the prescription process.

Another inefficiency in the wheelchair prescription process is that the clinicians need to give more consideration to the primary care provider's needs and the future placement of the patient during the wheelchair assessment process. When the patient goes to Wheelchair Clinic, his physiotherapist, occupational therapist, as well as his primary care provider are there to express the needs of the patient. It is not until this point that the primary care provider formally gives input on his needs in a chair as well. This may pose a large problem if the ward therapist has not considered the primary care provider's needs and it causes a change in prescription. To remedy this problem we recommend that the Wheelchair Clinic include the primary carer's needs in the patient assessment form. However, this recommendation poses yet another obstacle: getting in contact with the patient's primary care provider. To address this problem we went to the RHNd's principal social worker whose job is to be an interface between the hospital and the outside world. Her recommendation was that the social work department could set up and organise meetings between the occupational therapist and the patient's primary care provider. This would help to save the occupational therapist's time, and still address the needs of the primary care provider.

An additional inefficiency we observed occurs when a therapist representing the patient in Wheelchair Clinic is unfamiliar with the patient. This unawareness results because the therapists rotate wards every six months, even if they are in the middle of a wheelchair prescription. Consequently, a ward therapist may get a patient half way through the prescription process, and be unaware of the steps taken by the previous clinician. Some of the interviewees suggested that the ideal solution would be if the therapists did not change wards, but it is against hospital policy. Therefore, we suggest that a better transfer of patient records and trial evaluations could help to remedy the knowledge gap.

We have discovered that the limited availability and disorganisation of loan chair system also contributes to inefficient use of clinician's time. Before the patient attends Wheelchair Clinic the occupational and physiotherapists seat the patient in several loan chairs to find what they think is the best chair for the patient's postural needs. This helps tremendously in Wheelchair Clinic, making it easier to prescribe the correct wheelchair to the patient. Only one ward has its own set of loan chairs, so the other therapists have trouble locating the appropriate chairs for trial. Refining this system and creating a system for organising the loan chairs would benefit the patients as well as the therapists.

One device that could help alleviate the loan chair problem is a seating simulator. By finding the patient's target seating position and appropriate adaptations, the simulator shows the clinicians exactly what kind of chair the patient needs. Another problem that the seating simulator could resolve is the standard by which therapists measure each patient. The simulator could measure the patient in his prime seating position and then the therapist could easily input the data into a database of patient information.

EXPERT SYSTEM RECOMMENDATIONS

From our evaluation of the CAWPS program and research into the other computer systems available for wheelchair prescription, we have determined that no functioning expert system for wheelchair prescription currently exists. Therefore, the RHNd requires a custom developed system. Because of the complex variables of wheelchair prescription and their dissatisfaction with excessive paper work, we feel that a computer-based system is required. We feel that a custom designed expert system could be helpful for the therapists, and may remedy many of the inefficiencies that occur in the wheelchair prescription process at the RHNd. The system should include each of the available wheelchair specifications and the available adaptations. This added information would diminish the existing knowledge gap between the technicians of Wheelchair Clinic and the therapists conducting the wheelchair assessments. The consideration of the primary caregiver's needs and environmental aspects in prescription is another inefficiency that an expert system could remedy. Including these aspects into the system would help insure that clinicians address these issues. In addition, the expert system should be accessible on the hospital network and include a database of patient records and the prescriptions made. This database would allow clinicians easy access to patient information that would be helpful when therapists rotate wards. Furthermore, it would help the RHNd determine which wheelchairs to incorporate into the loan chair stock, by keeping track of the most commonly prescribed wheelchairs.

In our evaluation of the CAWPS program and interviews with the members of Wheelchair Clinic, we were able to define what the RHNd requires in an expert system. After our trial and evaluation of the CAWPS program, we have found that the clinicians would like to be able to view and alter the rule-base that the system uses. In addition, the trials revealed that the clinicians disliked the illogical sequencing of the CAWPS decision tree questioning and that they would rather input the patient information into a computerised version of their assessment form. Consequently, we have decided that the decision tree type system would be inappropriate. The order of the decision tree questioning depends on the answers provided and therefore developers could not structure the decision tree in the standardised format of the assessment form. If the RHNd developed a decision tree the ward therapists would be required to input the assessment information twice because the system would discount information as it narrowed the wheelchair selection. All the assessment information is important for the hospital database. In addition, if the RHNd desired to change the rule base it would have to redevelop the whole decision tree framework.

The computerised version of the assessment form could serve as the front end of the expert system. This would alleviate the ward therapists from having to input the assessment information more than once. Consequently, the input of information would be less time consuming. Neural network and rule-based type expert systems are appropriate for the data analysis. Developers have programmed both of these system types to allow for changes in the rule-base and have used fuzzy logic to allow for the complex and highly varying results that are common in wheelchair prescription. In a customised expert system, fuzzy logic would be an important application because it allows the system to determine when to apply specific rules. Therefore, we recommend that the RHNd consider fuzzy logic in the development of a neural network or rule-based expert system.

The main difference between rule-based and neural network type expert systems is in the development of rules. In a rule-based system developers must define the rules, but a neural network develops the rules itself by pattern recognition and data compression. If the RHNd chooses to pursue a rule-based system we recommend they expand upon the simple flowchart model system we have developed to define their specific prescription rules further. Since some of the clinicians experienced difficulty answering the questions in the interview and questionnaire, and each member of Wheelchair Clinic contributes their own expertise, we recommend that the clinicians hold focus groups. In the focus groups the staff should not attempt to analyse the whole prescription process in one sitting because of the complexity of the problem. Prerau (1990) argues that it is better to break the process down into subcategories and analyse them one at a time. We recommend breaking the process down by addressing such aspects as wheelchair and adaptations or by physical problems. In addition, if the RHNd chooses to take the neural network approach we recommend that they use an ARTMAP type system or a comparable type that are designed to deal with complex varying data. We contacted a neural network company, Wards Inc., and obtained a neural network demo for the RHNd to sample.

In our research we have also discovered problems inherent in the adoption of any type of expert system. There exists the possibility of staff members relying too heavily on the decisions made by the expert system. In addition, staff members may not be willing to use the system if it is too complicated or bothersome (Berry, Berry &

Foster, 1998). One way to remedy this situation would be to develop a computerised prescription aid rather than a full-fledged expert system. If the RHNd adopted a system like Rehab Anywhere or RehabCentral, it would streamline and organise the prescription process without the time burden of developing a custom expert system. If customised to the RHNd assessment process, the prescription aids could also allow for the development of a prescription database. The RHNd is already trying to create a database on the hospital network with Microsoft Access, and this is a step towards a customised computer aid. It would also be useful to the ward therapists if the system included the available wheelchairs and specifications. The ultimate expert system decision depends on the time and resources the RHNd wants to put into the project.

VI. APPENDICES

APPENDIX A: Wheelchair Clinic Background

The Royal Hospital for Neuro-disability (RHNd) is a leading treatment centre for neurological disorders in England. It is located in London and was founded in 1854 by the Reverend Dr. Andrew Reed. It was formerly known as the "Hospital for Incurables," because there are no real cures for neurological disease, only treatment. The hospital treats a variety of diseases and conditions, the most common being multiple sclerosis, muscular dystrophy, and central nervous system damage.

To assess patients who require wheelchairs and make prescriptions, the Department of Biomedical Engineering has developed "Wheelchair Clinic." It is managed by Department Head Dr. Steve Cousins and consists of a team of seating technicians, physiotherapists, and occupational therapists. The team members are Seating Technicians Tim Sewell, Karen Howlett, and Ron Clark, Senior Physiotherapist Amanda Wright, and Senior Occupational Therapist Helen Gill. Also present during Wheelchair Clinic are the patient, the patient's primary care provider, and his or her primary ward therapist.

Patients are referred to Wheelchair Clinic if they need a wheelchair for the first time, require a change in wheelchair, or need a new seating system. Before referral to the clinic the ward occupational therapist and physiotherapist conduct a wheelchair assessment using the standard seating assessment form. They then set up a time for the patient and the team to meet for a 15-minute evaluation that can be extended up to 30 minutes. The meetings occur on Wednesdays and the Wheelchair Clinic team sees no more than five patients. At 1:45 p.m. the team goes over the patient's wheelchair history and physical status. Then at 2:00 p.m. the clinicians meet with the patient to assess the patient's range of movement and postural problems. Following this assessment the team gives objectives and recommendations and asks for the patient's comments. Finally, they make a prescription that is either to reassess the patient with an alternative wheelchair or continue with the assessment of the existing wheelchair prior to a definite prescription. The clinicians again discuss the prescription with the patient after the clinic session to ensure understanding. They then circulate copies of the prescription to the ward physiotherapist, ward occupational therapist, Wheelchair Clinic senior physiotherapist, Wheelchair Clinic senior occupational therapist, and unit managers (if appropriate) for review. After the prescription, the team must discuss any funding problems with the Wheelchair Department that may result in a revised prescription (Wheelchair Clinic Organisation Procedure, 1998).

Appendix B: Wheelchair Adaptations

On the following page is a copy of the spreadsheet we designed of RHNd wheelchair adaptations. After the technical staff determined for us the six most commonly prescribed wheelchairs (Shadow, Cirrus, PAP, Carters Recliner, Action 2000, and 8L/9L/Apollo), we consulted the Wheelchair and Seating Department Manager, Karen Marshall. She provided us with the information on which adaptations fit each wheelchair. After that meeting, we provided the members of Wheelchair Clinic with a draft of the spreadsheet to review. They had a few minor revisions and we incorporated those corrections into the current version.

We based the spreadsheet on a price list that Mrs. Marshall had already created. We broke the spreadsheet up into the same categories (pelvic support, pressure cushions, trunk support, lower-limb support, foot support, upper-limb support, head support, special seating, and power adaptations) and added a section for tilt-in-space and reclining back. We listed the wheelchair models across the top of the spreadsheet and the adaptations down the left side. An "X" indicates that an adaptation fits a wheelchair and an "O" shows that it does not fit.

The spreadsheet serves as a quick reference for the ward therapists when determining if a wheelchair is appropriate for a specific patient. It is a simple instrument to find out if a wheelchair will take the desired adaptation. It also helped us to design our secondary questionnaire and subsequent model expert system. We were able to determine which wheelchairs provide for tilt-in-space, a reclining back, and matrix seating. With this information, we designed the questionnaire to find out when certain wheelchairs were inappropriate for prescription.

X = fits

O = does not fit

Adaptation	Price (in £)	Action 2000 standard	Action 2000 reclining	8L/9L	Apollo standard	Apollo powered
Tilt in Space						
Back Reclines			X			
Pelvic Support						
Pelvic strap	£11.81	X	X	X	X	X
Y-shaped pelvic strap	38.37	X	X	X	X	X
Back fastening pelvic strap	11.81	X	X	X	X	X
Padded sleeve for pelvic strap	18.8	X	X	X	X	X
Ramp sag infill	33.9	X	X	X	X	X
Wedge ramp sag infill	36.59	O	X	O	O	X
Split level wedge ramp sag infill	74.09	O	X	O	O	X
Drop-in seat insert with ramp	147.05	X	X	X	X	X
Drop-in seat insert with wedge ramp	150.14	X	X	X	X	X
Pressure Cushions						
Low profile modular propad	34.92	X	X	X	X	X
High profile modular propad	42.43	X	X	X	X	X
RoHo (includes quatro)	274.05	X	X	X	X	X
Split low profile modular propad	56.92	X	X	X	X	X
Split high profile modular propad	59.92	X	X	X	X	X
Trunk Support						
Back sag infill	51.82	X	X	X	X	X
Wing back cushion	131.19	X	X	X	X	X
Wing supports (each)	40.36	X	X	X	X	X
Wing supports (pair)	80.72	X	X	X	X	X
Lumbar support	12.79	X	X	X	X	X
Lower Limb Support						
Knee straps (comp. w/brackets)	115.7	X	X	X	X	X
Knee adductor pad (each)	9.63	X	X	X	X	X
Knee adductor pad (pair)	18.35	X	X	X	X	X
Knee adductor block	26.64	X	X	X	X	X
Side cushions (pair)	42.78	X	X	X	X	X
Paddled ankle strap	40.9	X	X	X	X	X
Foot support						
Toe straps (pair)	12.53	X	X	X	X	X
Foot straps (pair)	14.53	X	X	X	X	X
Extended footplate (each)	18.3	X	X	X	X	X
Extended footplate (pair)	36.59	X	X	X	X	X
Extended foot board	36.59	X	X	X	X	X
Padded foot plates/ foot board	26.91	X	X	X	X	X
Foot wedge (each)	9.15	X	X	X	X	X
Foot wedge (pair)	18.3	X	X	X	X	X
Foot block	110.32	X	X	X	X	X

X = fits

O = does not fit

Adaptation	*Price (in £)*	Shadow	Shadow (powered)	Cirrus	PAP	Carters Recliner
Upper Limb Support						
Padded round tray	**128.12**	X	X	X	X	X
Widened arm pad (each)	**26.5**	X	X	X	X	X
Widened arm pad (pair)	**53.54**	X	X	X	X	X
Half tray	**46.55**	X	X	X	X	X
Tray cushion	**95.79**	X	X	X	X	X
Tray wedge	**155.52**	X	X	X	X	X
Head Support						
L-shaped head rest		X	X	X	X	X
U-shaped head rest	**111.68**	X	X	X	X	X
Head strap	**16.68**	X	X	X	X	X
Padding for head rest extension	**18.83**	X	X	O	O	X
Special Seating						
Matrix size 4 full (incl. 1 cover)	**1,293.00**	X	X	O	X	X
Matrix cover	**104**	X	X	O	X	X
Foam carve		X	X	O	X	X

X = fits

O = does not fit

Adaptation	Price (in £)	Action 2000 standard	Action 2000 reclining	8L/9L	Apollo standard	Apollo powered
Tilt in Space						
Back Reclines			X			

Pelvic Support

Pelvic strap	£11.81	X	X	X	X	X
Y-shaped pelvic strap	38.37	X	X	X	X	X
Back fastening pelvic strap	11.81	X	X	X	X	X
Padded sleeve for pelvic strap	18.8	X	X	X	X	X
Ramp sag infill	33.9	X	X	X	X	X
Wedge ramp sag infill	36.59	O	X	O	O	X
Split level wedge ramp sag infill	74.09	O	X	O	O	X
Drop-in seat insert with ramp	147.05	X	X	X	X	X
Drop-in seat insert with wedge ramp	150.14	X	X	X	X	X

Pressure Cushions

Low profile Modular propad	34.92	X	X	X	X	X
High profile Modular propad	42.43	X	X	X	X	X
RoHo (includes Quatro)	274.05	X	X	X	X	X
Split low profile Modular propad	56.92	X	X	X	X	X
Split high profile Modular propad	59.92	X	X	X	X	X

Trunk Support

Back sag infill	51.82	X	X	X	X	X
Wing back cushion	131.19	X	X	X	X	X
Wing supports (each)	40.36	X	X	X	X	X
Wing supports (pair)	80.72	X	X	X	X	X
Lumbar support	12.79	X	X	X	X	X

Lower Limb Support

Knee straps (comp. w/brackets)	115.7	X	X	X	X	X
Knee adductor pad (each)	9.63	X	X	X	X	X
Knee adductor pad (pair)	18.35	X	X	X	X	X
Knee adductor block	26.64	X	X	X	X	X
Side cushions (pair)	42.78	X	X	X	X	X
Paddled ankle strap	40.9	X	X	X	X	X

Foot support

Toe straps (pair)	12.53	X	X	X	X	X
Foot straps (pair)	14.53	X	X	X	X	X
Extended footplate (each)	18.3	X	X	X	X	X
Extended footplate (pair)	36.59	X	X	X	X	X
Extended foot board	36.59	X	X	X	X	X
Padded foot plates/ foot board	26.91	X	X	X	X	X
Foot wedge (each)	9.15	X	X	X	X	X
Foot wedge (pair)	18.3	X	X	X	X	X
Foot block	110.32	X	X	X	X	X

X = fits
O = does not fit

Adaptation	Price (in £)	Action 2000 standard	Action 2000 reclining	8L/9L	Apollo standard	Apollo powered
Upper Limb Support						
Padded round tray	128.12	X	X	X	X	X
Widened arm pad (each)	26.5	X	X	X	X	X
Widened arm pad (pair)	53.54	X	X	X	X	X
Half tray	46.55	X	X	X	X	X
Tray cushion	95.79	X	X	X	X	X
Tray wedge	155.52	X	X	X	X	X
Head Support						
L-shaped head rest		X	X	X	X	X
U-shaped head rest	111.68	X	X	X	X	X
Head strap	16.68	X	X	X	X	X
Padding for head rest extension	18.83	O	X	O	O	X
Special Seating						
Matrix size 4 full (incl. 1 cover)	1,293.00	O	O	O	O	O
Matrix cover	104	O	O	O	O	O
Foam carve		O	O	O	O	O

APPENDIX C: Wheelchair Dimensions

On the following page is a spreadsheet of the dimensions of six wheelchairs commonly prescribed at the RHNd. From our preliminary interviews, we found that one of the inefficiencies in the wheelchair prescription process was that the ward therapists were unaware of the dimensions of each of the wheelchairs. To remedy this problem, the technical staff selected six commonly prescribed wheelchairs to narrow the knowledge base. The six most commonly prescribed wheelchairs that the technical staff chose are the Shadow, Cirrus, PAP, Carters Recliner, Action 2000, and 8L/9L/Apollo. From this list, we looked in brochures for the dimensions of each of the wheelchairs that were most pertinent to prescription. For instance, a crucial dimension in wheelchair prescription is the width of the seat. We list the features of each of the chairs down the left-hand column, and the wheelchair models across the top of the spreadsheet. We have converted each of the chair dimensions to inches because it is the measurement that the RHNd prefers. The spreadsheet serves as a reference for the ward therapists when determining if the dimensions of a wheelchair are appropriate for a particular patient.

Features	Shadow	Cirrus WIDE	Cirrus NARROW
Seat width	15",18"	14.6",16.1",17.7",19.7"	11.8",13.4",15",17"
Seat depth		17.7"-23.6"	16.5"-22.4"
Seat height		20.9"	19.7"
Seat to footrest		16.5"-20.5"	16.5"-20.5"
Overall width		26.4"	23.6"
Overall length			
Overall height		42"	42"
Folded width			
Wheelchair weight		31kg	30kg
Max client weight			
Backrest		b/t 75^{o} and 135^{o}	
Back height		20.9"	20.9"
Footrest	support footplates	easily swung away/removable	
Footrest length	15",18"stand,heavy duty,90^{o}		
Legrests		elevated to any position	
Armrests	standard,angled/adjustable	easily removed	
Armrest height	adjust height/bracing bar	5.9"-11.8"	5.9"-11.8"
Rear wheels	12.5"	24"/20"	24"/20"
Front castors		6.5"/4.5"	6.5"/4.5"
Brakes	attendant controlled	linked	
Wheel base length			
Push handle height		adjustable	
Trays	15",18" contoured, 18" PVC		
		side knee pads provided(outside knees)	

Features	PAP	Action 2000	
		t	s
Seat width	16"-18"(rec:17.3)	15",16",17",18"	"
Seat depth	15"-21.7"	16",17"	"
Seat height		17.1"-20.1"	"
Seat to footrest	15"-21"		
Overall width		23"/23.6"/24.6"/25.6"	"
Overall length		40.5"	"
Overall height			
Folded width		11.8"	"
Wheelchair weight		14.5kg	"
Max client weight		113kg	"
Backrest	angle-11°	fixed or folding 10°	"
Back height	22.2"-23.8"	16.1"	"
Footrest	flexion angle 90°-135°	80° swing away/detach	"
Footrest length	8.3"-15.7"	13"/17.7"	"
Legrests	hanger angle 45°-135°	70° tapered/elevating	"
Armrests		full length ht/adjust	"
Armrest height	7.9"-9.8"	fix 9.8"/adjus 7.5"-10.6"	"
Rear wheels		12 1/2"	release/24x 1 3/4"
Front castors		8x1 1/4"	"
Brakes		push to lock	"
Wheel base length		32.3"	"
Push handle height		34.1"-36.6"	"
Trays	w-22",l-24",cutout-6"	Desk available	"
			2 handrim options
			5 real wheel options

Features	Remploy 8L	Ben 9L	Apollo
Seat width	17"	17"	17"
Seat depth	17"	17"	17"
Seat height	19"	19"	19"
Seat to footrest		13"-17"	13"-17"
Overall width	37"	26"	
Overall length	41"		
Overall height	37"	38"	38"
Folded width	11 1/2"	11"	
Wheelchair weight	18.5kg	13.63kg	55.66kg
Max client weight	100kg	110kg	101.6kg
Backrest	15° from verticle	reclining	
Back height	17 1/2"	17"	19 1/2"
Footrest	heel support strap		
Footrest length	footboard extension		
Legrests	elevating	elevating	
Armrests	detachable	remove/adjust	
Armrest height	10"		
Rear wheels	22"	12 1/2"	12 1/2"
Front castors	7 1/2"	7 1/2"	7 1/2"
Brakes			manual
Wheel base length	17"		
Push handle height			
Trays	detachable tray		

Appendix D: Content Analysis of Interviews

After our preliminary interviews, we created a spreadsheet of responses. The spreadsheet contains the responses of all the staff members we interviewed. We have shown on the spreadsheet the results of the content analysis we performed on the interview data. First, we transcribed and printed each interview. Then, we read each interview extracting from each question the core response, which are the main answers to our questions. We entered this information onto the spreadsheet.

The questions we used to obtain this information are located on page #97. The numbers to the questions correspond to the numbers in the first column of the spreadsheet. Each column indicates a different respondent's answers, and each row provides all the answers to a particular question. For example, if one wants to find all the responses to question #1, one would look to the first column and then read across the row. The responses continue to the following pages. Likewise, if one wants to find all the answers that one respondent gave, one would look down the appropriate column.

Using this format allowed us to highlight the areas about which the staff agreed. We evaluated each response by the frequency it appeared throughout our results to each question. The most frequently appearing responses we considered the primary responses and the second most frequent are the secondary responses. We have highlighted in blue the primary answers given by the respondents. The green highlighted responses are the secondary answers. In particular, if one wants to see the most common answer given to question #3a, one would look to the first column for #3a. Then, move across the row looking for blue highlighted responses. The primary response to question #3a is primary care provider and the secondary response is funding. The highlighted responses indicate areas of agreement among the therapists.

Interview Questions that Correspond to Spreadsheet

1. Please describe your current role in wheelchair prescription.

2. Do you feel that there are any other factors that should be added to the evaluation form to aid in the prescription process?

3a. What are the additional factors that are not reflected in the assessment forms?

3b. Do you feel that these factors could be incorporated into an evaluation form or expert system?

4. Do you use a systematic method when looking at the information gathered?

5a. Do you first determine a basic wheelchair type and then move into specialisation?

5b. How so you keep informed and up to date on the available wheelchair technology?

6. What aspects of the evaluation help to determine the special accessories that need to be added to the wheelchair?

7. What do you think is the most time consuming or inefficient part of wheelchair prescription?

8. Do you think an expert system would be a beneficial aid in wheelchair prescription?

9. Do you think that it is feasible to attempt to create an expert system to aid in wheelchair prescription?

10. Do you think there are any systems currently available, that could help simplify the wheelchair prescription process?

11. What did you think of Nigel Shapcott's CAWPS program?

	Primary Response
	Secondary Response

1	Physician	OT	PT	Tech Staff	Tech Staff
2	no	yes	yes	yes	yes
3a	clinical, funding	environmental, physical issues, family, primary care provider, functional ability	funding, trial chairs, time patients sits, cognitive ability, personal knowledge	other operators compatibility with chair, patient safely maneuver	environment, accessory compatibility
3b	yes		yes	yes	
4	yes, comfort is vital	yes, physical issues	yes	no	
5a	yes	yes	yes	yes	?
5b	talk to people, Naidex, colleagues	Naidex, Steve and seating techs	journals, W/C clinic	internet, catalogues, mailings	
6	how the patient sits, stability, observation	physical, environmental, family, functional, financial, patient needs, pressure sores, travelling, future placement	physical assessment, patient needs, family needs, staff concerns, postural control	motor control, cognitive ability	
7	loan system	loan chairs, applicable patients, limited preparation, too many observers	trial parts (loan)	loan equipment	relatives, modifications
8	yes	yes	?	yes	
9				yes	
10				no	
11				not logically organised, questions too long and in depth	

1	Tech Staff	Tech Staff	Tech Staff	BE
2	yes	yes	yes	yes
3a	anticipated changes, patient goals		anthroprometric measurements, patient's future progression, funding, past experience	funding, primary carer, family, transport, tilt test
3b	yes		yes	yes
4	yes, assessment form order		yes, first postural needs and long term	yes, life threatening risks, proper symmetry
5a	yes		yes	no
5b	meetings, Naidex, Kings Health Care, Postural Mobility, contacts		Postural Mobility, trade fairs, Naidex	conferences, seating seminars, literature review
6			postural needs, then process of elimination	trunk, spine, musculature, cognitive status, patients motivation, environmental, transport
7	relatives, undecided therapists, multiple assessments, unrealistic expectations	undecided therapists, prescribed chair unsuitable	whole process, using therapists to choose wheelchair	trials, assessment forms, prescription acceptance
8	yes	?	yes	yes
9			?	yes
10			no	
11			questions illogical, needs to be user-friendly	too time consuming, customise ability, change rules

1	BE	Nurse	OT	OT	PT
2	no	yes	yes	yes	yes
3a	relatives, carers, unrealistic expectations	should include nursing	assessment done on each loan chairs, goals, past experience	equipment history, funding, relatives, basic patient measurements	intended environmental use, dimensions, relatives wishes
3b	yes			yes	yes
4	no		yes, physical condition, postural needs, functional needs	?	yes, initial supportive trunk and knees to floor
5a	yes		yes		yes
5b	manufacturers, Naidex		rely on BE dept	reps come in	talk to W/C clinic
6			patient's goals, compromise between physical and functional needs	?	
7	observation, positioning, assessment, loan equipment		loan equipment, W/C clinic	trial chairs, adaptations, waiting for actual chair	targeting of initial base, loan chairs, waiting for arrival chairs
8	yes	yes	yes	yes	?
9					
10					
11					

1	PT	PT	OT
2	yes	yes	yes
3a	transport, needs of care provider, qualitative aspects	tone and posture, functional, carers, family	environmental, funding, health authority involvement
3b	yes	yes	yes
4	no	yes, guided by form, pick out patient problems and match chair that will meet those needs	yes
5a	yes	yes	
5b	in-service training, talk to BE dept	W/C clinic, training, reps	co-workers, BE dept, reps
6		complex postural support	wheelchair trials
7	assessment, problem solving	chair not fully meeting patient's needs, not enough preparation for W/C clinic	trial wheelchairs, time with reps
8	yes	yes	yes
9	yes		
10	?		
11			

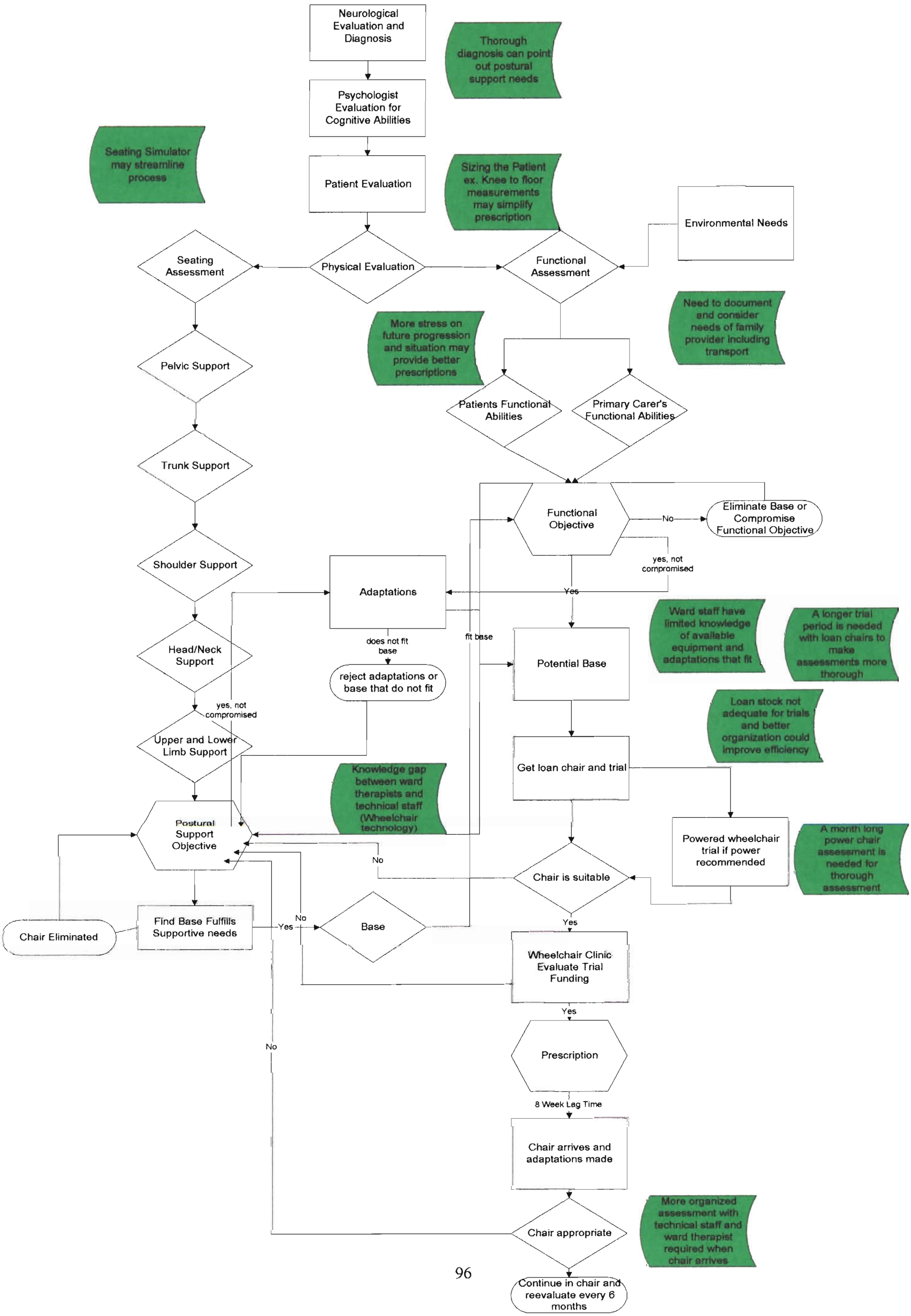
APPENDIX E: Flowchart of the Prescription Process

We developed a flowchart of the RHNd's prescription process from the data we collected from our staff interviews and shadowing sessions. It is a basic outline of the prescription process as we perceived it, but the actual process is a little more complex. The green curved boxes represent inefficiencies and suggestions at various stages that respondents supplied in the interviews. The square boxes represent routine steps and the diamond shaped boxes represent decisions that clinicians make throughout the patient evaluation and prescription. The hexagonal boxes represent major decisions in the process, which include the postural support objective, the functional objective, and the actual prescription. In addition, the oval boxes represent terminating decisions that rule out or include a particular chair or adaptation.

There are two main branches to the flowchart, the side leading to the postural support objective, and the side leading to the functional objectives. The ward occupational therapist and the ward physiotherapist develop these objectives or main goals in a combined effort. Through the interviews and shadowing sessions, we learned that providing the correct postural support is of vital importance. In addition, the therapists will never prescribe a chair that compromises the patient's supportive needs. We also discovered that the actual progression through the seating assessment is not a linear process, because clinicians usually start at the pelvis and move either up or down the patient's body. Often the clinicians cycle through the process multiple times. The actual progression depends on the clinician conducting the assessment and the status of the patient, but we included a linear sequence for the sake of simplicity. Furthermore, we discovered that the patient's and the primary caregiver's functional abilities are important in the evaluation, but are secondary to the postural needs and are sometimes compromised. Consequently, we have flow directed towards the postural support objective to the determination of an appropriate base and only then towards the functional objective. In addition, we constructed the flowchart so that when a clinician rules out a wheelchair the arrows flow back towards the postural support objective because the supportive needs are always the primary consideration.

In the remaining sections of the flowchart we have indicated the basic steps that clinicians take as a they proceed with the prescription. Normally prescription begins with the evaluations by the neurologist and clinical psychologist and then the ward therapists develop the wheelchair objectives in their assessment. The therapists then conduct wheelchair trials. Next comes the evaluation by Wheelchair Clinic and, if approved, the prescription. Following the prescription, we indicate the normal eight-week lag period for the wheelchair arrival and the subsequent re-evaluation.

We have placed the green highlighted boxes indicating the inefficiencies and suggestions at the stages in prescription where the problems occur. These include things that therapists tend to overlook in initial assessments and ways that the prescription can be more thorough. One major suggestion is that a standardised method of measuring patients, such as a seating simulator, could simplify the identification of an appropriate sized wheelchair. In addition, many of the interviewees felt that therapists need to consider the future progression of the patient and the primary caregiver's needs. The other major concerns are that the ward therapists have limited knowledge of the wheelchairs and adaptations and that the loan chair system needs better organisation. We provide these markers to indicate where in the prescription process the RHNd could make improvements.


Neurological Evaluation and Diagnosis
Thorough diagnosis can point out postural support needs
Psychologist Evaluation for Cognitive Abilities
Seating Simulator may streamline process
Patient Evaluation
Sizing the Patient ex. Knee to floor measurements may simplify prescription
Environmental Needs
Seating Assessment
Physical Evaluation
Functional Assessment
Need to document and consider needs of family provider including transport
More stress on future progression and situation may provide better prescriptions
Pelvic Support
Patients Functional Abilities
Primary Carer's Functional Abilities
Trunk Support
Functional Objective
No
Eliminate Base or Compromise Functional Objective
yes, not compromised
Shoulder Support
Adaptations
Yes
Ward staff have limited knowledge of available equipment and adaptations that fit
A longer trial period is needed with loan chairs to make assessments more thorough
does not fit base
fit base
Head/Neck Support
reject adaptations or base that do not fit
Potential Base
Loan stock not adequate for trials and better organization could improve efficiency
yes, not compromised
Upper and Lower Limb Support
Get loan chair and trial
Knowledge gap between ward therapists and technical staff (Wheelchair technology)
Postural Support Objective
Powered wheelchair trial if power recommended
A month long power chair assessment is needed for thorough assessment
No
Chair is suitable
Yes
Chair Eliminated
Find Base Fulfills Supportive needs
Yes
No
Base
Wheelchair Clinic Evaluate Trial Funding
Yes
No
Prescription
8 Week Lag Time
Chair arrives and adaptations made
Chair appropriate
More organized assessment with technical staff and ward therapist required when chair arrives
Continue in chair and reevaluate every 6 months

APPENDIX F: Content Analysis of the Questionnaire

The following spreadsheet is a content analysis of the information we obtained from the secondary questionnaire. We categorised the information into two sections. The first is the reasons for prescription of the different types of seating and propelling. In the top section we have include the physical and postural reasons for prescription and below that section we list other considerations. We list the most common responses at the top of each column and the number in parentheses indicates the number of respondents supplying that answer. In the second section we compile the positive and negative aspects of the six types of wheelchairs. We break down the positive and negative responses into physical, environmental, funding, and primary caregiver concerns. Again, we list the most common responses at the top of each column. We used this content analysis to create our model expert system (see Appendix G).

Physical and Postural Reasons for Prescription							
***The paranthetical numbers indicate the number of respondents supplying that response**							
Matrix	**Tilt-In-Space**	**Reclining Back**	**Standard**	**Self Propel**	**Power Control**	**Foam Carve**	**Power Assist**
Rated "unplaceable" on Chailey sitting scale. Patient unable to support himself in upright position and resist gravity. **(7)**	Requires forward position for stand transfer or increase function feeding. Upper limb activity/ orientation/ need for rest (recline)/ Dynamic seating. **(6)**	Used only in one position with wedged seat cushion and relief from gravity but does not need tilt in space. **(4)**	Active, unsupported sit balance for long periods (upright, symmetrical posture without any external support, no deformity) good hip flexion, degree of trunk control. **(6)**	Good upper limb function-range in joints and strength in arms and hands. **(3)**	Control of environment, independence (motor control). **(2)**	No change likely in physical status. **(3)** Patient not difficult to position.	Only able to self propel short distances or cannot fatigues easily/only can use one upper limb independently
Strong (complex) postural deformity. **(2)**	Pressure Relief from force of gravity. **(3)**	To take lateral weight because of minimal paraspinious muscle tone-15 degree recline to increase friction between back and back support poor trunk control. **(2)**	Self propelling and no contractures or postural problems which will get worse if acted on by gravity. **(2)**	Dynamic sitting balance and cognition in tact. **(2)**	Patient has lack of strength in upper limbs or tendency to move into poor posture when self-propelling.	Allows patient more freedom for movement. **(2)**	Manual mobility compromises situation.
Prevention or correction of postural deformity. **(2)**	Possibility of improvement or deterioration condition. **(2)**	Upright posture (1st) but hip flexion to break up extensor spasms (reflexes).	Able to stand transfer. Co-ordinated head, arm, neck and head movement.	Co-ordination in shoulder, arm, head, and neck movement.	Whole range of controls/switches used for range of disabilities.	Comfort is primary concern for intimately fitting system.	
Poor acceptance of base support in sitting and lying. **(2)** Unable to maintain position with static seating.	Repositioning for postural problems easier when tilted-use of hoist and reposition. **(2)**	Beginning indication of spinal deformity which is currently correctable with minimal adaptations	If the chair is for short distances or transit use only.	Physical, social, emotional, cognitive, behavioural, learning ability, motivation, attention and environment.	Demonstrates functional ability to use power control safely.	Extreme lack of hip flexion and if leg support needed.	
Likelihood for condition to deteriorate. **(2)**	Good for respiratory needs. **(2)**	No active sit tolerance or requires lateral support to maintain posture. Minimal head control.		Sight and hearing intact.	Sight and cognitive ability intact (movement of head and neck).		
Uncorrectable spinal deformity.	Improvement of head positioning especially for poor trunk control.	If range of movement in pelvis and/or spine is limited because unable to achieve 90 degrees. Poor trunk posture. Will prevent slouching or falling forward.			Cognition to get around but without physical ability to do so.		
Poor hip flexion; less than 90 degrees or unequal right to left. Wing swept hips.	Blood pressure problems.						
Inaccessible to functional activities because of low support.	Effects position of diaphragm and other internal organs.						

Other Considerations in Prescription							
Rather use matrix because it is more adaptable than foam carve.					Sight and spacial awareness are not intact. Lack of motivation. **Do not prescribe. (3)**	Cheaper and less labor intensive than Matrix. **Prescribe instead of Matrix. (7)**	Home environment (hilly or ramps/slopes). **(6)**
					Unable to problem solve or stay alert. **Do not prescribe. (2)**	Lighter for carer than Matrix. **Prescribe instead of Matrix. (3)**	Primary caregiver unable to push chair. **(6)**
					Likelihood to harm others or escape. **Do not prescribe.**		

*The parenthetical numbers indicate the number of respondents supplying that answer

	Shadow	Cirrus	PAP	Carters Recliner
Negative Physical				
	No split back(2)	Cannot be used if patient too tall (over 5'10", inadequate seat depth and width)(3)	Does not supply a lot of lateral or sacral support(2)	Does not have tilt in space (clinicians may prefer it over recline alone) (3)
	Patient may require more stable base due to behaviour(2)	Can not accommodate strong extensor flexion requires reinforcement at hinge(2)	Cannot be used if patient cannot achieve 90 degrees at hips (backrest will not recline)(2)	May be difficult for patient to self-propel is a larger wider chair(3)
	Not used for matrix if T.I.S. not needed(2)	May be insufficient/Inadequate postural support(2)	Has limitations accommodating severe deformity (may not offer adequate postural support) (2)	Although feasible probably not used for matrix(2)
	May be too heavy to self-propel	If patient too heavy may bottom out(2)	Cannot accommodate extreme hip flexion sag <60degrees both sides	Strong extensor spasms can be too much for current recline mechanism (firmer or solid back would be better)
	Foot plate removal	May not be stable enough for behavioural problems	Cannot be motorised	Hard to do standing transfers
		Not used if multi-adjustable features were not needed to accommodate patient's deformities		Not appropriate if patient is small in stature
Environmental				
	May be too heavy/bulky(4)	Needs adequate turning space	Only for indoor use (6)	Too large/long especially in transport (high headrest)(3)
	Does not fold		Heavy/bulky (3)	A lot of adaptations
				Rear wheels are not quick release
Funding				
	Expensive, but physical factors takes priority(3)	Expensive and wheelchair service does not always fund (£1200 compared to Carters £250) (8)	Many wheelchair services will not fund it(2)	Wheelchair service may specify it as their choice over Shadow or PAP
		Cost could not be justified if client only required recline		
Primary caregiver				
	Heavy/ bulky to manoeuvre/ cannot fold to put in car (2)	T.I.S. mechanism can be altered which could cause safety issues(4)	Heavy and bulky for carer to push(6)(power assist partial solution)	Heavy to push(4) Not aesthetically pleasing(3)
	Untrained carer may change position (safety issue)	Extra wheelchair weight may want lighter chair for travelling(3)		Push handle height is not adjustable-may make pushing by shorter or older carers difficult
				Bad height extension adaptations very difficult and manufacturers option has pressure risk curved tubing will contact back

***The parenthetical numbers indicate the number of respondents supplying that answer**

	Shadow	Cirrus	PAP	Carters Recliner
Positive				
Physical				
	Usually used for matrix especially with power and power assist/ Base of choice(3)	Primary chair prescribed for T.I.S. facility	Removable split back for better positioning of patient (5)	Cannot change position of recliner
			Large mass for greater stability control patient behaviour(3)	Primary chair prescribed for reclining back need
			If patient 90 at hips then can use 1/2 matrix	Prescribed if tilt-in-space not required
				More stability and is used when less need for pressure relief
Environmental				
				Easier to manoeuvre than Shadow and has bigger wheels
Funding				
	More effective over period of time and has a longer life span		Less expensive than Shadow(2)	Cheaper option (250 compared to 750 for Shadow) would use for matrix if funding severely restricted (4)
Primary caregiver				
	Has adjustable height push handles and the Recliner doesn't so it is easier to push			Lighter weight and easier to manoeuvre than Shadow (2)

*The parenthetical numbers indicate the number of respondents supplying that answer

	Action 2000	8L/9L	Apollo
Negative			
Physical			
	Does not provide enough recliner/back not high enough(2-3" lower than Carters)/limited head support(**4**)	May be too heavy to self propel/ lighter more modern design easier to propel(**6**)	Movement may affect stability
	Patient too tall/too heavy(**3**)	Does not accommodate tilt in a seat	May not provide efficient base of support, control
	Unable to put in back cushion or other adaptations for adequate trunk support(**2**)	If patient too heavy needs heavy duty	
	Not strong enough frame for muscle tone behavioural stability/weight(**3**)	Armrests are large and cannot be removed for transfer	
	Patient may have used 8/9L for years and not want change(**2**)	Rear wheels not camhead so the patient may find it hard to push in straight line	
	Plastic footplates break when patient stands on them	Lack of adjustment for head height and wheel position	
Environmental			
	Not sturdy for difficult terrain(**2**)	Not easy to manoeuvre(**2**)	Apollo not outdoor chair may need indoor/outdoor powered chair(**4**)
	Long term reliability unknown	Lack of adjustment for head height and wheel position	If environment is a risk
		8L does not come in funky colours	
Funding			
	Carter may be marginally cheaper(**3**)	Same price as a more fashionable chair	
	More expensive for 8L standard chair(**2**)		
	Wheelchair service may refuse to fund it		
Primary caregiver			
	Push handle height is not adjustable-may make pushing by shorter or older carers difficult	Heavier than other models	
	Bad height extension adaptations	Transport: rear wheels not quick release stronger size and weight/Harder to fold up than Action 2000	
		Not aesthetically pleasing to young users	

*The parenthetical numbers indicate the number of respondents supplying that answer

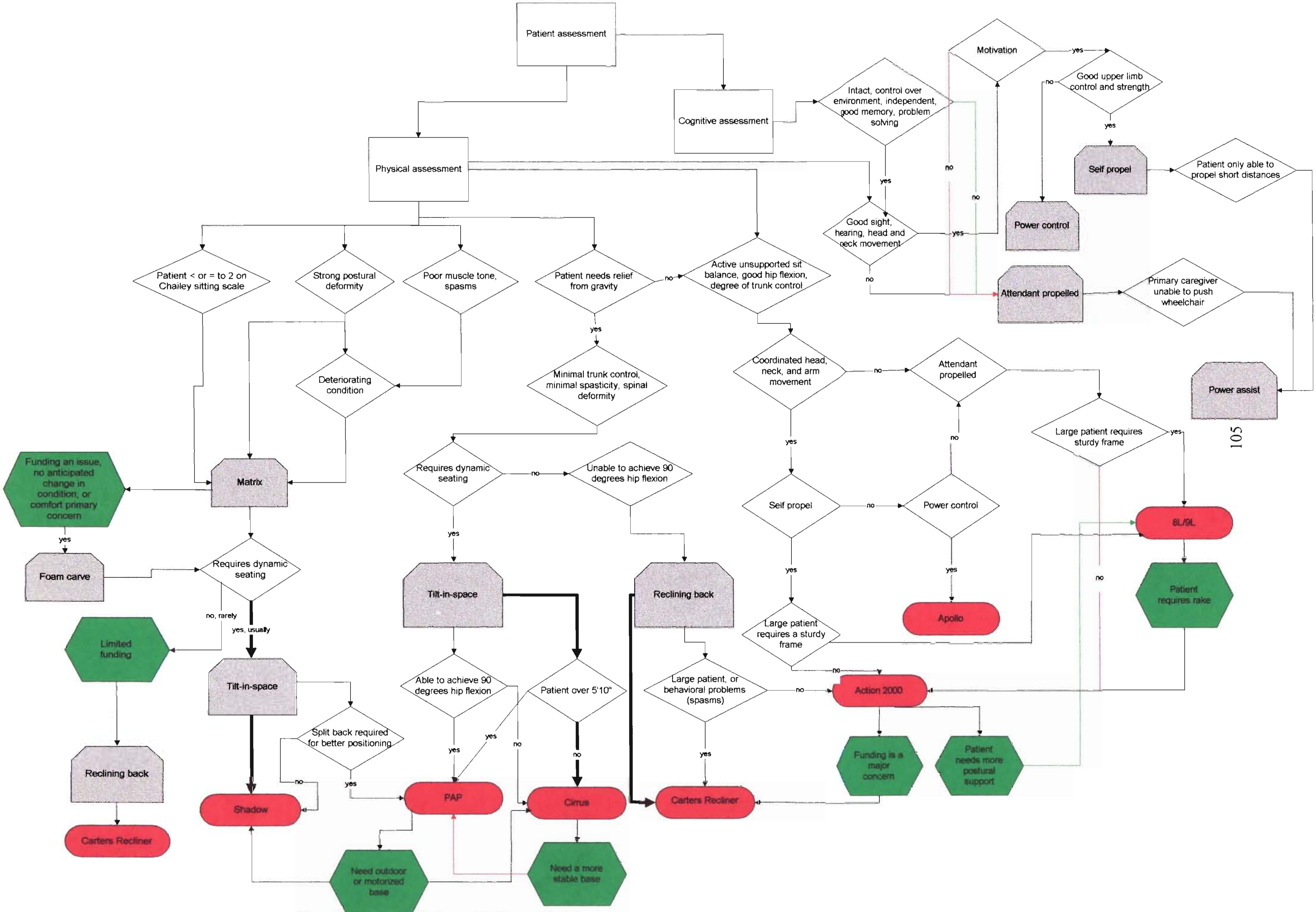
Positive	Action 2000	8L/9L	Apollo
	Armrests smaller/easier to remove for transfer	8L used if patient can self propel and has good upper body strength	
Environmental			
Funding			
Primary caregiver			
	More aesthetically pleasing than Carters Recliner		

APPENDIX G: Flowchart Model of Expert System

This flowchart models the decision process that occurs when the RHNd's clinicians select an appropriate wheelchair for prescription. It serves as an initial step in the RHNd's development of an expert system rule-base. Again, we only included the six most commonly prescribed wheelchairs, as selected by the staff (Shadow, Cirrus, PAP, Carters Recliner, Action 2000, 8L/9L/Apollo) to simplify the model. We based the flowchart on the information we obtained from the secondary questionnaire. We developed this flowchart to provide the RHNd with a simplified outline of the decisions involved in the wheelchair prescription process. The RHNd will review and modify the model as it further analyses the prescription process in focus group meetings.

The flowchart begins with square boxes that indicate standard processes; these include the patient assessment, physical assessment, and cognitive assessment. Further down the flowchart are diamond shaped boxes that represent integral clinician decisions. The grey heptagonal boxes symbolise the major types of seating and control which include matrix, foam carve, tilt-in-space, reclining back, power control, self propel, and attendant propelled. On the bottom half of the flowchart, the oval red boxes indicate the wheelchair selections. The hexagonal boxes that appear throughout the diagram represent secondary considerations that may affect the wheelchair decision. We included the varying colours in the connecting arrows only for clarity; the colours do not symbolise anything. However, the thick lined arrows represent the primary choice that clinicians make for the majority of the patients.

We broke the flowchart up into two main branches. On the left side we have placed the physical assessment and the subsequent decisions to determine the appropriate wheelchair. On the right side we have placed the cognitive assessment. The right branch serves to determine if the patient is a candidate for power control, self-propelling, or attendant propelled. Consequently, under the physical assessment we have included self-propelled, power controlled, and attend propelled as diamond shaped decision boxes because a yes/no decision has further implications in the wheelchair prescription. Then the chart flows through the various decisions to the wheelchair selection. Connected to the wheelchair selection boxes we have included secondary considerations that may affect wheelchair prescription. For clarity, we have only included the major factors we defined in our content analysis. We have provided a more detailed description of factors that affect the wheelchair decision in the content analysis of the secondary questionnaire (See Appendix F).


Patient assessment
Cognitive assessment
Physical assessment
Intact, control over environment, independent, good memory, problem solving
Motivation
Good upper limb control and strength
Self propel
Patient only able to propel short distances
Power control
Good sight, hearing, head and neck movement
Attendant propelled
Primary caregiver unable to push wheelchair
Power assist
Patient < or = to 2 on Chailey sitting scale
Strong postural deformity
Poor muscle tone, spasms
Patient needs relief from gravity
Active unsupported sit balance, good hip flexion, degree of trunk control
Deteriorating condition
Minimal trunk control, minimal spasticity, spinal deformity
Coordinated head, neck, and arm movement
Attendant propelled
Large patient requires sturdy frame
Funding an issue, no anticipated change in condition, or comfort primary concern
Matrix
Requires dynamic seating
Unable to achieve 90 degrees hip flexion
Self propel
Power control
8L/9L
Foam carve
Requires dynamic seating
Tilt-in-space
Reclining back
Patient requires rake
Apollo
Large patient requires a sturdy frame
Limited funding
no, rarely
yes, usually
Tilt-in-space
Able to achieve 90 degrees hip flexion
Patient over 5'10"
Large patient, or behavioral problems (spasms)
Action 2000
Split back required for better positioning
Reclining back
Funding is a major concern
Patient needs more postural support
PAP
Cirrus
Carters Recliner
Shadow
Carters Recliner
Need outdoor or motorized base
Need a more stable base
yes
no

APPENDIX H: Instruments

Wheelchair Prescription Process Interview

Respondent ______________________

Date ______________________

1) Introduction

2) Purpose of study: **To identify the methods and or reasoning clinicians use when making a wheelchair prescription. We would like to know if a typical order exists in which information is reviewed and if some aspects more important than others. We are going to attempt to synthesise this information into a general procedure that can be integrated into a basic design for a computer based prescription process.**

An expert system is a computer program that uses expert extracted knowledge to synthesise and organise desired information. Specifically in wheelchair prescription, an expert system will provide a generic wheelchair recommendation.

3) During the interview we will be trying to get information about:

The process you currently use to prescribe wheelchairs.

The sequence in which you review patient information.

Your recommendations on the improvement of wheelchair prescription.

2) Statement of consent and permission to tape record interview.

3) Assurance of limited confidentiality. No names will be disclosed in the results of this interview and the results of this will only be used for research purposes. Upon request a written copy of the interview will be submitted to you for your approval before the results are used.

6) If you have any questions or would like to see a copy of our finished project you can contact us at extension 5247.

Interview Questions

1) Please describe your current role in wheelchair prescription.

2) The patient assessment form includes relevant medical history, physical status functional status, equipment history, and intended environment use. Are there any additional factors that you feel should be added to the evaluation form to aid in the prescription process?

3) (a.) What other factors influence decisions that are not reflected in your evaluation forms or evaluation protocol?

   (b.) Do you feel these factors (question 3a) could be incorporated into an evaluation form or computer based expert system?

4) Do you use a systematic method when looking over the information gathered? Do you use some sort of rating system between criteria? Is one aspect more important than another is?

5) (a.) Do you first determine a basic wheelchair type that is needed for the patient and then move into specialisation?

   (b.) How do keep informed and up to date on the available technology?

6) What aspects of the evaluation help to determine the special accessories that need to be added to the wheelchair?

4) What do you think is the most time consuming or inefficient part of wheelchair prescription?

5) Do you think an expert system would be a beneficial aid in wheelchair prescription?

6) At this point in time, do you think it is feasible to attempt to create an expert system that will aid in the wheelchair prescription process?

7) Do you think there are any systems currently available, computer based or otherwise, that could help simplify the wheelchair prescription process?

Questions Concerning Wheelchair Selection

Please indicate the role(s) you play in wheelchair prescription:

OT ______

PT ______

Technical Staff ______

Wheelchair Clinic ______

Purpose: We are attempting to determine what chairs would be appropriate for certain patient conditions and situations. To simplify this process we have restricted the amount of wheelchairs to be considered. When filling in this questionnaire we would like you to focus on these 6 wheelchair types: the **Shadow (Matrix Base),** the **Cirrus**, the **PAP**, the **Carter's Recliner**, the **Action 2000**, and the **8L/9L/Appollo.**

How familiar are you with the wheelchairs?

V = Very Familiar F = Familiar U = Unfamiliar

Shadow (Matrix Base) _____

Cirrus _____

PAP _____

Carters Recliner _____

Action 2000 _____

8L/9L/Appollo _____

Many of the following questions include probes. For example:

- **Physical features**

These are provided just as guidelines. Please expand upon them as necessary and be specific. If in any case you feel the probes are not applicable, please indicate by writing N/A. Also, if you feel there is additional relevant information, please include that. You can write on the back of the paper to expand upon the questions as necessary. Please indicate the number of the question that your answer corresponds to.

Matrix Seating

1) What physical, postural factors (in the assessment or beyond) indicate that the patient requires matrix seating?

2) Why would you **not** use the Shadow base for matrix seating?
Physical, Environmental, Funding , Primary Carer

3) Why would you use a PAP rather than a Shadow for matrix seating?
Physical, Environmental, Funding , Primary Carer

4) Why would you use a Recliner rather than a Shadow for matrix seating?
Physical, Environmental, Funding , Primary Carer

5) Why would you choose foam carve rather than matrix to meet a patient's special seating needs?
Physical, Environmental, Funding , Primary Carer

6) If there are any other points you would like to add about matrix seating and its prescription that have not been covered in the previous questions please address them here:

Tilt-in-Space

7) What physical, postural factors (in the assessment or beyond) indicate that the patient requires a tilt-in-space mechanism on the wheelchair?

8) What factors would rule out the Cirrus if tilt-in-space was needed?
Physical, Environmental, Funding , Primary Carer

9) What factors would rule out the PAP chair if tilt-in-space was needed?
Physical, Environmental, Funding , Primary Carer

10) If the patient needed both matrix seating and tilt-in-space would you ever rule out the Shadow? Why?
Physical, Environmental, Funding , Primary Carer

11) Would a chair with tilt-in-space ever be prescribed for a patient who does **not** need the tilt-in-space mechanism? Why? Which chairs would this occur with?

12) If there are any other points you would like to add about tilt-in-space and it prescription that have not been covered in the previous questions please address them here:

Reclining Back

13) What physical, postural factors (in the assessment or beyond) would indicate that the patient needs a chair with a reclining back, but not tilt-in-space?

14) Why would you **not** prescribe a Cirrus for a patient who required a wheelchair with a reclining back?
Physical, Environmental, Funding , Primary Carer

15) Why would you **not** prescribe a Carters Recliner for a patient who needed a wheelchair with a reclining back?
Physical, Environmental, Funding , Primary Carer

16) Why would you **not** prescribe an Action 2000 recliner for a patient who needed a wheelchair with a reclining back?
Physical, Environmental, Funding , Primary Carer

17) If there are any other points you would like to add about a reclining back and its prescription that have not been covered in the previous questions please address them here:

Power Control

18) What physical, postural factors (in the assessment or beyond) would indicate the patient would benefit from power control?

19) What factors would indicate that a power wheelchair is **not** appropriate for a patient?
Cognitive ability, Motivation

20) Why would you **not** prescribe the Apollo for a patient who required a powered wheelchair, but did not need matrix seating?
Physical, Environmental, Funding , Primary Carer

21) What would indicate that the addition of the power assist to the wheelchair is required?
Physical, Environmental, Funding , Primary Carer

22) If there are any other points you would like to add about power control and its prescription that have not been covered in the previous questions please address them here:

Standard Chairs

23) What physical, postural factors would indicate that a patient does **not** need tilt-in-space, matrix seating, nor power control and is a candidate for a standard type chair?

24) What factors would indicate that the patient could propel himself or herself?

25) Why would you **not** prescribe the standard Action 2000 for a patient that required a standard wheelchair?
Physical, Environmental, Funding , Primary Carer

26) Why would you **not** prescribe the 8L/9L for a patient that required a standard wheelchair?
Physical, Environmental, Funding , Primary Carer

If there are any other points you would like to add about standard wheelchairs and their prescription that have not been covered in the previous questions please address them here.

APPENDIX I: Glossary of Terms

Algorithm- A formal procedure guaranteed to produce correct or optimal solutions.

ARTMAP- A type of neural network designed to deal with nonstationary data.

Belt driven- Wheelchair model propelled by motor connected to rear wheel by belt. Generally allows for smoother ride.

Case based reasoning- An expert system based on cases that are developed using a random sample of previously diagnosed cases.

Decision tables- An expert system that uses a list of indicating factors that are rearranged in every possible scenario and then each question is individually diagnosed.

Decision trees- An expert system that uses solutions obtained through a series of questions, which are answered in a flowchart format.

Dependent mobility chairs- Wheelchairs that require another individual to propel them. Examples are strollers and transport chairs.

Depth- The ability to handle difficult problem domains using complex rules in an expert system.

Direct drive- Motorised wheelchair model that has motor directly connected to drive train (wheel). It allows for increased speed and power.

Fold-up design- Wheelchair design with an “X”-frame that can fold up for easy storage.

Fuzzy logic- A superset of Boolean logic that uses a continuous range of truth values on the interval [0,1].

Hammock seating- Wheelchair seating style that has flexible material stretched across the frame horizontally.

Independent manual mobility chairs- Wheelchairs that are propelled manually by the patient.

Interface- Method of control of motorised components of wheelchair. Examples are joysticks or directional buttons.

Knowledge acquisition- The process that involves eliciting, analysing, and interpreting the knowledge that a human expert uses when solving a particular problem and then transforming it into a suitable machine representation.

Matrix- A customised seating system which aims to provide preventative and corrective body support.

Mobile device- Category of rehabilitative equipment that involves movement. Wheelchairs, Walkers, and scooters fall under this category.

Neural network- Computer programming application that mimics the neuronal network of the nervous system and is designed to learn complex rules by recognising patterns in input data.

Polar graph- Program used by RHNd to visualise patient satisfaction in a circularised graphical format.

Power driven wheelchairs- Wheelchairs that are motorised.

Pressure management- Method of seating to define ideal posture for distribution of pressure on patients that lack muscle strength to do so themselves.

Purposive sampling- Goal orientated sampling used when explicit information is required from specific people.

Rule based reasoning- A rule-based expert system is a set of expert defined rules.

Seating system- Devices used to support individuals in corrective postures for rehabilitation. A wheelchair is a seating system.

Self-knowledge- The ability of an expert system to examine its own reasoning and explain why it came to the conclusion it did.

Symbolic reasoning- Problem solving based on the application of strategies and heuristics to manipulate symbols standing for problem concepts.

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