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AN EVALUATION OF WHEELCHAIR RACING HAND GEAR

BY

CATHERINE L. JACOBSON ©

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ABSTRACT

An Evaluation of Wheelchair Racing Hand Gear

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The purpose of this research was to determine if currently available forms of hand gear worn by wheelchair racers met their needs in order to develop appropriate design specifications for improving hand gear. The procedure used was an adaptation of the Functional Clothing Design Process (Orlando-DeJonge, 1984) and the User-Oriented Product Development Process (Rosenblad-Wallin, 1985).

Literature reviews, a market survey, observations, interviews and questionnaires were used to collect data. Four female and fourteen male wheelchair athletes were interviewed or agreed to fill out a questionnaire. Athletes wore customized or manufactured hand gear which met many, but not all, of their comfort, fit, protection, weight, flexibility, durability and traction needs. A final list of design specifications will depend upon future material performance tests and athletes' individual requests for hand gear. Future hand gear must be designed according to (a) the athlete's stroking style, (b) which fingers are grouped together and (c) the athlete's hand measurements.

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CHAPTER I - INTRODUCTION

The concept of sport for people with disabilities was first introduced in England in the later 1940's and then in the United States in the early 1950's (Corcoran et al., 1980). The change in attitude towards, and acceptance of, sport for people with disabilities was instigated by the pioneering efforts of spinal cord injured (SCI) veterans of World War II (Botvin-Madorsky & Curtis, 1984) and the extensive efforts of Sir Ludwig Guttman, a man who recognized sport as a vital part of the physical and psychological health of people with disabilities (Jackson & Fredrickson, 1979). Reasons for participating in sport are no longer just rehabilitative in nature as many people participate to maintain a healthy lifestyle. As well, some athletes consider training a full-time job and participate at high level national and international events (Burnham, 1993). Since the first Stoke Mandeville competitions involving 16 athletes, "wheelchair sport has grown rapidly in popularity and competitiveness as was demonstrated in the 1992 Summer Paralympic Games which involved 3,032 competitors from 96 countries around the world" (Burnham, p. 1). Not only has the number of competitors increased, but so has the variety of sports in which they participate. The sports include swimming, football, basketball, tennis, table tennis, track and field events, weight lifting, murderball, volleyball, skiing (downhill and cross-country), biathlon, ice-sledge racing and sledge hockey (Botvin-Madorsky & Curtis, 1984; Curtis & Dillon, 1985; Anonymous, 1994).

An increase in the number of people with disabilities participating in a variety of sports indicates a growing need for functional sportswear and equipment to combat injury and enhance physical performance. Unfortunately, research and literature from a clothing and textile perspective on sportswear/equipment design for the athlete with a disability is virtually non-existent. Over the past two decades, extensive research dealing with clothing for people with disabilities has focused on (a) clothing and its importance for social acceptance, (b) fitting and dressing problems, and (c) appropriate alterations, pattern adaptations and closures to deal with the fitting and dressing problems that many people with disabilities experience.

The importance of well-fitting and attractive clothing for a positive self image and societal acceptance has been cited by many researchers (Hanselman-Ahrbeck & Friend, 1976; Feather, Martin, & Miller, 1979; Hoffman, 1979; Kernaleguen, 1978; Menec, 1989; Newton, 1976; Rudd, 1990; Young, 1988). Clothing for people with disabilities should be attractive and fashionable and minimize a visible physical disability or figure variation to an observer (Hoffman; Menec; Newton). This is especially important as clothing helps to create a positive first impression (Kaiser, 1985; Krieger, 1988). Many people with disabilities, in fact most people in general, may spend time on appearance to avoid unnecessary sympathy and patronage (Feather, 1976; Macartney, 1973).

Fashionable clothing which disguises visible physical disabilities or figure variations should also allow for independent dressing (Hoffman, 1979; Kaiser, 1985; Kernaleguen, 1978; Krieger, 1985; Macartney, 1973; Menec, 1989; Newton, 1976; Young, 1988). Independence in personal and everyday activities is important for positive feelings of self esteem (Macartney; Menec) and thus, clothing should minimize or solve problems with dressing caused by a lack of coordination, a limited range of movement or the inability to grasp (Forcese & Shannon, 1983; Macartney; Menec). Modifications to ready-to-wear clothing and appropriate clothing styles, fabrics and closures have also been investigated and discussed relative to independent dressing (Cochrane & Kelly, 1989; Colter, 1988; Dallas & White, 1982; Forcese & Shannon; Hoffman; Jenkins, 1989; Kernaleguen; Macartney; Mackay, 1983; Menec). "While it is recognized that functional features make dressing easier and add to physical comfort, these features should not be achieved at the expense of attractiveness" (Levitan-Rheingold, Boettke-Hotte, & Mandel, 1980, p. 72).

Fitting problems with ready-to-wear clothing are common for many people within society. One group of people who have distinct fitting problems with ready-to-wear apparel are those who use a wheelchair. These individuals have a unique body physique because they are constantly in a sitting position. This creates fitting problems since ready-to-wear apparel is designed for the standing, symmetrical figure (Colter, 1988; Kernaleguen, 1978; Jenkins, 1989). The typical seated figure often has a rounded back and shoulders, and a hollow or concave chest. This may create a lack of fabric ease across the back and excess fabric across the chest in ready-to-wear shirts, blouses, blazers and other tops. As well, the seated figure has a shorter waist to hip measurement at centre front and a longer waist to hip measurement at centre back resulting in excess folds of fabric in the abdomen, and not enough fabric ease across the buttocks. Pant legs are often too short, riding up the leg of the seated wearer. A person who uses a wheelchair and leads a (physically) active lifestyle typically has well developed shoulder and upper arm muscles, often larger than the average person's, which results in tight fitting sleeves and shoulders (Colter; Kernaleguen; Jenkins).

It is evident that many of the everyday clothing needs of people with physical disabilities are well understood. Therefore, it seems logical to begin exploring untouched areas in the realm of clothing for people with disabilities. Increased participation in recreational and competitive sport has had a very positive impact on many athletes' physical and psychological well-being. Research focusing on the design of appropriate sportswear and equipment for athletes with disabilities could lead to improved products which may enhance athletic performance. To date, no research has been published on the forms of hand gear worn by the wheelchair athlete and as a result, this research evaluated wheelchair racing hand gear to assess how well the needs of these athletes are being met.

Purpose of the Research

The main purpose of this research was to determine if currently available forms of hand gear worn by wheelchair racers were meeting their needs. This evaluation led to the development of appropriate design specifications that may be used for improving hand gear.

Justification

In the past, people with disabilities were considered helpless invalids and outcasts from the rest of society (Steadward & Walsh, 1986). Their needs, such as those for clothing, were overlooked while the needs of the majority took precedence (Altman, 1981; Feather et al., 1979; Reich, 1976). In 1978 Kernaleguen stated that society had begun to realize people with disabilities could be both economically productive and socially functional. Crucial to this change of attitude was the involvement of people with disabilities in recreational and organized sport, an important means of integrating people into society (Botvin-Madorsky and Madorsky, 1983). In the end, sport was instrumental in "making people realize that sickness and disability are not synonymous" (Jackson & Fredrickson, 1979, p. 296) and that it is remaining athletic abilities, motivations and satisfactions that need to be focused upon (Kennedy, 1980).

As part of an individual's rehabilitation process, sport can play an important role in increasing one's motivational levels, acceptance of the disability and ability to function more independently in daily activities (Ferrara, Buckley, Messner, & Benedict, 1992). The role of sport has definitely found a place in the everyday lives of people with disabilities, and is no longer considered important only for rehabilitation. Although sport is not the only type of everyday recreational outlet, participation "...does improve mobility, balance, endurance, decrease weight, and eliminates or helps to diminish the sense of depression that so often accompanies a serious or permanent physical disability" (Jackson & Fredrickson, 1979, p. 296). As well, sport has important social implications for people and "for many people the value of sport would be lost without the opportunity to socialize with friends, relatives, co-workers and classmates" (McClellan & Frogley, 1993, p. 5).

Kennedy (1980) stated that a lack of relevant sport literature and media exposure in the past has isolated wheelchair athletes from public recognition. Therefore, research and publication of the abilities and achievements of these athletes and literature on wheelchair sports, will encourage the demise of any remaining social stigma and economic barriers that keep people with disabilities from achieving their potential in society (Jackson & Fredrickson, 1979). Many clothing and textile experts have the skills necessary for designing functional and protective sportswear and equipment which would protect the athlete from injury and in turn, enhance athletic performance. In particular, people who use wheelchairs rely heavily on their hands to perform everyday activities such as transferring on and off a wheelchair and propelling the wheelchair (Gellman et al., 1988; Aljure, Eltorai, Bradley, Lin, & Johnson, 1985). Any injury to the hands could result in a loss of independence. Therefore, the evaluation of wheelchair racing hand gear to develop design specifications for (a) improving the efficiency and performance of the racer and (b) protecting the wheelchair user's hands during wheelchair racing to safeguard independence in everyday life, is warranted.

Objectives

The objectives of this research were:

1) To determine what types of hand injuries, medical or physical problems are experienced by the wheelchair athlete that might be reduced by wearing hand gear.
2) To assess fit and comfort of hand gear currently worn by wheelchair racers.
3) To assess the protection provided by hand gear currently worn by wheelchair racers.
4) To assess the flexibility and weight of hand gear currently worn by wheelchair racers.
5) To identify and assess other relevant aspects of wheelchair racing hand gear.
6) To develop and recommend appropriate design specifications for producing hand gear for wheelchair racers.
7) To contribute to the literature on sportswear needs of athletes with a disability.

Definitions

Hand Gear: is anything the wheelchair racer wears on his/her hands during racing including, but not limited to, gloves.

Design Factors: For this research, design factors are the general concepts which broadly describe a design problem and determine what is in need of further, more specific, investigation.

Design Criteria: Once established, the design factors are thoroughly investigated to break them down into smaller components, known as design criteria.

Design Specifications: After all the conflicts between design criteria are identified and solved, a final set of design criteria are determined. This final list of criteria becomes the design specifications.

Wheelchair Racers' Needs: are the important (design) factors of hand gear that must be met so that athletes can race efficiently without harming the hands. Comfort, fit, protection, weight and flexibility were the initial needs identified and operationally defined in this research.

Comfort: Smith (1986) considered comfort as a "neutral sensation, when we are physiologically and psychologically unaware of the clothing we are wearing" (p. 23). For the purposes of this research, comfort is defined as a racer's state of mind during racing in which the task at hand (racing) is the focus of attention allowing the athlete to perform efficiently. Comfort is operationally defined in the interview (Section B; Section D, questions: 4, 5, 6 & 9) and questionnaire (Section II; Section III; Section IV, question 5; Section V, question 2).

Fit: "By definition, dynamic fit refers to whether a garment allows the body to perform usual tasks without garment interference and resistance" (Tremblay, 1989, p. 16). "Static fit...is the relationship between garment size and body size" (Tremblay, 1989, p.18). In this research, fit is defined as the desired relationship between the size of hand gear and the hand so that the athlete can proficiently perform necessary movements of racing. Fit is operationally defined in the interview (Section B; Section C, question 2; Section D, question 2) and questionnaire (Section II; Section IV, question 4; Section V, question 1).

Protection: is defined by how well a wheelchair racer's hand gear prevents an athlete from sustaining an injury which would inhibit further racing and/or negatively affect everyday life. Protection is operationally defined in the interview (Section A, question 3; Section B; Section D, questions 2, 3, 9, 10, 11) and the questionnaire (Section II; Section III, question 6; Section IV, questions 1, 2, 5; Section V, question 3).

Weight: is defined as the lightness or heaviness of hand gear deemed appropriate or desired by the wheelchair racer. Weight is operationally defined in the interview (Section B; Section D, question 5) and the questionnaire (Section II; Section V, question 5).

Flexibility: is defined as the ability for the wheelchair racer to flex and extend his/her wrist, fingers, thumbs while wearing hand gear. Flexibility is operationally defined in the interview (Section B) and the questionnaire (Section II; Section IV, question 3; Section V, question 4).

Glossary of Terms

Disability: The World Health Organization (1980) states in "the context of health experience, a disability is any restriction or lack...of ability to perform an activity in the manner or within the range considered normal for a human being" (p.143).

Person with a Physical Disability: is "anyone who does not have full functional mobility. This means that the person is unable to perform the typical daily tasks that are...required to move freely and care for one's own well being" (Quinn & Chase, 1990, p. 2) without human or mechanical aid.

Able-Bodied Athlete: is anyone participating in competitive sports who does not have a physical disability such as paralysis, blindness or amputation (Jackson & Fredrickson, 1979).

Athlete with a Disability: is anyone participating in competitive sports who has a physical disability which hinders his/her ability to compete with able-bodied athletes.

Arthritis: is a crippling disease which, according to Cochrane and Kelly (1989), and Hoffman (1979), can cause severe pain, redness, heat, swelling, deformity and stiffness. The joints in the hands are often deformed and the hand itself has a problem gripping and functioning properly. Body movement and range of body motion are often extremely limited.

Cerebral Palsy: Individuals with cerebral palsy suffer from either impairment or loss of voluntary muscle due to damage during brain development. They have involuntary, awkward and spastic movements, as well as poor balance. It is not uncommon for other disabilities, such as mental retardation, to accompany cerebral palsy (Cochrane & Kelly, 1989; Hoffman, 1979).

Muscular Dystrophy: is a disease in which one is disabled by a chronic and progressive weakening of voluntary muscles. People with muscular dystrophy often have limited range of body movements and can have difficulty, for example, raising their arms above the head (Hoffman, 1979).

Multiple Sclerosis: is a progressive and chronic crippling neurological disease which results in severe weakening of muscles accompanied by spasms, sight impairment, lack of balance and intention tremors (Cochrane & Kelly, 1989; Hoffman, 1979).

Spinal Cord Injury: Those who have suffered an injury to their spine may experience one or more of the following: spasms, loss of sensation and balance, changes in motion, lost control of joints and paralysis (Cochrane & Kelly, 1989; Hoffman, 1979).

Paraplegic: is a person who is paralysed in the lower extremities (Cochrane & Kelly, 1989). This can range from total abdominal and leg paralysis to only quadricep dysfunction (Corcoran et al., 1980).

Quadriplegic: is a person who is paralysed in the upper and lower extremities. Body mobility can be as little as limited hand movement (no trunk and lower extremity strength) to good use of fingers and hands with a "generalized weakness of the trunk and lower extremities" (Corcoran et al., 1980, p. 700).

Medial versus Lateral: The median sagittal plane divides the body into right and left halves. "A structure situated nearer to the median plane of the body is said to be medial to the other...a structure that lies farther away from the median plane than another is said to be lateral to the other" (Snell, 1986, p. 1). Refer to Figure 1.

Proximal versus Distal: These terms "describe the relative distances from the roots of the limbs; for example, the arm is proximal to the forearm and the hand is distal to the forearm" (Snell, 1986, p. 1). Refer to Figure 1.

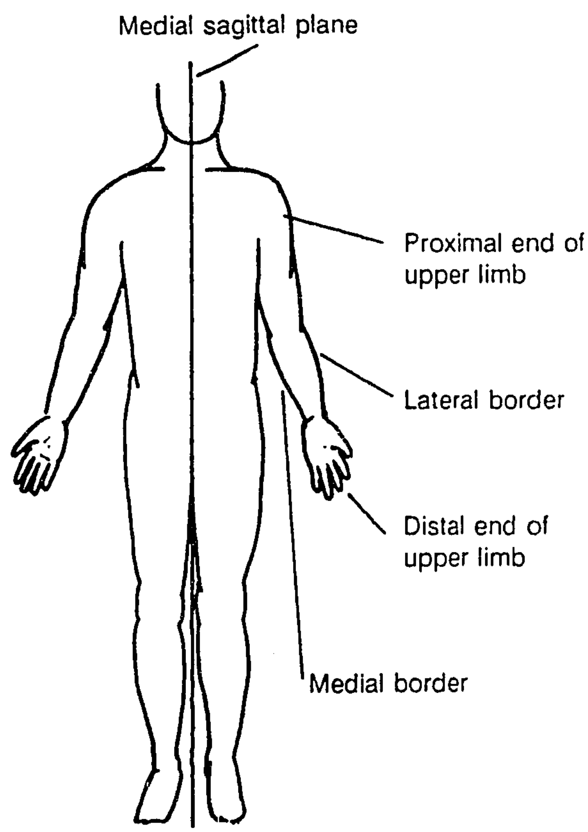


Figure 1. Medial versus lateral; Proximal versus distal. (Adapted from Snell, 1986).

Pronation: is "A movement in which the palm of the hand is moved downward or backward" (Hole, Jr., 1992, p. 546); more specifically, according to Snell (1986, p. 5), pronation of the forearm "is a medial rotation of the forearm in such a manner that the palm of the hand faces" backward.

Supination: is a movement where the palm faces upward when the arm is outstretched (Hole, Jr., 1992); more specifically, according to Snell (1986, p. 5), supination "of the forearm is a lateral rotation of the forearm from the pronated position, so that the palm of the hand" faces forward.

Flexion: "Flexion at a joint results in a decrease of the angle between the two segments that meet at that joint" (Hay & Reid, 1982, p. 12).

Extension: is the "movement by which the angle between the parts at a joint is increased" (Hole, Jr., 1992, p. 540). Extension "means straightening the joint" (Snell, 1986, p. 5) and is the opposite of flexion (Hay & Reid, 1982).

CHAPTER II - REVIEW OF LITERATURE

In order to design wheelchair athletes' sportswear and equipment, a designer must properly assess their needs, which necessitates a detailed review of all relevant literature. The first part of the literature review discusses the anatomy of the hand. Physical disabilities, the importance of physical activity for people who use a wheelchair, statistics on people with a disability in Canada and those participating in physical activity are discussed. To focus more specifically on wheelchair racing, the concept of wheelchair sport, the numbers of Canadian athletes participating at high level competitions, the wheelchair sport classification system, equipment and stroking techniques and injuries are all discussed. Comfort, fit and protection, three of the design factors, are also reviewed.

The Human Hand

Hand function is very important to humans as "...most of us require good hands for almost everything we do save abstract thought" (Brown, 1987, p. 2). "The hand is an organ of grasp as well as fine movements. It is an organ of sensation, fine discrimination, and exquisite dexterity" (Cailliet, 1971, p. 1). The upper extremity (the arm) is responsible for placing the hand in the necessary position for function.

Bones of the Upper Extremity

The bones of the upper extremity are the humerus, radius, ulna and those of the hand. The humerus extends from the clavicle and scapula (at the shoulder) to the elbow. The radius and ulna constitute the bones of the forearm and extend from the elbow to the wrist. The hand is made up of a wrist, a palm and five digits. "The...wrist consists of eight small carpal bones...The resulting compact mass is called a carpus" (Hole, Jr., 1992, p. 151). The palm consists of five metacarpal bones and the fingers consist of the phalanges bones. Each finger consists of three phalanges bones while the thumb consists of two (Hole, Jr.). The carpal bones are generally cuboidal, while the phalanges and metacarpal bones are tubular (Groner & Weeks, 1992).

The eight carpal bones are arranged in two rows. The proximal row (nearest the forearm bones) consists of the scaphoid, lunate, triquetral and the pisiform bones (from lateral to medial). The pisiform is located on the palmar surface of the triquetral. The distal row, from lateral to medial, consists of the trapezium, trapezoid, capitate and hamate bones (Cailliet, 1971; Snell, 1986). "The carpal bones form an arch that is concave on its palmar surface" (Cailliet, p. 10).

The concave arch is spanned by the transverse carpal ligament (flexor retinaculum) and the resulting hollowed space is known as the carpal tunnel. Running through this tunnel are the tendons of the flexor digitorum profundus, flexor digitorum superficialis, flexor carpi radialis and flexor pollicis longus and the median nerve (Cailliet; Katz, 1994; Snell).

Muscles of the Hand

Hand movement results from the contraction of intrinsic and extrinsic muscles. The intrinsic muscles have both attachments within the hand. The extrinsic muscles have their proximal attachment on the humerus or forearm bones and pass over the wrist and carpal bones to attach to the digits. All extrinsic muscles pass over the carpal bones completely, attaching upon the metacarpal and phalangeal bones, except the flexor carpi ulnaris; the flexor carpi ulnaris attaches to the pisiform (Byrne, 1959; Cailliet, 1971; Enna, 1988)

Intrinsic muscles. The intrinsic muscles are those that attach within the hand and act upon the digits (Cailliet, 1971). These muscles are made up of: (a) the thenar group which performs thumb function; (b) the hypothenar group which performs the fifth or little finger function; and (c) the interossei and lumbricals which "perform abduction and adduction of the fingers and combine with the extensor tendons for finger extension" (Cailliet, p. 34).

Extrinsic muscles. The extrinsic muscles are composed of two sets of muscles: the *extensor* forearm muscles and the *flexor* forearm muscles. The extensor forearm muscles are either superficial (surface) muscles or deep muscles and are primarily associated with wrist movement. The flexor forearm muscles have a superficial group which attaches to the second and third metacarpal, the pisiform and the fifth metacarpal. The deep layer of muscles is necessary for finger flexion (Cailliet, 1971; R. Steadward, personal communications, November 14, 1994).

Nerves of the Hand

There are three nerves which carry motor (muscle function) and sensory (sensation) fibres throughout the hand. These nerves are the median, ulnar and radial nerves. This section is divided into a discussion of the motor function and sensory function of the three nerves.

Motor function. The median nerve runs down the lateral side of the upper arm and crosses over, halfway, to the medial side. As it enters the wrist, it passes through the centre of the carpus, through the carpal tunnel, and splits into two branches in the palm of the hand. The motor branches of the median nerve innervate muscles in the forearm and hand (lumbricals 1 and 2, and short muscles of thumb, or the thenar group) (Snell, 1986). Within the hand, the median nerve is important for a 'precision' grip (Cailliet, 1971). See Table 1 for a listing of the specific muscles.

The ulnar nerve passes superficially along the medial side of the forearm travelling deeply into the hand. The motor branches of the ulnar nerve supply forearm and hand muscles (hypothenar group, palmaris brevis, lumbricals 3 and 4, interossei and adductor pollicis muscle) as indicated in Table 1 (Snell, 1986). The ulnar nerve is important for a powerful grip (Cailliet, 1971).

The radial nerve enters the arm, giving off branches to the medial and long heads of the triceps muscle. It continues downward along the posterior side of the arm and into the forearm where it stimulates the extrinsic muscles, as indicated in Table 1. In the hand, it is responsible for innervating the extrinsic muscles of the thumb and fingers (Cailliet, 1971; Snell, 1986). See Table 1 for a list of the forearm and hand muscles.

Table 1

Upper extremity muscles innervated by the median, ulnar and radial nerves

	MEDIAN NERVE	ULNAR NERVE	RADIAL NERVE
FOREARM MUSCLES	- pronator teres - flexor carpi radialis - palmaris longus - flexor digitorum superficialis - flexor pollicis longus - pronator quadratus - HALF of flexor digitorum profundus	- carpi ulnaris - HALF of flexor digitorum profundus	- brachioradialis - extensor carpi radialis longus - ALL muscles in the posterior fascial compartment: a) extensor carpi radialis brevis b) extensor digitorum c) extensor digiti minimi d) extensor carpi ulnaris e) anconeus f) supinator g) abductor pollicis longus h) extensor pollicis brevis i) extensor pollicis longus j) extensor indicis
HAND MUSCLES	- lumbricals 1 & 2 - short muscles of thumb: a) abductor pollicis brevis b) flexor pollicis brevis c) oppenens pollicis	- lumbricals 3 & 4 - palmaris brevis - interossei (8 in total) a) palmar (4) b) dorsal (4) - short muscle of thumb: a) adductor pollicis - short muscles of little finger: a) abductor digiti minimi b) flexor digiti minimi c) opponens digiti minimi	

Sensory function. The sensory branch of the median nerve "passes into the second and the third web spaces" (Cailliet, 1971, p. 47) giving sensation to the skin on the palmar side of the thumb, the index, middle and (half of) ring fingers as well as the distal ends of the middle finger, index finger and thumb on the dorsal side of the hand. Approximately half of the palm of the hand is innervated by the median nerve as well (Snell, 1986). Refer to Figure 2.

The ulnar nerve stimulates the skin on the dorsal and palmar sides of the little finger, half of the ring finger, as well as the skin on the palm and back side of the hand (Snell, 1986; R. Steadward, personal communications, November 14, 1994). See Figure 2.

The radial nerve stimulates the skin on a portion of the back of the hand as indicated in Figure 2 (Snell, 1986; R. Steadward, personal communications, November 14, 1994).

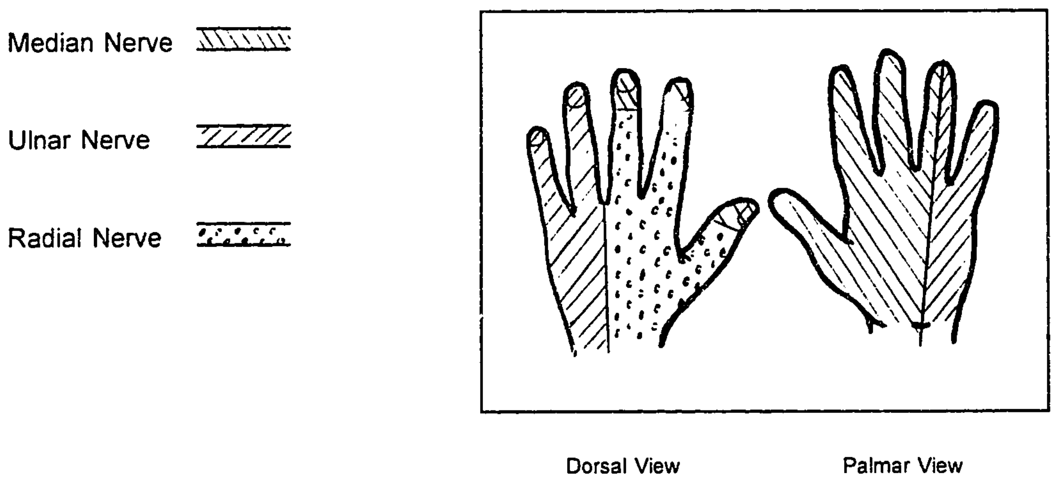


Figure 2. Parts of the (LEFT) hand to which the nerves supply sensory fibres. (Adapted from Cailliet, 1971).

Hand Impairments

When the hand loses high quality sensation due to nerve impairment, it loses the ability to complete the skilled functions it was designed to do. Nerve impairment may be a result of nerve compression or nerve severance. Nerve compression results in damage to and swelling of a nerve. The pain felt by a person may be sharp and burning, often occurring at night or during rest (Cailliet, 1971). Hand dysfunction may be very slight early in the development of a progressive nerve disorder. "Slight clumsiness, minimal dulling of sensibility or marginal weakness may all affect overall hand efficiency" (Brown, 1987, p. 4).

Nerve compression is most likely to be problematic for the median nerve. This compression commonly occurs at the wrist and results in numbness, burning and (the eventual) tingling of the first three fingers. Clumsiness, accompanied by weakness and an inability to hold objects may occur (Cailliet, 1971). The ulnar nerve undergoes compressional forces at the elbow. "The patient may initially complain of hypersensitivity of the fourth and fifth fingers varying from a mild sensation to a 'burning' feeling. Numbness may develop and 'weakness and clumsiness' are claimed" (Cailliet, p. 71). Difficulty spreading the ring and little fingers may be noted and the elbow at the ulnar grove may be sore (Cailliet).

When a person experiences a high level spinal cord severance, he/she will find it difficult to complete many self-care activities. When the lesion is at the C4, C5 and C6 levels of the spinal cord, people will have some use of their hands although they will have difficulty washing, brushing their teeth or shaving in so much that they may become dependent on others or on electronic equipment (Cooper, 1990; Lamb, 1987). When the spinal cord has been injured at the C7 level, wrist flexion and extension may be possible. Wrist flexion and extension is present and some finger flexion and extension enables a person to perform grasping and releasing actions at a C8 level of injury. Unfortunately, no intrinsic muscles function. If an individual is injured at the thoracic level, or lower, their hands are not affected (Shephard, 1988). Figure 3 depicts the levels of the spinal cord.

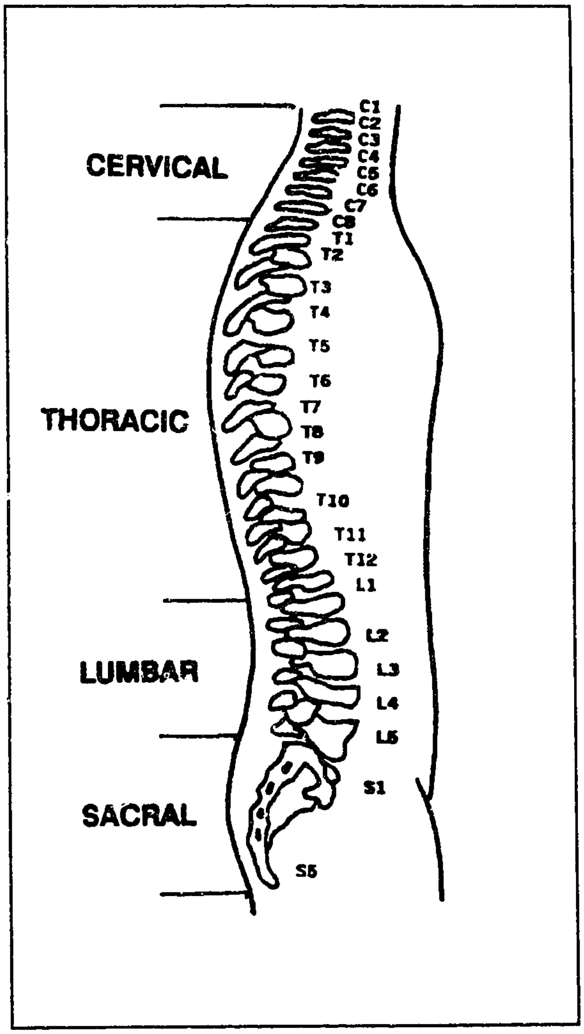


Figure 3. Anatomical levels of the spinal cord. (Adapted from Cooper, 1990).

People with Physical Disabilities

People with physical disabilities are those who require some type of aid, be it human or mechanical, to function properly in everyday life. Physical disabilities are a result of birth defects, diseases or accidents. Birth defects such as cerebral palsy or muscular dystrophy, disabling diseases such as arthritis or multiple sclerosis and amputations, strokes and accidental spinal cord injuries are some causes of disabilities which can affect hand dexterity, range of body movements and ease of mobility (Hoffman, 1979; Quinn & Chase, 1990).

Canadian Statistics

Statistics dealing strictly with the number of people in Canada who have a disability were not attempted until the 1980's. The Canadian Health and Disability Survey (Statistics Canada, 1985) was conducted as a supplement to the 1983/84 Canadian Labour Force Survey (LFS). This survey represented Canada's first attempt to collect national data on the prevalence of disability based on the functional definitions of disability and handicap accepted by the World Health Organization (Statistics Canada). This first attempt collected information on the numbers of Canadians with some level of disability, the number of Canadians who used an aid or prosthesis or had special transportation needs, their employment status and level of education. As well, the number of Canadians with a disability who owned their home was determined, as was the number of children with a disability in need of special schools or classes.

The Health and Activity Limitation Survey (HALS), conducted in 1986 and 1987, gathered information about the nature and severity of disability and the barriers which people with disabilities encounter in their daily activities (Lavigne & Morin, 1991). This survey included all persons with a physical or psychological disability living in Canada. The HALS surveyed people with disabilities to determine such things as participation in cultural activities inside and outside the home, support networks and participation in physical activities. HALS is the most recent collection of data and it determined that, in 1986/87, there were 3.3 million people living in Canadian households and health institutions who had a disability. Table 2 breaks down this number into categories of household, health institution and age. As well, the initial summary of HALS done by Statistics Canada (1990) mentioned that approximately 46,030 people were using a wheelchair for mobility in 1986/87.

Table 2

Canadians with a disability: Household, health institution and age[a]

AGE	HOUSEHOLD	HEALTH INSTITUTION
0 - 14 years	275, 045	2, 395
15 + years	2, 794, 550	244, 880

[a] adapted from Lavigne & Morin (1991).

Physical Activity and People who use Wheelchairs

Medical improvements have enabled spinal cord injured individuals who use a wheelchair to live as long as the able-bodied population. Spending many years in a wheelchair without exercise is one major reason for the high fatigue and low fitness levels of many people. This inactivity can lead to obesity, skin and bladder infections, increased muscle tension leading to spasticity and contracture, muscle and joint pain and stiffness, decreased lung volume and strength of respiratory muscles, an inefficient heart muscle, decreased blood circulation to the brain, organs, muscles, poor posture, muscular weakness, fatigue, osteoporosis and lowered self-esteem (Gairdner, 1983). Physical activity can be an effective measure against these medical problems. A physically fit person who uses a wheelchair will have enough cardiac reserve for the daily demands of wheelchair mobility, wheelchair transfer activities, getting up and down curbs and ramps, social and recreational activities (Corcoran et al., 1980; Gairdner).

A summary of the highlights of the Health and Activity Lifestyle Survey illustrates the numbers of people who participate in some form of physical activity:

Approximately 48% of disabled adults never participate in physical activities.

Thirty percent of disabled adults report that they participate in physical activity three or more times per week.

There is no marked difference in the levels of participation between men and women.

The proportion of disabled persons who do not participate in any physical activity increases with age and with severity of disability but decreases with educational level.

The proportion of disabled adults who do not participate in any physical activity is highest in Newfoundland and lowest in British Columbia.

The majority of the disabled adult population are satisfied with the frequency of their participation in physical activities.

Physical inability to do more is the obstacle most frequently reported by disabled adults who are dissatisfied with the frequency of their participation in physical activities. (Lavigne & Morin, 1991, p. 13)

Wheelchair Sports

As previously mentioned, the concept of wheelchair sports for spinal cord injured people arose in England just after the second World War mainly due to the large number of veterans who returned home injured from the war (Corcoran et al., 1980). Modern technology and drug development (especially penicillin) saved the lives of many spinal cord injured veterans (Savitz, 1978). When the idea of sport as a form of rehabilitation arose, "the Spinal Injuries Centre of the Stoke Mandeville Hospital was opened, and sport was introduced for the veterans, who, in the past, had been considered outcasts of society and hopeless invalids, with a short duration of life" (Steadward & Walsh, 1986, p. 8). By the early 1970's the concept of wheelchair sports had been recognized as being the right of every citizen, and not simply an end product of rehabilitation (McClellan & Frogley, 1993).

In 1948, the first ever Stokes-Mandeville Games for the paralyzed was held with 14 men and 2 women participating. These games became an international event in 1952 when a team from Holland came to England. The first Olympic Games for the Physically Disabled were held in 1960 in Rome. Canada's entry into wheelchair sport was marked by the Pan American Wheelchair Games held in Winnipeg in 1967 (Kennedy, 1980). In 1976, the Games in Toronto hosted blind, amputee and spinal cord injured athletes together for the first time. Cerebral palsied athletes were then included in these games in 1980 at Arnhem. The Stoke-Mandeville games are still taking place in England, except when they are held in conjunction with the Olympics (Steadward & Walsh, 1986). Even more recently, the 1994 Commonwealth Games held in Victoria included athletes with disabilities for the first time in Commonwealth Games history.

The winter Paralympic Games were first held in 1976 in Ornskoldsvic, Sweden. There were twelve countries competing in cross-country skiing and alpine events. In 1992 in Tigne, France, twenty four countries participated in five events: alpine skiing, cross-country skiing, biathlon, ice-sledge racing and sledge hockey. The first winter Paralympic Games to be organized in conjunction with the Olympic Games were those held in 1994 in Lillehammer, Norway (Anonymous, 1994).

Due to their frequent integration with able-bodied competitions, track racing, field events and road racing are three of the most popular and highly developed disciplines of wheelchair sport. Track racing includes the sprinting and middle distance events (such as the 100, 200, 400 and 800 metre races). Throw events such as the shot put, the discus and the javelin constitute field events. Road racing varies from the 10K to the marathon (C. Timm, personal communications, October 18, 1994).

Canadian Statistics

The Canadian Wheelchair Sports Association is currently compiling and reviewing a document which will assess wheelchair sport development. Although the information is not ready for public scrutiny, the researcher was able to get some general information about wheelchair sports (C. Timm, personal communications, October 18, 1994). There are approximately 261 active wheelchair athletes in Canada (Table 3). The breakdown of the athletes participating in track, field, and road racing at the 1994 National and 1994 World Championships is summarized in Table 4.

Table 3

Active wheelchair athletes in the 10 provinces of Canada[a]

BC	AB	SK	MB	ON	QB	NS	NB	PEI	NF	TOTAL
25	20	8	7	150	35	5	5	3	3	261

[a] C. Timm, personal communications, October 18, 1994

Table 4

Canadian athletes at the 1994 Canadian National Championships and the 1994 World Championship[a]

EVENT	TRACK	FIELD	ROAD
1994 Marathon Championships			20 Males, 3 Females
1994 National Championships	39 Males, 11 Females	0 Males, 4 Females	
1994 10K Championships			22 Males, 3 Females
1994 World Championship Team	10 Males, 4 Females	4Males, 0 Females	

[a] C. Timm, personal communications, October,18 1994

Classifying Wheelchair Athletes

The main goal of classification is to provide athletes with an equitable starting point for competition. Wheelchair athletes have various levels of ability and disability and must undergo medical and functional examinations which test the function and strength of their muscles. The athlete is then classified into one of four classes in track (T1, T2, T3, T4) or one of eight classes in field (F1-F3 and F4-F8). The lower classification numbers consist of athletes with lower levels of muscular function and strength (such as quadriplegics) and the higher numbers consist of athletes who have more muscular function and strength (such as paraplegics). For example: in track, classes T1 and T2 consist of quadriplegics; classes T3 and T4 consist of paraplegics (C. Timm, personal communications, October 18, 1994). Although this is the current method of classification in Canada, the whole concept of classifying wheelchair athletes is under review.

The medical classification system. Dr. Ludwig Guttman introduced a classification system in 1956 which consisted of two classes: incomplete and complete lesions (McClellan & Frogley, 1993). There were complaints from athletes about "the inequities resulting from vast discrepancies in the physical abilities within the classes" (McClellan & Frogley, p. 1). What resulted after this was a medical classification system which allowed doctors to diagnose and categorize athletes. The medical system of classification included seven classes, eight in swimming, dependent upon the location of the spinal injury (Clark, 1986). This classification system was based on the spinal anatomical level of preserved neural function of the spinal cord (McCann, 1993).

The medical classification system was summarized by Clark (1986): Class 1A: total or partial quadriplegia (some hand involvement, weak triceps, severe weakness of trunk and lower extremities). Class 1B: total or partial quadriplegia (not quite as severe as 1A with normal or good tricep strength). Class 1C: total or partial quadriplegia (not as severe as 1A or 1B with normal or good tricep strength, normal or good finger flexion and extension, no intrinsic hand function). Class 2: total or partial paraplegia - no useful trunk sitting balance (total abdominal paralysis to poor abdominal muscle strength). Class 3: total or partial paraplegia (slightly more trunk sitting balance, though not normal due to some abdominal and spinal extensor musculature). Class 4: total or partial paraplegia (no quadricep to very weak quadricep strength). Class 5: complete or incomplete paraplegia (some quadricep strength). Class 6: used for swimming only.

The medical classification system was appropriately named because the knowledge and expertise needed to measure physical abilities (resources) came from people in the medical sciences (McCann, 1993). Problems with the medical classification system have resulted from: inaccurate anatomical assessments; variations in the calibre of medical professionals on classification committees; poorly cooperating athletes and/or the use of braces, straps, chair design, prothesis, etc... which enhanced the athlete's functional ability (McClellan & Frogley, 1993).

Functional classification system. Recently, measurements of physical resources have become less important and observing an athlete performing in competition has begun to influence the athlete's class. This method of classifying athletes corresponds with the promotion of combining athletes with different disabilities into one classification system. There is some reluctance to accept this functional classification system. McCann (1993) states that impairment is critical to classifying an athlete because the "unchangeable factor which determines potential sports performance is the level of preserved motor function. If the impairment is not measured, the athlete's performance lacks relevance for meaningful study or...comparison with performance standards or with the performances of other athletes" (p. 4). Kruimer (1993) is skeptical that some classes of athletes will be systematically discriminated against. Furthermore, other problems with observing athletes during competition and functional tests (to designate classification) are that the athlete may not perform to his/her potential and athletes who know how to accommodate or substitute for a hidden impairment may not be obvious through observation, resulting in an inaccurate classification (McCann).

Hainey (1993) states that the main reason the functional classification system (introduced in 1985) has been met with resistance is because of the concern it is not fair to all athletes or disabilities. Unfortunately, as Hainey points out, it is impossible for any system of classification to be completely fair and both models (medical and functional) have the potential for inequity. The biggest obstacle to overcome is getting the opponents of the functional system to find a way to correct the problems they see with the system (Hainey). Kruimer (1993) suggests that the way to ensure fair competition is to have a classification system which is "sport-specific and based on biomechanical principles as well as physiological and anatomical principles. To determine the class of an athlete at least one sport technical classifier and one medical classifier are needed" (p. 6).

Wheelchair Racing Equipment

Athletes were the initial creative force behind wheelchair design and improved fitting procedures. Now this challenge is undertaken by manufacturers who produce lightweight three wheeled chairs, customized to each athlete's specific needs (van der Woude, 1993). C. Timm (personal communications, October 18, 1994) indicated that the three-wheel racing chair has rubber-covered push rims attached to the rear wheels which the athletes stroke to propel the chair. "A compensator device is used to set front wheels to the curvature of the track, removing the need for the athlete to steer around bends. This frees the athlete's hand for using the push rims" (C. Timm). Figure 4 is a simplified illustration of a typical racing chair.

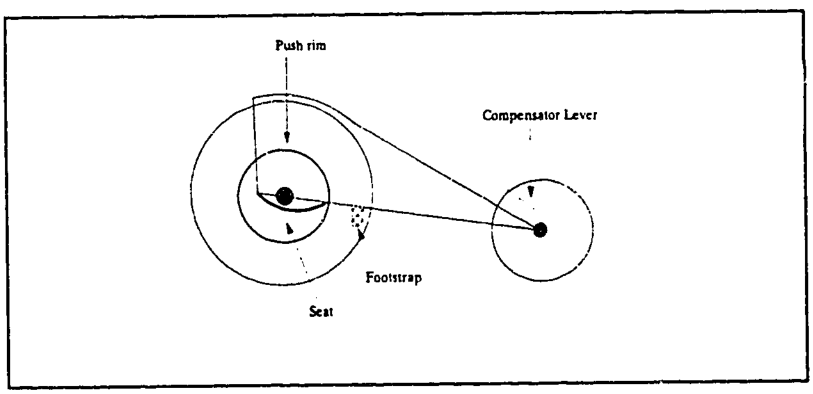


Figure 4. Illustration of the racing chair. (Adapted from Cooper, 1990).

Wheelchair racers wear either "customized" hand gear or manufactured made-to-measure hand gear. The customized hand gear consists of a pair of baseball (batting) gloves or handball gloves which are heavily taped at the point of contact with the push rims (C. Timm, personal communications, October 18, 1994). Manufactured hand gear is obtained from Harness Designs, Inc. (Champagne, Illinois, USA) or from One Step Beyond in Toronto, Ontario (R. Leworthy, personal communications, November 15, 1994). Although padding of the hand gear absorbs more energy than bare hands (thus, slowing the racer down), the protection is necessary (Higgs, 1993).

Wheelchair Propulsion and Stroke Techniques

The traditional hand-rim propulsion technique is where the hand grabs and encloses the rim. The large surface contact between the hand and the rim results in a high level of friction which enables force transmission. However, grabbing the rim can also act as a brake at the start and end of the push phase (van der Woude, 1993). On the other hand, the 'butterfly' technique, used at high velocities, is a 'non-grabbing' technique where the athlete strikes the rim with a short, but high, impulse or force (van der Woude). Athletes are also thought to generate more force at the push rims by using momentum from their (moving) trunk which results in obvious head movement. A general observation is: the lower the spinal lesion of an athlete, the less the head will move (Cooper, 1990). The athlete's arm movements, when analyzed, begin at the top of the push rim and continue until the athlete has raised the arms rearward and the hands are as far back as possible (see Figure 5).

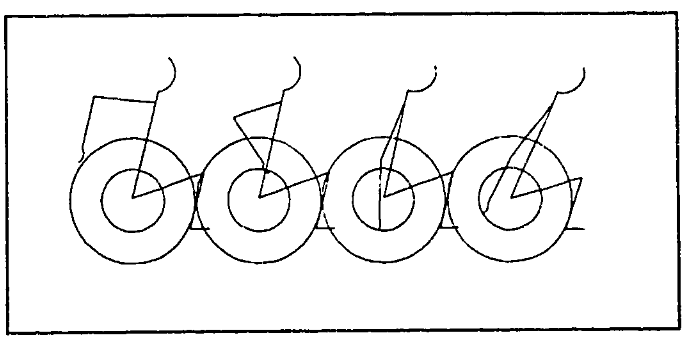


Figure 5. Arm movements of the wheelchair racer. (Adapted from Cooper, 1990).

There is a lack of literature dealing with the specific stroking techniques of the wheelchair racer. The researcher relied mainly upon personal communications (R. Leworthy, November 15, 1994; R. Steadward, November 14, 1994) to identify two general techniques used by the athletes: a backhand stroke and that which uses the index/middle fingers and thumb. The backhand stroking technique is one in which contact with the push rim occurs on the backside of the fingers, typically the index, middle and ring fingers. This stroking technique was developed and adopted by quadriplegics because these athletes cannot raise their hands upward and rearward as paraplegic, cerebral palsy or leg amputee athletes can (Higgs, 1993). In the most extreme cases, the athlete's hands remain in contact with the push rim the entire time to produce the greatest amount of force (and thus, speed) possible. The other stroking style involves the index/middle fingers and thumb. Typically, the athlete's hand is in a tight fist and initial contact with the push rim occurs on the dorsal or back side of index/middle fingers. As the athlete continues the stroke, pushing further down the rim, the hand rotates (pronation) so that the thumb comes in contact with the push rim and is then "flicked" (deflected) off the rim bringing the arms upward and rearward to complete the stroke (R. Leworthy, personal communications, November 15, 1994).

A point to mention: Athletes initally began wearing gloves to protect their hands from blisters. As the chair style changed along with the propulsion techniques (from a grabbing to a striking style), athletes began building up their gloves with tape to provide protection from the force their hands were now being subjected to (R. Steadward, personal communications, January 20, 1995). The history of hand gear development is not documented in literature.

Injuries

Burnham (1993) summarized research studies which outlined the location, prevalence and incidence of injuries sustained by wheelchair athletes. These descriptive reports and surveys have only been published in the last 10 years. The prevalence and incidence of injuries sustained by wheelchair athletes depends on how injury is defined. "The most common injury site, although less troublesome in terms of time lost and professional treatment required, is the hand" (Burnham, p. 4). Most of these injuries are to the skin of the hand. In addition, some of the hand injuries are characterized by hand numbness and pain. Compression of the median nerve is largely due to wheelchair propulsion as the hand contacts the push rim on top of the carpal tunnel. As well, entrapment of the ulnar nerve occurs at the wrist (Burnham). Ferrara and Buckley (1993) stated that "Athletes with disabilities, as a group, have never had a comprehensive program of research regarding sport injury issues" (p. 2). Thus, Athletes with Disabilities Injury Registry has been developed in the United States to "determine the risk of injury and to identify the common injury locations for athletes with disabilities" (Ferrara & Buckley, p. 2).

Pain in the shoulder girdle, soft tissue injuries (tearing and overstretching ligaments, overuse of muscles and tendons) in the shoulders, elbows, wrists and hands, blisters and skin lacerations/abrasions are common injuries as noted by Burnham (1993). As well, Curtis (1982) discussed the problems of decubitus or pressure areas (pressure sores) for those who lack feeling caused by shear forces and pressure over the sacrum and buttocks in combination with sweat and moisture accumulation.

Carpal tunnel syndrome (CTS). Carpal tunnel syndrome, first recognized in 1854 as a complication of trauma, is now considered a very common nerve entrapment syndrome, especially common in middle age women (Katz, 1994). This common and painful condition, resulting from damage to the median nerve, is a result of intense, repetitive activities and vibration and/or activities which cause continual flexion and extension of the wrist (Greenspan, 1988; Katz). Pain in the thumb, index and middle fingers, aggravated by wrist motions, and pain in the arm, shoulder and neck (especially nocturnal pain) are some of the symptoms. People who suffer from severe CTS may experience a decrease in their grip strength.

Long term use of a cane, a pair of crutches or a wheelchair can exert a force over the carpal tunnel area, putting the users at risk for carpal tunnel syndrome (Werner, Waring, & Davidoff, 1989). Gellman et al. (1988) state that there is a high frequency of carpal tunnel syndrome in paraplegic patients. The likelihood of incidence is intensified by the fact that paraplegics rely on their upper body to perform everyday activities such as transferring on and off of a wheelchair and propelling the wheelchair in order to move (Gellman et al.; Aljure et al., 1985). Aljure et al. also feel that there is a direct relationship between the length of one's spinal cord injury and the development of CTS. Some wheelchair athletes may suffer from pain and tingling in their hands which may be an indication of carpal tunnel syndrome (Curtis, 1982).

Investigations tested the hypothesis that a padded glove might protect the hand in the carpal tunnel region. The results of this research, however, did not indicate that padding the carpal tunnel region would minimize nerve dysfunction (Burnham, 1993).

Comfort

Clothing comfort is a term many researchers find difficult to define, although it is agreed that it may be explained in psychological or physiological terms (Clulow, 1984; Dayal, 1980a; Shivers, 1980). Shivers stated that physiological clothing comfort is "the proper relationship between body heat production and loss" (p. 242) and psychological clothing comfort is attained when one feels confident in certain fabrics, designs or colours. Comfort is a state of neutrality more than a state of pleasure and is not noticed as much as sensations of discomfort (Dayal; Smith, 1986). "Clothing...does contribute to our comfort if it fits well, does not impede movement, feels pleasant to the skin, makes us look attractive and suitably dressed for the occasion, and allows the heat balance within the body to be maintained" (Clulow, p. 20).

Physiological or thermal comfort is very dependent upon conductive, convective, radiative and evaporative qualities of clothing (Shivers, 1980). Because the temperature outdoors cannot be adjusted, there is a demand for designing outdoor clothing that will maintain the body's thermal balance and thus, comfort (Vokac, Kopke, & Keul, 1976). Measuring thermal comfort may be done both subjectively and objectively (Munson & Hayter, 1978). Rohles (1980) used a 9-category thermal comfort sensation scale and a seven-point thermal comfort semantic differential scale to measure subjective thermal comfort. Subjects may fill out ballots consisting of the words cold, cool, slightly cool, comfortable, slightly warm, warm and hot to allow a researcher to better understand how people feel in various conditions (Rohles Jr., 1971). Observations are also important as comfort sensations may cause a person to behave in certain observable ways allowing a researcher to make deductions about his/her thermal comfort (Vokac et al.). For example, when a person is feeling chilly, he/she will put on a sweater or rub his/her arms. This can be observed and the meaning deduced by a researcher.

Tactility, hand or how a fabric feels when one touches it, has been found to play an important role in comfort. "The results of hand tests are expressed in such words as soft, crisp, firm, hard, harsh, dead, lively, cold, warm, waxy, dry" (Dayal, 1980b, p. 27). Questionnaires (self-administered comfort scales/ballots) and wearer trials can help determine discomfort sensations, thermal sensations and tactile sensations felt by individuals which are created by certain fabrics and garments (Smith, 1986; Wallenberger, 1982). Conducting the wear tests in an outdoor environment or in a closely controlled, indoor climate chamber is possible. Wearer trials are also important for assessing fit.

Fit

Clothing designed for special needs, like protective sports equipment, must fit properly to allow the wearer to function efficiently in order to perform the task at hand (McConville, 1986). The fit of an item may be determined through both objective and subjective methods of data collection. Dynamic fit has been considered instrumental in determining a wearer's efficiency at performing a task and can be measured by using simple motor tests and time motion studies. Static fit is the relationship between garment and body size and can be measured using wear trials or semantic differential scales (Tremblay, 1989). While the subjects are partaking in wear trials, the investigator may observe the subject for obvious fit problems. Cameras, or videotaping, can be useful tools for providing visual illustrations of such problems. As well, the subject can fill out an evaluation immediately following the wear test (McConville). Although the investigator may take time to ask any questions after the wear test is done (McConville), van Schoor (1989) states that it is sometimes more appropriate to ask the subject questions during the actual wear trial. For example, "just before removing each garment, subjects were questioned about how...fit affected the suitability of the garment during wear" (Fraser & Keeble, 1988, p. 568). The semantic differential scales may be used in a questionnaire to "measure both the direction and the intensity of a respondent's feeling towards a given concept" (Tremblay, p. 17, 18).

Protection

Clothing and equipment can protect the body from harmful chemicals, forms of radiation and from physical injury. Of relevance to this research is protecting the body from injury sustained by impact. "There are numerous situations in which clothing provides the best source of protection from impact...In contact sports, body padding provides the only feasible source of protection" (Watkins, 1977, p. 154). Protecting the athlete is difficult, especially when contact with other players or other obstacles is part of the game. This makes the reduction of injury an important area of study. Impact studies may be used to develop protective equipment for athletes, construction workers or any other individual in need of protection from impact. Observations may be used to effectively study where on the body, how and why an individual receives physical, and potentially harmful, blows to his/her body (Watkins).

CHAPTER III - THE FUNCTIONAL DESIGN PROCESS

A constant challenge facing clothing designers "is to create designs that will be attractive and socially acceptable on bodies that may not conform to typical contours, surfaces, or motions" (Lamb & Kallal, 1992, p. 42) such as those of the average population. Because many special needs of a wearer/user cannot be immediately identified, a design process is needed which requires the researcher to extensively explore the design problem. This means that the designer cannot rely solely on the traditional intuitive problem solving design process that goes on inside the head, which Jones (1981) refers to as the black box design method. As a result, several researchers have developed procedures which combine this intuitive approach with the structured approach to design, enabling designers to meet the challenges they are being faced with to produce clothing and clothing-related products which better meet the needs of the user or wearer. Orlando DeJonge (1984) summarized this need for a new way of designing:

> A new approach to clothing design is sweeping the country as designing clothing for special purposes is becoming an important field. The need for specialized clothing for sports activities, industrial use, and energy conservation is increasing. In response a new kind of clothing designer must emerge to provide imaginative solutions to the clothing problems of the future. (p. vii)

This study has identified three different processes which have relevance to the evaluation of wheelchair racing hand gear and are worthy of discussion and comparison. The first is the functional design process outlined by Orlando-DeJonge (1984); the second is the user-oriented product development process and its application to clothing and textiles by Rosenblad-Wallin (1985); and the last to be discussed is the functional and fashion apparel design process by Lamb and Kallal (1992) (see Table 5).

The Functional Clothing Design Process

Orlando-DeJonge developed a framework for functional apparel design based on Jones' (1981) more generic functional design process, and formally presented it in the foreword to Watkin's (1984) book, Clothing: The portable environment. Orlando-DeJonge's process, beginning with a general request for clothing intended to meet a special need, "takes the designer step-by-step from the initial idea through an evaluation of the final design" (p. vii). The seven steps are very interrelated and allow for a systematic inquiry into the design problem. As a result of an extensive investigation into the design situation to evaluate user needs, design specifications are developed which aid the designer in determining various creative solutions to the design problem. One way to determine the appropriateness of the various solutions is to execute textile performance tests on various materials and experiment with various methods of construction. These tests are important to help the designer establish which solutions are the most feasible for the final design. The process utilizes an objective evaluation of the final prototype by assessing how well it meets all the established specifications. As well, the user evaluates the performance of the garment in its use-situation. Orlando-DeJonge states that "By keeping in mind the consumer and the desirable effects of the final product, today's designer can do much more than fashion designing" (p. xi).

Several researchers have successfully adapted and used Orlando-DeJonge's (1984) functional clothing design process. Tan (1993) applied this approach to designing protective flight suits for the Canadian armed forces. As well, relevance of Orlando DeJonge's method was implied by Fraser and Keeble (1988) in their research on protective clothing and pesticide use. Van Schoor (1989) adapted the functional clothing design method to design and evaluate disposable coveralls for pesticide application.

User-Oriented Product Design Method

Rosenblad-Wallin (1985) applied the user-oriented design method to clothing products "whose functional properties are of great importance" and "can be generalised to all users and to products with close connection to human beings" (p. 279). This method starts in the use-situation of the user, in contrast to the "traditional" starting point of product development which might be using the introduction of a new or improved material as the catalyst for design. In such a traditional situation, clothing manufacturers would decide the user needed a new product and would proceed to formulate their own ideas about user needs based on their internal knowledge of the target group, as opposed to basing demands or needs on problems arising in the actual use-situation.

Rosenblad-Wallin's (1985) process also takes functional and symbolic values of the product into account. "The more pronounced the functional demands of clothing, the less important the symbolic values" (Rosenblad-Wallin, p. 282). They may be less important but they will never be completely ignored. Some examples of functional values are protection from the climate or environment, as well as comfort in terms of fit, ease of movement and thermal sensation. Symbolic values considered in this process are group membership, self esteem and respectability. Rosenblad-Wallin (1985), through several case studies, illustrated the applicability of this process to clothing design. The author points out that this process has been successful in consumer packaging designs, aids for people with disabilities and medical-type of equipment.

Functional and Fashion Apparel Design Framework

Lamb and Kallal's (1992) goal when forming their conceptual framework for apparel design was to develop "a general framework that could be applied to design of any type of apparel, including garments intended for people whose needs are not routinely met in the market place and therefore have been considered special" (p. 42). It does not differentiate between functional and fashion designs, but rather "combines functional, expressive, and aesthetic (FEA) considerations" (Lamb & Kallal, p. 42) specific to any design problem, fashionable or functional in nature. The functional, expressive and aesthetic (FEA) criteria play a role in this process in the first and fifth stage. In the first stage, they are developed to guide the designer to solutions. In the fifth stage, the design is evaluated to see how well the FEA criteria have been met. Furthermore, Lamb and Kallal aimed to develop a simple process for students to use and adapt as they were challenged with various design problems. There are six stages in this model inspired from other work such as Koberg and Bagnall's (1981) book The universal traveller: A soft-systems approach to creativity, problem-solving and the process of reaching goals and Hanks, Belliston and Edwards (1977) book, Design yourself. The use or success of Lamb and Kallal's (1992) recently developed process has yet to be documented in the literature.

Summary of the Design Processes

In Table 5, the stages of the various processes have been synthesized and collapsed into five phases. The first phase is the identification of a problem. The second phase is the exploration of the problem to determine the critical factors. The third phase results in design specifications arising from the critical factors of the problem. The fourth phase includes any testing of materials/textiles or construction techniques and any brainstorming and problem solving needed to develop several potential and creative solutions to the design problem. The fifth phase is the evaluation of the final prototype.

Upon placing the stages of the processes into phases, it becomes evident that Lamb & Kallal's (1992) framework misses a very important phase, encouraging a designer to jump from the identification of a problem straight to results. In this process, the preliminary design ideas or solutions are developed in its second stage, as opposed to the sixth stage in Orlando DeJonge's (1984) process and the seventh stage in Rosenblad-Wallin's (1985) process. This major oversite of the Lamb and Kallal process in which the exploration of the design and problem situation is not separated from the development of solutions could encourage premature solutions to be generated which could lead to an inaccurate assessment of the user's true needs.

Table 5

The phases of three functional design processes

Orlando-DeJonge's (1984) Functional Clothing Design Process	Rosenblad-Wallin's (1985) User-Oriented Product Design Process	Lamb & Kallal (1992) Functional and Fashion Apparel Design Process
Stage 1: Request for a design.	Stage 1: Identification of problem area.	Stage 1: Problem identification.
Stage 2: Design situation explored. Brainstorming; interviewing and observations of users; setting of general objectives. Stage 3: Problem structure perceived. Identification of the critical factors of problem through market analyses, surveys and literature.	Stage 2: Problem analysis. The size and priority of problem and the users involved are determined. Stage 3: Formulation of the project. Objectives set. Stage 4: Formulation of the demands. Subjective and objectives methods of data collection used to determine the user/use-situation or general demand.	
Stage 4: Specifications described. Assessments are done to describe the design specifications. Stage 5: Design criteria established. All the design specifications are charted, ranked and weighed against one another to set priorities.	Stage 5: Data processing and analysis: Data are processed and analyzed; resulting variables are assigned priorities. Stage 6: Use-demand specifications. From the above results, design specifications are determined.	Stage 2: Preliminary ideas. Design solutions developed through brainstorming, sketching, research, question and answer sessions, surveys. Stage 3: Design refinement. Preliminary ideas undergo scrutiny; the priorities among the functional, expressive and aesthetic criteria are set; the designs undergo refinement.
Stage 6: Prototype development. Testing textiles and construction techniques are done; brainstorming; development and comparison of design solutions to develop a final prototype.	Stage 7: Ideas and technical solutions. Are formed to initiate creative product development. Stage 8: Evaluation of resulting prototypes. Done so modifications may be made and a final prototype selected.	Stage 4: Prototype development Any standards testing (of textiles); production of best prototypes
Stage 7: Design evaluation. The final design is evaluated to determine if the design specifications have been met and how the user group rates the final result.	Stage 9: Final prototype evaluation. Evaluation of the final prototype picking the one "that gives the best functional and symbolic product values" (p. 282) and that best meets the objectives.	Stage 5: Evaluation. The garments are judged according to, if and how well they meet the FEA criteria. Stage 6: Implementation. Resulting prototype decided upon.

In essence, both Orlando DeJonge's (1984) functional clothing design process and Rosenblad-Wallin's (1985) user-oriented product design process are the same. The main difference is the wording and number of stages. With the inconsistency of wording came a need to redefine the stages of the process to meet the needs of this research. The following section of this chapter will outline how the functional design process was interpreted for this research.

Conceptualizing the Functional Design Process

The main purpose of this research was to determine and evaluate wheelchair racers' needs for hand gear in order to recommend design specifications. Although a functional clothing design process had much relevance to this study, it was not necessary for the researcher to use the process in full, starting at a request for a design/identification of a clothing problem and ending at the evaluation of the final prototype. This research focused on what Orlando-DeJonge (1984) portrayed as the first five stages of the functional clothing design process and Rosenblad-Wallin (1985) depicted as the first six stages of the user-oriented product (clothing) design process. The procedures developed specifically for this study are set into five stages which take the researcher from the identification of a need for an improved design to a list of design specifications.

Problem identification. In the first stage, a problem with the design of currently worn clothing or a clothing related product is identified. This identified need or deficiency may be realized by a user/wearer or by a researcher (Orlando-DeJonge, 1984; Rosenblad-Wallin, 1985).

Exploration of the user and use situation. To better understand the problem at hand, the designer must become well acquainted with the user and the use situation. This may be done through broad literature reviews, market surveys, observations and informal interviews with users and/or experts on the user group under study. Following Orlando-DeJonge's (1984) process, this stage allows the researcher to consider "as many different directions for investigation as possible" (p. vii), and following Rosenblad-Wallin's (1985) process, the researcher is able to determine "the size and priority of the problem and to point out the users concerned" (p. 280).

Identification of the design factors. The third stage begins with an analysis of the information (data) collected from the second stage in order to focus on more specific aspects of the problem under investigation. It is simply a more focused continuation of the second stage where "the designer moves from the entire spectrum, opened through divergence, to the focal areas of design concern" (Orlando-DeJonge, 1984, p. viii). More specific literature reviews, interviews, focus group interviews, questionnaires, surveys of users and market surveys may be done to begin determining the users' needs and demands so as to isolate the main factors of the design problem. "Completion of this stage results in the identification of critical areas for further research" (Orlando-DeJonge, p. ix).

Development of the design criteria. Once the design factors have been determined, the researcher may begin various assessments to develop a list of design criteria. These assessments include activity, movement and/or impact assessments and analyses of comfort, fit, protection or any other design factor. An activity assessment "involves greater in-depth observation...of...the activity as it is being performed in its natural setting" (Orlando-DeJonge, 1984, p. ix). Movement assessments are done to determine if the clothing under investigation interferes with the task of the wearer and to "identify body movement needs in relation to specific tasks" (Watkins, 1977, p. 161) a wheelchair racer must perform. Impact assessments may be done to measure the impact incurred by the wearer in activities such as contact sports (Orlando-DeJonge). Filming the activity is done if possible, or a "simulation of the activity may be enacted and observed" (Orlando-DeJonge, p. ix). The importance of these assessments is to develop "specifications that will help the designer create a garment that does not interfere with a wearer's tasks, and...may even assist them" (Orlando-DeJonge, p. ix).

Establishing the design specifications. After their development, the design criteria may be analyzed using an interaction matrix to determine whether any conflicts exist between the paired criteria. The list of the resulting design specifications will be priorized and solutions to any areas of conflict will be sought. The designer will then use the specifications to design and develop the prototype. This helps the researcher identify and visually display the conflicts that arise. The interaction matrix has been successfully used in past research (Tan, 1993; Tremblay, 1989; Van Schoor, 1989).

This resulting process must not be seen as linear, but as circular with feedback loops directing the researcher back and forth over stages. In order to come up with a final and select set of design specifications which are well understood and justified, the researcher must continually research literature, study the user group and the use situation through objective and subjective methods of data collection. If new design factors are identified at any point of the research, the researcher must be able to use literature reviews, interviews, observations and other forms of data collection to break the factor(s) into more criteria. These resulting criteria must be compared with previously established criteria until a concrete set of specifications may be developed. The importance placed on the first five stages can only result in better design solutions and fewer modifications at the design stage.

CHAPTER IV - PROCEDURES AND FINDINGS

The procedures as outlined at the end of chapter three were used for this research. This chapter describes this procedure in detail and the data collection methods used. As well, the findings are introduced. Figure 6 summarizes the procedures used for the research.

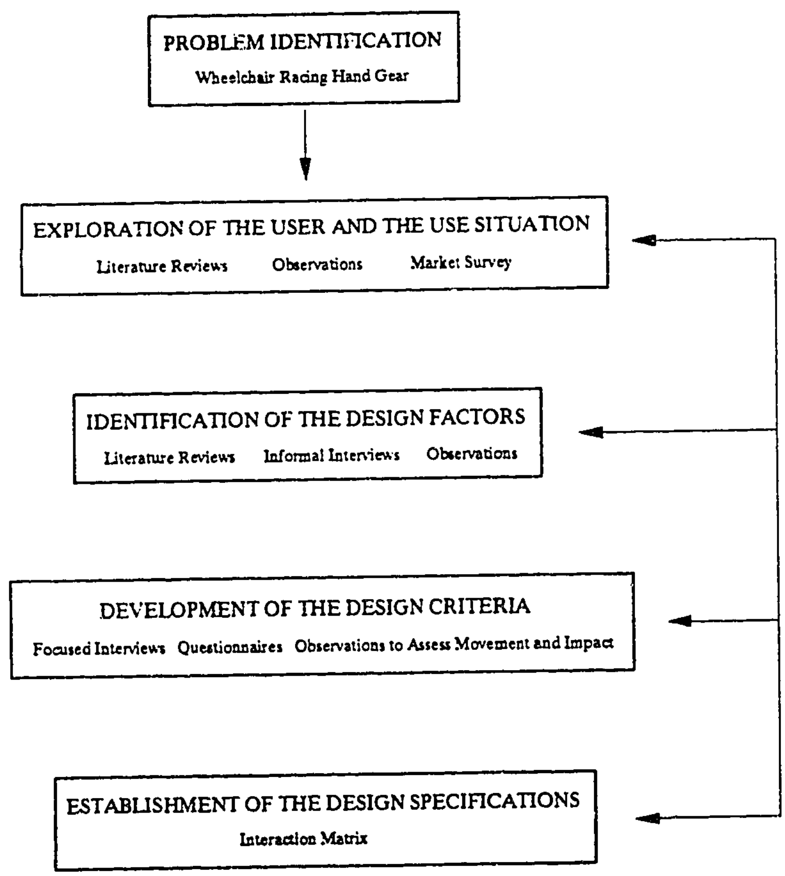


Figure 6. Procedures used for the research.

Problem Identification

A literature review was completed, summarizing research which concentrated on the clothing needs of people with disabilities. The researcher concluded that although a great deal of research existed on this topic, no one had explored the sportswear needs of the athlete with a disability. Informal interviews with wheelchair sports experts identified the need to study sportswear and equipment design for the wheelchair racer. In particular, the researcher focused the study on an evaluation of wheelchair racing hand gear to assess the athletes' needs.

Exploration of the User and the Use Situation

An extensive literature review (summarized in Chapter 2) was done so the researcher could become knowledgable about the user group (wheelchair racers) and the user group's activity (wheelchair racing). The concepts focused on were: the anatomy of the hand, physical disabilities, statistics on Canadians with a disability, the importance of physical activity for people who use a wheelchair, the history of wheelchair sports, the number of Canadian athletes participating in wheelchair sports, the classification systems used to categorize athletes and the general injuries sustained by wheelchair racers.

The literature reviewed on the hand indicated the importance of this intricate body part. The muscles and nerves of the hand are very important for performing daily tasks such as written communication, opening a door, touch sensations and, for the wheelchair user, mobility. It is apparent that damage to the nerves can have negative implications on a person's ability to complete daily tasks which reduces one's independence. As well, a person who uses a wheelchair and (especially) wheelchair athletes are thought to be very susceptible to the common nerve ailment, carpal tunnel syndrome. This condition causes a person pain, numbness in the hand and deteriorating hand function.

There are a variety of disabilities affecting human beings which are a result of birth complications, disease or injury (such as spinal cord injury). There were approximately 3.3 million people with disabilities in Canada in 1986/87. Many of these individuals require some type of help, either human or mechanical, to function in everyday life. Those who have had leg amputations, or have severed their spinal cord, may need to use a wheelchair. Approximately 46, 030 Canadians were using a wheelchair in 1986/87. It has been noted that physical activity is especially important for individuals who use a wheelchair to reduce their chances of experiencing problems with obesity, low energy levels, an inefficient heart and lungs, and depression.

Since the middle of this century, the number of people participating in wheelchair sport has grown drastically. This is evident when one compares the 1948 Stoke Mandeville Games to the 1992 Summer Paralympic Games: 16 competitors versus 3,032 competitors. Individuals participating in wheelchair sport may have paraplegia, quadriplegia, a lower limb amputation or cerebral palsy. Wheelchair sports experts are presently analyzing the athletic classification system for wheelchair sport. The functional athletic classification system, the proposed alternative to the medical classification system, is one which would allow athletes of differing disabilities to compete against one another. There is some opposition to this system which incorporates observations of the athlete during competition and during functional (sport-related) tests. Injuries have not been well documented over the past years. Fortunately, the "Athletes with Disabilities Injury Registry", recently developed in the United States, should become a useful tool for athletes, coaches and medical experts to better understand and treat injuries. Common problems and injuries are blisters and abrasions to the hands, shoulder pain, tearing and overstretching ligaments, muscles and tendons in shoulders, elbows, wrists and hands.

Approximately 261 Canadian athletes are registered with provincial wheelchair sports associations as actively participating in wheelchair sports. Although the number of wheelchair athletes and the size of the Canadian market seem modest, the importance of hand gear is not; this is obvious as all athletes wear some form of hand gear during training and racing to protect their hands. The popularity of wheelchair sports has been increasing since their inception and shows no sign of diminishing. For example, members of the non-profit organization, "The Link Foundation", travel across Canada encouraging people with disabilities to participate in community sport and educate all people about sport and people with disabilities.

Observations of athletes were made by the researcher to visually understand wheelchair racing. The researcher noted that wheelchair racers used customized three-wheel chairs for racing as well as a specific, consistent and forceful stroke. This information helped the researcher identify areas in need of further investigation: wheelchair design and propulsion techniques.

A market survey was conducted to identify what racing hand gear was available on the Edmonton market. Eco Medical Equipment, Golden Boy Medical, Health and Rehabilitation Specialties, Medichair, Advanced Motion Sales and Service Inc., and Alberta Glove Co., Ltd were contacted and asked if they sold hand gear for wheelchair racing. The market survey was unsuccessful as none of the places sold any racing hand gear. As well, people in these companies did not know where to purchase any form of manufactured racing hand gear.

Identification of the Design Factors

To begin focusing on more specific issues of the design problem, the researcher began unstructured interviews with athletes and coaches, observations of hand gear worn by racers and focused literature reviews. The unstructured interviews (Appendix 1), personal communications and observations were done to discover information about what racers wore on their hands and why. It was determined that athletes were wearing either customized (home-made) hand gear or manufactured hand gear and that three of their general needs were comfort, fit and protection.

In order to understand these three concepts and how researchers in the past had defined and measured them, a literature review was done on comfort, fit and protection. The researcher was concerned about defining these terms as each athlete was likely to interpret them subjectively. Past research pointed out that comfort is a difficult term to define while feelings of discomfort are easier to determine. In the end, the researcher identified comfort as the athlete's state of mind during racing where he/she could remain focused on racing. In the past, (static) fit was investigated by measuring the difference in size between the clothing item and the actual body (anthropometric) size. As well, (dynamic) fit was defined as the ability for an individual to perform tasks while wearing the clothing item. For this research, it was decided that "fit" would consider both the relationship between hand size and hand gear size, as well as the ability of the racer to perform all racing movements while wearing hand gear. Protection was a concept that had not been examined extensively from an "impact" point of view. Research literature was available dealing with protection from chemicals and fire. However, the protection needed by wheelchair athletes is from physical injury incurred by the impact of the hand stroking the pushrim. Watkin's (1977) research on the functional design of protective hockey equipment was the only article that dealt with this subject. As well, there was information on impact in her book; Clothing: The portable environment (Watkins, 1984). For this research, protection was widely defined in terms of how well hand gear protects the athlete from impact and related injuries, such as blisters, abrasions and carpal tunnel syndrome, which could interfere with independence in everyday life.

The researcher identified the need to study wheelchair design and stroking techniques after the initial observations in stage two. The limited amount of literature dealing with these topics necessitated using information acquired from personal communications and informal interviews. Racers use customized three-wheeled wheelchairs. The two back wheels of the chair have a smaller inner wheel known as the push rim, covered in rubber, which the racer strokes to propel the chair. Literature identified two general propulsion techniques: the traditional grabbing technique where the hand encloses the push rim and a "butterfly" technique where the hand strikes, but does not encircle, the rim. Two stroking styles were initially identified: a) the index/middle fingers and thumb stroke and b) the backhand technique (back side of the index, middle and ring fingers).

Development of the Design Criteria

A focused interview (Appendix 3) and a questionnaire (Appendix 4) were used to assess racers' evaluations of comfort, fit and protection. After the first interview, flexibility and weight were determined as other design factors and items addressing them were added to the research instruments. As well, the interviews and questionnaires were designed to determine any other relevant needs of racers. Observations of athletes during training and racing were done to assess the movements necessary for racing and to observe if hand gear interfered with racing movements.

Development of the focused interview. The format of the focused interview was inspired by Tan's (1993) focus group interview with Canadian Forces Personnel. Initially, the researcher wanted to execute focus group interviews but this proved impossible due to the small number of wheelchair athletes in Edmonton. It would have been difficult to get an appropriate number of athletes together in a group setting with similar abilities/disabilities, who raced in the same class and who used the same stroking style. Thus, it was determined that focused interviews providing one on one interactions (between athlete and researcher), would be acceptable.

General questions, exploratory in nature, were asked to determine what types of hand gear were worn by the athletes in the past and present, and what problems were associated with them. These questions were also asked to determine design factors and criteria, as well as, gather information on flexibility and weight (Section A: #1, 2, 4, 5; Section C: #1; Section D: #8, 12). Questions focusing on stroking styles, general comments of protection, types and locations of injuries incurred by the hand were asked to gather information on protection (Section A: #3; Section B - when applicable; Section D: #1, 3, 4, 9, 10, 11). Questions were asked to gain insight on how hand gear might interfere with racing and the athletes' preferences for a tight vs. snug vs. loose fit (Section C: #2; Section D: #2, 7). Comfort of hand gear was assessed through questions determining if the hand gear ever interfered with the athlete's train of thought/concentration on the race (Section C: #2; Section D: #5, 6, 9).

Development of the questionnaire. Gorden (1969) stated that questionnaires are often more useful after some interviewing has taken place to pretest questions before distributing the final questionnaire. As well, questionnaires and interviews are "frequently...used as complementary instruments" (Gorden, p. 56). For these reasons and because there was unlikely to be a large enough number of subjects for a focus group interview, a questionnaire was also developed. The first interview, held prior to questionnaire distribution, proved useful in determining flexibility and weight as design factors which were included in the questionnaires (and future interviews). Questions asking athletes how long their hand gear lasted led to durability also being identified as a factor.

Information about the types of hand gear athletes wore, the problems, likes and dislikes they had with hand gear and other design factors (e.g. durability) was gathered through general, exploratory questions in Section I: #1, 2, 3, 4; Section II: #6; Section III: # 1, 2, 3, 4, 5; Section

VIII. The importance of protection and where the athlete needed protection were determined in Section II: #1; Section III: #6; Section IV: #1, 2; Section V: #3. The importance of comfort, where on the hand uncomfortable sensations commonly occurred and how each athlete ensured comfort were determined in Section II: #2; Section IV: #3; Section V: #2. The importance of fit, how it was acquired and the desired fit (tight versus snug versus loose) of the hand gear were defined in Section II: #4; Section IV: #4; Section V: #1; and Section VI. The athletes answered Section II: #5; Section IV: #3 and Section V: #4 to determine the importance of flexible hand gear, where flexibility was needed and how it was ensured/acquired. The importance of weight and how it was acquired was assessed from the answers in Section II: #3 and Section V: #5.

Observations. Observations of racers propelling their wheelchairs and of their hand gear were done throughout the research. At this stage, a video-recording was made of racers at the Commonwealth Games to closely assess their movements during racing and the areas of the hand which underwent impact with the push rim. The visual information supplemented the information gained from the focused interviews and questionnaires.

Findings of the Interviews, Questionnaires and Assessments

Eighteen athletes participated in this research by agreeing to take part in a focused interview or by filling out a questionnaire. Six athletes were interviewed: four in Edmonton, and two at the Commonwealth Games. Twelve athletes filled out a questionnaire: nine from the Canadian National Wheelchair Racing Team (1994 participants in the World's in Berlin) and three at the Commonwealth Games. The subjects consisted of four females and fourteen males; two were quadriplegics, ten were paraplegics, four had cerebral palsy and two had amputations.

From the collected information, it was determined that wheelchair racers are either (a) devising their own forms of hand gear, which the researcher has termed "customized hand gear"; or (b) buying and wearing manufactured hand gear from either Harness Designs, Inc., based in Champaign, Illinois or One Step Beyond in Toronto. Of the eighteen athletes, eight customized their current hand gear, nine athletes purchased Harness hand gear and one purchased hand gear from One Step Beyond.

Customized hand gear. Athletes who customized their hand gear started with a glove as the base upon which to build. The "base" varied from handball gloves to baseball/batting gloves to soft leather work gloves. Elastoplast tape, medical strapping tape and/or hockey tape were applied to the glove to build up the areas of contact with the push rim as well as to add extra protection to the hand gear as a whole. Some athletes glued or sewed rubber patches on top of the tape to increase the traction. Plates 1 to 5 illustrate some of the customized hand gear observed in this research. All photographs are credited to the researcher/author.

Plate 1. Customized hand gear composed of a soft leather work glove, elastoplast and rubber patches. The rubber has a grooved surface and was obtained from Sweden. It was glued onto the elastoplast and then the edges were taped down to reduce chances of peeling.

Plate 2. Customized hand gear composed of a baseball/batting glove and hockey tape. The tape was wrapped around the fingers, building up the areas in contact with the push rim.

Plate 3. Customized hand gear composed of a handball glove, elastoplast tape and rubber (on the thumb).

Plate 4. Customized hand gear composed of a handball glove, elastoplast tape and rubber patches (placed on areas of the hand gear which contact the push rim). This hand gear was created by building up the tape on TOP of the fingers (resembling a shield), as opposed to AROUND the fingers. The palmar side illustrates how the "tape shield" was held in place.

Plate 5. Customized hand gear composed of a handball glove, medical strapping tape and elastoplast tape. The palm of this hand gear was built up with tape to cushion the clenched hand during racing.

Manufactured hand gear. Some athletes wore one of the three styles of hand gear obtained from Harness Designs, Inc. A Two-Pocket Mitt style in which all four fingers were enclosed in a mitt-style of glove was observed by the researcher. There was an inside seam which divided the mitt into sections; one section for the index and middle fingers and the other section for the ring and little fingers. Rubber covered the entire back side of all four fingers, ending at the lower knuckles of the hand. A layer of foam existed between the rubber and leather (see Plate 6). The Two-Finger style of hand gear had the index and middle fingers encased in leather with the top/back side of this large "finger" covered in rubber. The ring and little fingers were encased in one soft leather finger (see Plate 7).

There is also a Three-Fingered Glove available from Harness Designs, Inc., which is similar to the Two-Fingered style except the ring and little fingers are encased in *separate* leather fingers. No athlete interviewed or spoken to in person had this form of hand gear and therefore, a photograph is not available.

View "A" View "B"

Plate 6. Manufactured Two-Fingered Mitt style of hand gear by Harness Designs, Inc., with velcro strap. View "A" shows the dorsal side of the hand gear. View "B" shows the hand in a fist position, with the velcro secured.

Plate 7. Manufactured Two-Fingered style of hand gear by Harness Designs, Inc. (without velcro strap).

The manufactured hand gear had some unique features incorporated into the designs. The hand gear came with an optional velcro strap at the end of the fingers which functioned to close the hand in a fist. This was an advantage for many racers as their hand muscles did not have to contract to hold the hand in a fist. Furthermore, the strap held the hand in a solid and fixed position which increased the consistency of the athlete's stroke. The variation in designs available provided the athletes with the opportunity to choose a form of hand gear which best suited their stroking style and needs. The rubber was durable and provided many of the athletes with sufficient traction with the push rim. As well, the Harness hand gear had a small knit section on the back side of the hand which seemed to maintain the closeness of fit.

To obtain Harness hand gear, the athletes traced their two hands and measured the circumference around the hand knuckles of both hands. This information, along with any specific requests of the athlete (e.g. 1/2 inch of padding instead of 1 inch), was sent to the company. The cost although it seemed to vary from athlete to athlete for reasons unknown to the researcher, was approximately $140 Canadian. A nylon knit glove liner could be worn under all styles of hand gear to wick moisture away from the hand and to act as a buffering layer between the hand gear and the skin. According to one athlete, One Step Beyond designs the mitt and two-fingered styles of hand gear which are available with the optional velcro strap. The cost was thought to be roughly the same as Harness's hand gear, according to one athlete. As well, an athlete, who filled out the questionnaire, stated that when ordering hand gear from One Step Beyond, she would measure the length of the fingers and the circumferences around (a) the ring and little fingers, (b) the index and middle fingers and (c) the palm. Unfortunately, no athlete interviewed wore hand gear from One Step Beyond and therefore, the researcher was neither able to get a photograph nor compare the quality of the two forms of manufactured hand gear. One athlete did mention that the rubber of the One Step Beyond hand gear was not durable and did not last as long as the rubber used on the Harness hand gear.

<u>Strokes</u>. There were two stroking techniques discussed by experts and some athletes as previously mentioned in Chapter 2. However, the researcher believed that another style existed after assessing the questionnaires and interviews. Athletes were indicating that they stroked the push rim on the (a) back side of their index, middle and ring fingers, (b) index/middle fingers and thumb, or (c) side of their index finger and thumb. Figure 7 illustrates the various locations on the hand where contact with the push rim occurs.

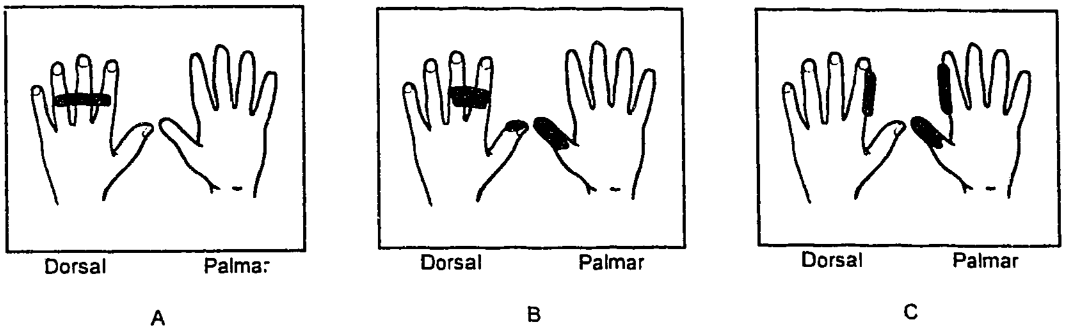


Figure 7. (LEFT) Hand contact with the push rim when using the backhand stroke (A); the index/middle fingers and thumb stroke (B); or the index and thumb stroke (C).

There were three athletes who stated they used a backhand stroking technique, ten athletes who stroked the push rim with the index/middle fingers and thumb, and five athletes who stroked the push rim with their index finger and thumb. The data on stroking styles, disability and type of hand gear are compared in Table 6.

Table 6

Disability, stroking style and hand gear type.

BACKHAND STROKE	INDEX & MIDDLE FINGERS/THUMB	INDEX FINGER/THUMB
Manufactured 2 Quadriplegic athletes	Manufactured 1 Cerebral Palsy athlete 2 Amputee athletes 5 Paraplegic athletes	Manufactured 0 athletes
Customized 1 Paraplegic athlete	Customized 2 Paraplegic athletes	Customized 3 Cerebral Palsy 2 Paraplegic
Total = 3	Total = 10	Total = 5

Two of the athletes who used the backhand technique bought manufactured hand gear, while one athlete customized it. Quadriplegics were most likely to use the backhand stroke as a result of their weaker arm and hand strength and manufactured hand gear seems to be designed for this stroking style. The reason that the one quadriplegic athlete (who used the backhand stroke) wore customized hand gear was because Harness hand gear was very uncomfortable and believed to be the cause of his tendonitis.

Eight of the ten athletes who used the index/middle fingers and thumb to stroke the push rim bought manufactured hand gear, while two customized their hand gear. Cerebral palsy, amputee and paraplegic athletes used the index finger/thumb or index and middle fingers/thumb stroking styles likely because of their good hand and arm strength. Manufactured hand gear was very suitable for this stroking style and as a result, the majority of athletes in this group selected this form of hand gear.

The five athletes who used the index/thumb stroking technique customized their own hand gear. The seam along the side of the index finger of (Harness) manufactured hand gear interfered with stroking. Thus, creating customized hand gear was obviously the best solution. The strong relationship between the index finger/thumb stroking technique and type of hand gear was verified by a racer who mentioned he would have to stop stroking the push rim on his thumb and index finger to adapt to manufactured (Harness) hand gear.

It is important to note that an athlete's choice of stroking style could depend on (a) the person coaching the athlete, (b) where the athlete first learned to stroke the wheelchair and (c) who first taught the athlete to customize hand gear or told the athlete where to purchase manufactured hand gear Although these extraneous factors were not considered in this research, they may have been useful to explain relationships between the type of hand gear, stroking style and disability.

<u>Problems, injuries, likes and dislikes</u>. Athletes shared their current and past hand gear experiences, problems, injuries, likes and dislikes with the researcher. It was common for customized hand gear to fall apart in the rain. As well, many of the athletes wearing customized hand gear found they often slipped or missed a stroke in wet weather due to the poor traction between the hand gear and the push rim. Those who used aquaseal, klister or another sticky substance to increase traction found the substances messy and likely to stain their clothing. Manufactured hand gear did not fall apart in the rain, and the rubber provided many, but not all, of the athletes with the traction needed between the hand gear and push rim. Often, manufactured hand gear was bulky or too long in the fingers and needed adjustment. This problem was rectified by taking the hand gear to a shoe repair shop where the excess rubber material was cut off and the seam resewn. Customized hand gear was more likely to fit well and

feel comfortable because it was built on the hand. However, it was not easy to create identical hand gear every time a new pair was developed. The time spent developing customized hand gear and fixing it up as it deteriorated was considered a burden by athletes. Many athletes repaired customized hand gear on a weekly basis; the length of time it lasted before complete replacement was necessary varied from two to six months.

Athletes were susceptible to blisters anywhere on the hand especially in areas which rubbed against the hand gear. The knuckles and areas of the hand which contacted the push rim were more likely to be blistered. Sprained and jammed fingers and thumbs, tendonitis in the wrist, and strained backs of hands were other common injuries which occurred. Two athletes managed to find interesting solutions to the problem of strain along the back of the hand: one clenched a tube during racing and one built up the palm of his hand gear to cushion the clenched hand. Only two racers stated that their hands tingled at the end of long races/marathons. This tingling only lasted for a short time after the race and could be an indication of median nerve damage or inflammation.

The table in Appendix 4 contains specific information collected from each of the eighteen athletes detailing each athlete's sex, disability, wheelchair athletic classification, form of current hand gear and problems experienced with hand gear. Cost and how long hand gear lasted is included when answered by athletes.

The athletes shared specific "likes" and "dislikes" of hand gear which are summarized in Table 7. There were some similarities between athletes' likes of customized and manufactured hand gear, as well as between their dislikes.

The similarities between customized and manufactured hand gear were comfort, weight, traction, fit, protection, durability and flexibility. Unique aspects which athletes liked only about customized hand gear were its inexpensiveness, design/form and versatility. Aspects which athletes liked only of manufactured hand gear were its consistency, replaceability, durability in rain or shine, ease of care, fist position from the velcro strap, rubber, ease in donning and the glove liner. There were fewer similarities existing between athletes' dislikes of customized and manufactured hand gear: cost and hardening in cold. (Note: cost is a like and dislike of customized hand gear). Table 8 shows a comparison between the likes of customized hand gear and the dislikes of manufactured hand gear and vice versa to determine what kinds of needs were being met by one form of hand gear and not by the other.

Table 7

Likes and dislikes of customized and manufactured hand gear

CUSTOMIZED	MANUFACTURED
LIKES	**LIKES**
- comfortable (3)[a]	- comfort (1)
- light weight (1)	- weight (1)
- durable (2)	- durability (6)
- grip/traction (2)	- traction (4)
- fit (2)	- fit (3)
- protection (1)	- protection (2)
- flexible (3)	- flexibility (of rubber) (1)
- dry quickly (1)	- consistency (2)
- inexpensive (1)	- replaceability (1)
- design/form (2)	- function (in rain or shine) (2)
- versatility (2)	- care (1)
	- fist position (1)
	- rubber (2)
	- rubber placement (1)
	- donning (1)
	- liner (1)
	- velcro (supports wrist)
DISLIKES	**DISLIKES**
- contact cement hardens (1)	- hardens in cold (1)
- expensive (1)	- cost (2)
- poor durability, especially in rain (4)	- break in time/stiff (4)
- aquaseal/klister (messy) (2)	- appearance (1)
- upkeep (4)	- bulky (1)
- construction time (2)	- quality (poor) of thread and seams (2)
- slip/poor traction in rain (3)	- stretching (fit) (2)
- tape deforms in heat (1)	- modifications needed (2)
- inconsistency -difficult to create identical pair (2)	- velcro closure (1)
- weight (heavy) (2)	- seam along index finger (2)
- tape (2)	- inside of hand gear gets rough (1)

[a] number in brackets represents the number of responses for the particular like or dislike.

Table 8

Likes versus dislikes

CUSTOMIZED HAND GEAR	MANUFACTURED HAND GEAR
LIKES 1) Design/Form	**DISLIKES** 1) Seam along index finger
	2) Appearance/(Bulk)
2) Inexpensive	3) Cost
DISLIKES 1) Deteriorates quickly	**LIKES** 1) Durability
2) Inconsistency between pairs of hand gear, construction	2) Replaceability
3) Upkeep time involved make replacing hand gear difficult	
4) Slip and tape peels in rain/heat will deform the tape.	3) Function (rain/shine)
5) Dislike tape	4) Rubber

The versatility of customized hand gear allowed racers to develop their hand gear so it had neither unwanted seams nor excess bulk. Cost was a like and dislike for customized hand gear and, as a result, does not give it (customized hand gear) a strong advantage over manufactured. The choice of materials used in the manufactured hand gear resulted in suitable durability and function (rain/shine). The use of rubber negated the need for tape (as used in and disliked about customized hand gear). As well, the ease in replacing manufactured hand gear reduced the chances of inconsistency between pairs, as was experienced by athletes who used customized hand gear.

In summary, the aspects liked for both customized and manufactured hand gear (comfort, weight, durability, traction, fit, protection, flexibility) represented the important aspects that were being met by current hand gear. The aspects disliked regarding customized and manufactured hand gear (hardening, cost) were problems that neither form of hand gear met very well. A knowledge of both likes and dislikes is important to the improvement of hand gear design.

Observations indicated that hand gear was not interfering with racing movements. There were comments that the hand gear was too long in the fingers and along the outer edge (by the little finger). If this was a problem, athletes would have the excess rubber cut off and the seam resewn. Many athletes explained that customized hand gear was more likely to interfere with racing when the tape started unravelling during wet conditions. However, customized hand gear was rarely too long or bulky.

Suggestions for improving hand gear. To add to the information gained from athletes' comments on problems, injuries, likes and dislikes, the athletes were all asked for suggestions for obtaining ideal hand gear. The following is a summary of what the *athletes* suggested:

- Soft, flexible rubber was suggested as the best material for hand gear where the hands come in contact with the push rim.
- Leather was suggested to be the most comfortable material for the majority or "body" of the hand gear.
- Knit material should be used for part of the hand gear as the stretch provided by the knit used in the Harness gloves maintains fit and provides some air circulation.
- The rubber, along the index finger, should wrap around and under the index finger of the (manufactured) Harness hand gear, moving the seam away from the edge of the index finger.
- Two or three different basic hand gear forms should be available for the racer to chose from and build upon (customize) to meet his/her own individual needs.
- Consistency in design (and fit) is needed from one pair of hand gear to another.
- Hand gear must last, be well constructed and must not fall apart; a racer will pay for quality.
- Hand gear must wear well, regardless of weather condition.
- Hand gear must protect the hands from injury where the hand strokes the push rim.
- Hand gear must have good traction with the push rim. Acquiring the greatest force without the impact slowing the athlete down was considered very important.
- Ease in care/laundering was desired by an athlete.
- Wet weather glove.

Evaluation of fit, comfort, protection, weight and flexibility. From the very early stages of the research, comfort, fit and protection were determined as three design factors of the design problem. After the first interview, it became evident that flexibility and weight of wheelchair racers' hand gear were important factors as well. As a result, wheelchair athletes were asked various questions to understand their needs in regards to fit, comfort, protection, weight and flexibility of hand gear. The specific answers from each of the athletes can be found in Appendices 5 through 9. The information has been summarized here to develop a general understanding of the athletes' answers.

Many athletes agreed that if the fit of hand gear was too loose, blisters were likely to form. Wearing the glove liners provided by Harness Designs, Inc. or applying elastoplast to fingers and blisters, seemed to help prevent blisters or protect current blisters. Many athletes who customized their hand gear were able to attain good fit as the hand gear was built on the hands. The athletes who wore manufactured hand gear would go to a shoe repair shop if the fit needed to be modified. Table 9 summarizes the preferences for tight, snug and loose hand gear.

Table 9

Preferences of tight, snug, loose fit

	TIGHT	SNUG	LOOSE
Around Fingers	6 athletes	10 athletes 1 liked index finger snug	1 athlete 1 liked middle/ring and little fingers loose
Around Thumb	6 athletes	11 athletes	1 athlete
Around Wrist	9 athletes	9 athletes	0 athletes
Across Knuckles	4 athletes	13 athletes	1 athlete

Although each term (tight, snug, loose) was clearly defined by the researcher for the athlete, there was still room for subjective interpretation. Most athletes in general did not like a loose fit. Overall, the majority of the athletes liked a snug fit more than a tight fit. The fit desired around the wrist, however, was evenly split.

A common opinion of racers was that when hand gear caused any discomfort, their concentration on the race was negatively affected. This was evident from the following quotes: "Should feel part of you so you don't focus on them"; " If they're not comfortable it will distract you from your race"; "If you 'feel' it you think about that and not pushing"; "Being uncomfortable can cause improper pushing and can also affect concentration". For some athletes, the rain and perspiration caused some discomfort. As well, one athlete stated that having a hand gear made of a soft fabric and one that flexed with the hand ensured comfort. Poor fit, inadequate protection or insufficient flexibility seemed to lead to discomfort.

Protection was considered the most important aspect of hand gear by two athletes, while one felt that the hands were not the most vulnerable part of the body during a crash. However, every athlete had all fingers encased in leather at the least, which indicated, if only indirectly, the importance of protection. As well, many felt that injuries to the hands would have a negative impact on their athletic careers: "If injured, you can't race"; " You want to train tomorrow". One athlete stated that wheelchair users rely on their hands for mobility and any injury to the hands could jeopardize their everyday life. No athlete made specific reference to carpal tunnel syndrome.

Most of the athletes felt that lighter hand gear was better for racing. With light hand gear, the athlete was able to make quick strokes necessary for sprinting without excess weight slowing the him/her down. Several athletes were indifferent to the concept of weight stating that as long as the hand gear was functional, weight was not important. One athlete stated that his hand gear must be solid and he attributed weight to solidness. Although heavy gloves might add to his momentum, he did suppose lightweight hand gear would be ideal.

Many athletes felt that hand gear needed to be flexible enough to get the hand into a fist/pushing position. The amount of flexibility required after the hand gear was donned varied. Several athletes felt flexibility was not important and only inhibited a consistent and powerful push. Other athletes, mostly those who customized their hand gear, felt that flexible hand gear was essential. A quote sums up this opinion well: "Hand movement is what propels the chair - if your hands are restricted your chair is restricted".

Synthesis of Data and Development of Design Criteria

From all the information gathered from the interviews, questionnaires, observations, literature reviews and market survey, traction was also determined a design factor. The data also provided the researcher with information necessary to recommend the design criteria.

Protection. Hand gear must protect the hand from impact with the push rim. As a result of this, hand gear must suit the stroking style of the athlete and the design criteria must be considered separately for each stroking style. The materials used must be able to dissipate the force incurred so the hand receives the least amount of impact possible. Hand gear must encase all parts of the hand and create a compact structure, decreasing the chances of the fingers getting caught in the spokes. Hand gear design must protect the back of the hand from (muscle) strain. The resulting criteria are:

- o will protect all parts of the hand contacting the push rim (suiting the stroking style)
- o materials used will dissipate the force from impact evenly
- o shall be compact
- o palm shall cushion the "clenched" or closed hand
- o will encase the entire hand
- o will protect hand from sharp objects on the chair and spokes of wheels

Comfort. To decrease an athlete's discomfort, hand gear should not be stiff thus requiring a (long) break-in period during training or racing. A knit liner provides the athlete with some protection from blisters which form when the hand gear rubs against the bare skin. As well, for those who perspire, a liner would wick moisture away from the hand to increase comfort. Hand gear should be comfortable in all weather conditions. As a result, hand gear should dry quickly in wet weather and be breathable to provide air circulation for those athletes who have the capacity to sweat (perspiration shall evaporate quickly). The resulting criteria are:

- shall not be stiff
- shall be air and water vapour permeable
- a liner shall wick moisture

Fit. If hand gear does not fit properly blisters are likely to form, especially on the areas of the hand which come in contact with the push rim. In general, athletes like the fit of the fingers and thumb to range between snug and tight to ensure a close fit while allowing for blood circulation. As well, athletes need some design ease across the knuckles of the hand and fingers when the athlete initially dons the hand gear. This will permit the athlete to flex the fingers and hand into a fist. A liner, worn underneath the hand gear, will the tighten the fit. Therefore, fit depends upon whether or not an athlete will wear a liner. To allow the athlete to get the wrist of the hand gear over the width of the hand, the wrist of the hand gear needs to be adjustable. In order for the hand gear to stay on, a snug to tight fit across the wrist is required. The hand gear must be just the length of the fingers so it does not get in the way during racing. The final criteria are:

- will be customized to athlete's specific hand measurements
- finger length will not interfere with racing
- the fit around the wrist must be adjustable

Traction. It is very important for the racer to contact the push rim with a strong and solid stroke to exert the strongest push possible. As a result, the athlete's hand must not slip on the surface of the push rim. A suitable material which provides optimum traction with the rubber of the push rim is needed. A resulting design criterion is:

- must never slip on the pushrim

Durability. The durability of hand gear depends upon the quality of materials used and the construction techniques executed during production. Hand gear must withstand the training and racing routines of the athletes, as well as the care procedures. This means that the materials chosen and construction techniques (seams) used must be of high quality to withstand pounding forces incurred from contact with the push rim. Wet weather conditions must not speed up the deterioration of the hand gear. Currently, manufactured hand gear is supposed to last up to 1500 km and any improved form of hand gear must also last this distance. The design criteria are:

- o shall be durable for 1500 km
- o shall withstand the impact with the push rim for 1500 km
- o must withstand all weather conditions for 1500 km
- o will withstand laundering/care procedures

Weight. The weight of the hand gear is a debatable subject as some athletes were indifferent to it, some insisted hand gear needs to be light for sprinting and others stated that weight increases the sense of solidness and power. However, the researcher feels that the majority of athletes would like light weight hand gear. Solidness and thus, a consistent stroke, is attainable with a compact design, as specified under protection. Hand gear must not tire the racer's arms as the arms are already under a tremendous amount of strain propelling the racing chair. Materials chosen must contribute to light weight. A criterion is:

- o shall be light weight

Flexibility. Hand gear must be flexible enough to don and doff. Once the hand gear is on the hand, it must have enough ease across the knuckles to flex the fingers into a fist. When the hand is in its pushing position, flexibility is not an important factor. The hand gear only needs to allow enough movement for the racer to apply brakes or use the compensator device. The resulting design criteria are:

- o shall be easy to don and doff
- o shall be flexible across the knuckles before hand takes on fist position
- o shall keep hand in a secure pushing position
- o shall allow for application of brakes/compensator lever

A general consideration for cost must be noted. Although some athletes have mentioned that they would pay a lot of money for excellent hand gear, the current cost must be taken into account. On average, many athletes pay around $140 for manufactured hand gear. Thus, the cost should be competitive with this price.

- o shall not exceed a $150 market price.

It was important to note that discrepancies occurred within the likes and dislikes of customized hand gear as some athletes liked a certain aspect and others disliked it. For example: one athlete liked and two disliked the weight; two athletes liked and four disliked the durability; two athletes liked and three disliked the grip/traction; and one athlete liked and one disliked the cost (inexpensive versus expensive). Discrepancies existed between manufactured hand gear likes and dislikes in terms of fit. Three athletes liked the fit, while two noted that the leather stretched, decreasing the quality of fit and two stated that they needed to modify the hand gear which indicated a problem with original fit. These discrepancies were considered an indication that the needs and preferences of hand gear were likely to differ from athlete to athlete. The resulting criterion is:

- shall be customized to suit athletes' specific requests.

Establishing the Design Specifications

The final set of 24 design criteria were determined in the previous stage (Development of the Design Criteria). In summary, these were:

1) will protect all parts of the hand contacting the push rim (suiting the stroking style)
2) materials used will dissipate the force from impact evenly
3) shall be compact
4) palm shall cushion the "clenched" or closed hand
5) will encase the entire hand
6) will protect hand from sharp objects on the chair and spokes of wheels
7) shall not be stiff
8) shall be air and water vapour permeable
9) a liner shall wick moisture
10) will be customized to athlete's specific hand measurements
11) finger length will not interfere with racing
12) the fit around the wrist must be adjustable
13) must never slip on pushrim
14) shall be durable for 1500 km
15) shall withstand the impact with the push rim for 1500 km
16) must withstand all weather conditions for 1500 km
17) will withstand laundering/care procedures
18) shall be light weight

19) shall be easy to don and doff

20) shall be flexible across the knuckles before hand takes on fist position

21) shall keep hand in a secure pushing position

22) shall allow for application of brakes/compensator lever

23) shall not exceed a $150 market price

24) shall be customized to suit athletes' specific requests

A thorough comparison to identify and resolve conflicts, and set priorities, was started by developing interaction matrices specific to each stroking style (Tables 10, 11 and 12). The reason for three separate matrices was to compare criterion 1, which was specific for each stroking style, to the other 23 criteria. It was decided that without information on material properties, only POTENTIAL conflicts could be determined; this is discussed in Chapter V.

Table 10

Interaction Matrix of Design Criteria - Backhand Stroke

DESIGN CRITERIA

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. will protect all parts of the hand contacting the push rim (suitable for backhand stroke)	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	0	1	1	1	0	0	1	1
2. materials used will dissipate the force from impact evenly		0	0	0	0	1	1	0	0	0	0	1	0	0	1	1	1	0	1	0	1	1	1
3. shall be compact			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
4. palm shall cushion the "clenched" or closed hand				0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
5. will encase the entire hand					0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1
6. will protect hand from sharp objects on chair and spokes of wheels						0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	1
7. shall not be stiff							0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
8. shall be air and water vapour permeable								0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1
9. a liner shall wick moisture									1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
10. will be customized to athlete's specific hand measurements										0	0	0	0	0	0	0	0	0	0	0	0	1	1
11. finger length will not interfere with racing											0	0	0	0	0	0	0	0	0	0	0	0	1
12. the fit around the wrist must be adjustable												0	0	0	0	1	0	0	0	0	0	1	1
13. must never slip on pushrim													1	1	0	1	0	0	0	0	0	1	1
14. shall be durable for 1500 km														0	0	1	0	0	0	0	0	1	1
15. shall withstand the impact with the push rim for 1500 km															0	0	1	0	1	0	1	1	1
16. must withstand all weather conditions for 1500 km																			0	0	0	1	1
17. will withstand laundering and care procedures																		0	0	0	0	0	1
18. shall be light weight																		0	0	0	0	1	1
19. shall be easy to don and doff																			0	0	0	0	1
20. shall be flexible across the knuckles																				0	0	0	1
21. shall keep hand in secure pushing position																					1	0	1
22. shall allow for thumb movement																						0	1
23. shall not exceed a $150 market price																							1
24. shall be customized to suit athlete's specific requests																							

0 = No Conflict 1 = Potential Conflict/Accomodation Required

Table 11

Interaction Matrix of Design Criteria - Index/Middle Fingers and Thumb Stroke

DESIGN CRITERIA

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. will protect all parts of the hand contacting the push rim (suitable for the index/middle fingers and thumb stroke)	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	1	1
2. materials used will dissipate the force from impact evenly		0	0	0	0	1	1	0	0	0	0	1	0	0	1	1	1	0	1	0	1	1	1
3. shall be compact			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
4. palm shall cushion the "clenched" or closed hand				0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
5. will encase the entire hand					0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1
6. will protect hand from sharp objects on chair and spokes of wheels						0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	1
7. shall not be stiff							0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
8. shall be air and water vapour permeable								0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1
9. a liner shall wick moisture									1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
10. will be customized to athlete's specific hand measurements										0	0	0	0	0	0	0	0	0	0	0	0	1	1
11. finger length will not interfere with racing											0	0	0	0	0	0	0	0	0	0	0	0	1
12. the fit around the wrist must be adjustable												0	0	0	0	1	0	0	0	0	0	1	1
13. must never slip on pushrim													1	1	0	1	0	0	0	0	0	1	1
14. shall be durable for 1500 km														0	0	1	0	0	0	0	0	1	1
15. shall withstand the impact with the push rim for 1500 km															0	0	1	0	1	0	1	1	1
16. must withstand all weather conditions for 1500 km																0	0	0	0	0	0	1	1
17. will withstand laundering and care procedures																	0	0	0	0	0	0	1
18. shall be light weight																		0	0	0	0	1	1
19. shall be easy to don and doff																			0	0	0	0	1
20. shall be flexible across the knuckles																				0	0	0	1
21. shall keep hand in secure pushing position																					1	0	1
22. shall allow for thumb movement																						0	1
23. shall not exceed a $150 market price																							1
24. shall be customized to suit athlete's specific requests																							

0 = No Conflict 1 = Potential Conflict/Accomodation Required

Table 12

Interaction Matrix of Design Criteria - Index Finger and Thumb Stroke

DESIGN CRITERIA

		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1.	will protect all parts of the hand contacting the push rim (suitable for the index finger and thumb stroke)	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	0	1	0	1	0	0	1	1
2.	materials used will dissipate the force from impact evenly		0	0	0	0	1	1	0	0	0	0	1	0	0	1	1	1	0	1	0	1	1	1
3.	shall be compact			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
4.	paln. shall cushion the "clenched" or closed hand				0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
5.	will encase the entire hand					0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1
6.	will protect hand from sharp objects on chair and spokes of wheels						0	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	1
7.	shall not be stiff							0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
8.	shall be air and water vapour permeable								0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1
9.	a liner shall wick moisture									1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
10.	will be customized to athlete's specific hand measurements										0	0	0	0	0	0	0	0	0	0	0	0	1	1
11.	finger length will not interfere with racing											0	0	0	0	0	0	0	0	0	0	0	0	1
12.	the fit around the wrist must be adjustable												0	0	0	0	1	0	0	0	0	0	1	1
13.	must never slip on pushrim													1	1	0	1	0	0	0	0	0	1	1
14.	shall be durable for 1500 km														0	0	1	0	0	0	0	0	1	1
15.	shall withstand the impact with the push rim for 1500 km															0	0	1	0	1	0	1	1	1
16.	must withstand all weather conditions for 1500 km																0	0	0	0	0	0	1	1
17.	will withstand laundering and care procedures																	0	0	0	0	0	0	1
18.	shall be light weight																		0	0	0	0	1	1
19.	shall be easy to donn and doff																			0	0	0	0	1
20.	shall be flexible across the knuckles																				0	0	0	1
21.	shall keep hand in secure pushing position																					1	0	1
22.	shall allow for thumb movement																						0	1
23.	shall not exceed a $150 market price																							1
24.	shall be customized to suit athlete's specific requests																							

0 = No Conflict 1 = Potential Conflict/Accomodation Required

4. What other forms of hand gear have you used in the past? If you customized this hand gear, please be very specific about the products you used and how you used them. If you purchased hand gear designed for racing, please describe in detail.

5. If your current hand gear is different from past forms, why is this so? (For example: What problems did you experience with PAST hand gear to make you change what you wear/use?)

6. Keeping your current hand gear in mind, write down at least three things you like about it and state why.

7. Again, keeping your current type of hand gear in mind, write down at least three things you dislike about it and state why.

II) For each of the following statements, place a check (✓) at the position on the scale that best represents how you feel about the statement, and then indicate why you feel this way.

1 Hand gear must protect the hand from injury during racing
strongly agree ____:____:____:____:____:____:____ strongly disagree

Why

2. Hand gear must be comfortable to race in
strongly agree ____:____:____:____:____:____ ____ strongly disagree

Why: ______________________________
____

3. Hand gear must be lightweight:
strongly agree ____:____:____:____:____:____ ____ strongly disagree

Why: ______________________________
____

4. Hand gear must fit well
strongly agree ____:____:____:____:____:____ ____ strongly disagree

Why: ______________________________
____

5 Hand gear must be sufficiently flexible:
strongly agree ____:____:____:____:____:____:____ strongly disagree

Why ______________________________
____

6 List any other factors you feel are important to functional hand gear and state why they are important

____
____
____

III) Answer the following questions.

1. In which season(s) of the year do you most often race?

__ Winter __ Spring __ Summer __ Fall

2 In what weather conditions does this require you to race? __________
____

3 In which weather condition do you most often race? __________

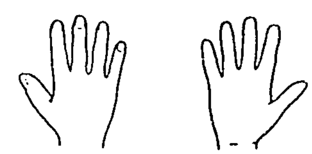
4 In what type(s) of weather does your hand gear function the least effectively? Why is this so? ______________________________
____

5 In what type(s) of weather does your hand gear function the most effectively? Why is this so? ______________________________
____

6 Describe any hand/wrist/arm injuries you have sustained during racing and what caused them ______________________________
____
____

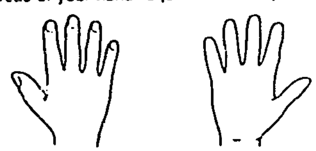
IV) Please answer the following questions using the hand diagrams and the space provided for a written response.

1 What areas of your hand come in contact with the push rim as you stroke the wheel?

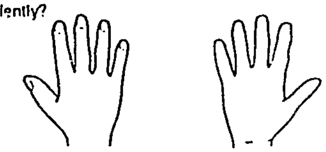


____
____

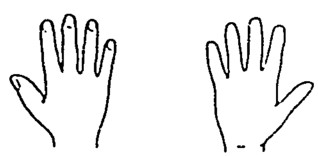
2 Which areas of your hand require the most protection?



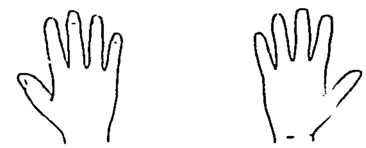
3. What parts of the hand gear need to be sufficiently flexible to allow you to race efficiently?



4 What parts of your hand gear have in ANY way ever interfered with your movements during racing? (For example: What parts of your hand gear have been caught on your racing chair?)



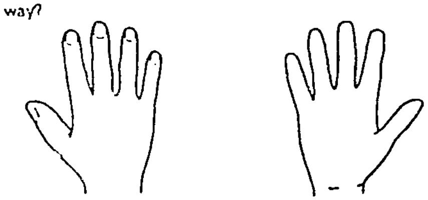
5 Has a form of hand gear ever irritated your hands? If so, what types of irritations did you receive, what caused them and where were they on your hand? (irritations can be such things as blisters, rashes, abrasions, cuts, etc. caused by your hand gear).



V) Complete the following statements as fully as possible. Please answer the questions using the hand diagrams and the space provided for written explanations.

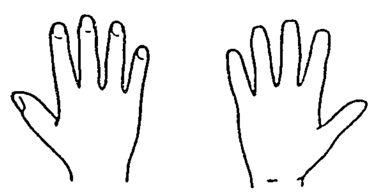
1 a) If you customize your hand gear, what do you do to ensure good fit?

b) If you wear a manufactured racing glove (ie: Harness® glove), does it fit you properly? Why/why not? Do you customize it in any way?



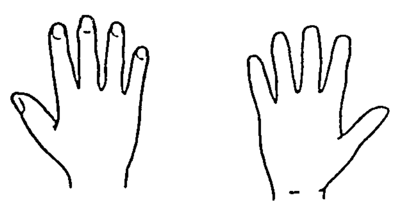
2. a) If you customize your hand gear, what do you do to ensure it is comfortable?

b) If you wear a manufactured racing glove (ie Harness® glove), Is it comfortable to race in? Why/why not? Do you customize it in any way?



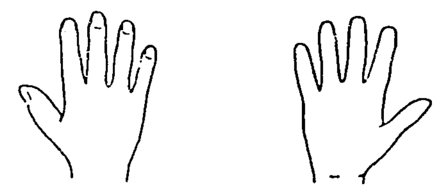
3. a) If you customize your hand gear, what do you do to ensure adequate protection from injury?

b) If you wear a manufactured racing glove (ie. Harness® glove), has it been designed to protect your hand adequately? Why/why not? Do you customize it in any way?



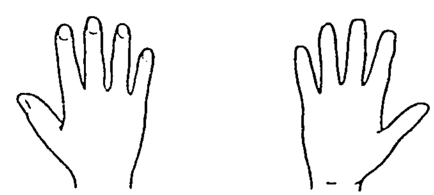
4. a) If you customize your hand gear, what do you do to ensure your hand gear is flexible enough to race in?

b) If you wear a manufactured racing glove (ie: Harness® glove), Is it flexible enough to execute all necessary racing movements? Why/why not? Do you customize it in any way?



5. a) If you customize your hand gear, what do you do to ensure it is an appropriate weight?

b) If you wear a manufactured racing glove (ie: Harness® glove), Is it an appropriate weight? Why/why not? Do you customize it in any way?



VI) **Consider how you like your hand gear to fit around your hand/fingers/thumb/wrist. Tight refers to a very tight fit where the hand gear fits as closely as possible, applying some pressure to the hand. Snug refers to a very close, yet slightly relaxed fit. Loose means the hand gear is larger than the hand.**

Place a check (✓) in the appropriate box which best describes how you like your hand gear to fit across certain parts of the hand (as indicated in the far left column). Please make any additional comments you feel would be useful for the researcher.

	TIGHT	SNUG	LOOSE
Around your fingers			
Around your thumb			
Around your wrist			
Across hand knuckles			

VII) **The next set of questions are designed to help the researcher determine if any information arising from the questionnaire is specific to sex, class of athlete or past experience.**

1. Male ______ Female ______

2. Quadriplegic ____ Paraplegic ____ Cerebral Palsy ____
   Amputee ____ Other (please specify) ____________________

3. How many years you been involved with a wheelchair? ____________

4. What is your wheelchair athletic classification? ____________

5. In what events do you participate in? ____________________

6. For how many years have you participated in wheelchair racing:
   a) recreationally ____________
   b) competitively (at the national level or higher) ____________

VIII) **Please use the following space to make ANY comments you think would be useful for improving the hand gear available for you and fellow athletes. If possible, make specific comments for improving hand gear in terms of fit, comfort, protection, flexibility and weight.**

____

____

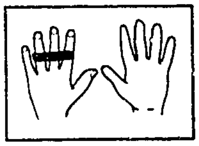
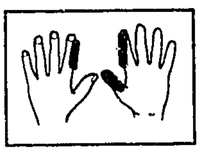
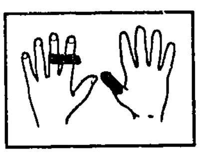
____

THANK YOU FOR COMPLETING THE QUESTIONNAIRE ☺

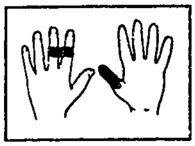
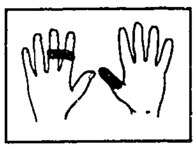
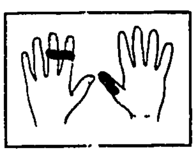
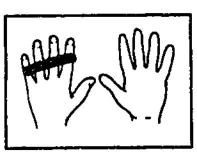
APPENDIX 4

Athlete's sex, disability, wheelchair athletic classification, current hand gear and problems associated with hand gear.

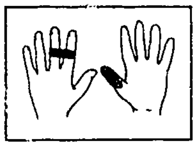
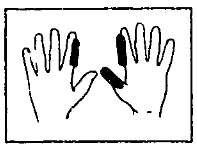
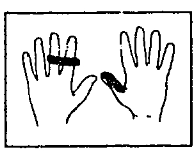
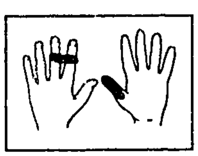
Athlete's sex, disability, wheelchair athletic classification, current hand gear and problems associated with hand gear.

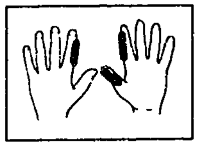
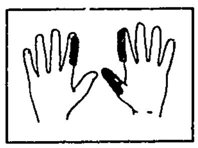
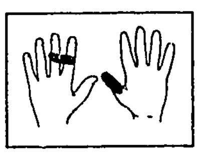
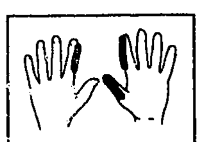
ATHLETE, DISABILITY, ATHLETIC CLASSIFICATION	STROKE	DESCRIPTION OF CURRENT HAND GEAR AND -PROBLEMS ASSOCIATED WITH HAND GEAR (CURRENT OR FORMER)
Subject 1 Male Quadriplegic T-2 Interview	- back side of index, middle, ring fingers. 	- Customizes hand gear: soft leather work gloves, taped with elastoplast to hold fingers (index, middle and ring) together. A "Swedish" rubber is glued to top of three fingers and to the thumb (refer back to plate 1). - The contact cement hardens and the upkeep of this hand gear is time consuming. - Has tried Harness hand gear (mitt style) which hardened in cold weather (about 2° C) and caused tendonitis. - Harness had too much rubber along the pinky which was interfering with racing (rubbing against the push-rim and spokes) (was sized down).
Subject 2 Male Cerebral Palsy T-4 Interview	- side of the index finger and inside edge of the thumb. 	- Customizes hand gear: baseball batting glove (soft leather and stretchy material) are taped with a roll of hockey tape; tape wrapped around fingers, with the most build up on the thumbs and index fingers (refer back to plate 2). Has tried a coated cotton industrial glove as a base which stretched and became heavy when wet. - Hand gear is not durable, and the wet/rain decreases its durability and traction. - This athlete had many blisters and tendonitis in the wrist.
Subject 3 Male Cerebral Palsy T-3 Interview	- dorsal side the index finger. 	- Harness hand gear (mitt style): tapes index fingers and wrists with moleskin, wears wrist bands and knit glove liner underneath the Harness hand gear (refer back to plate 6). - Customized hand gear - tape wore down and peeled off; retaping decreased size and increased weight. - Skin abrasions occur on (mostly left) index fingers' knuckles, and wrist (if wrist bands not worn); break-in time necessary.

Athlete description and comments on current and past hand gear continued...

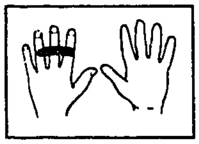
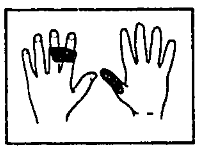
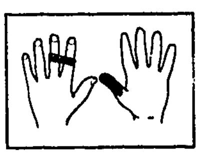
Subject 4 Female Paraplegic T-4 Questionnaire	- back side of thumb and dorsal side of the index/ middle fingers. 	- <u>Harness</u> hand gear (two-fingered style): must modify gloves as the index/middle finger pocket is too long. Harness costs $130 and lasts five to six months. - Soft leather of Harness gloves stretches and blisters are a problem from loose fitting gloves. - Customized hand gear - tape and elastoplast would wear down too quickly.
Subject 5 Male Paraplegic T-4 Questionnaire	- dorsal side of middle/ index fingers; ventral side of thumb. 	- <u>Harness</u> hand gear (two-fingered style): modifications occur when ordering gloves - asks for 1/2" foam padding instead of 1". As well, clenches a 5/8" tube in palm to reduce tendon stretch over the back of hand. Total hand gear costs $178 and lasts 2 to 3 months (1500km). - Some problems have been blisters and abrasions; a past problem was stretching the tendon in back of hand. - Harness hand gear becomes cold and brittle in snow. - Customized hand gear: slipped in rain, tape deformed in heat, difficult to reconstruct identical hand gear.
Subject 6 Male Amputee T-4 Questionnaire	- dorsal side of middle/ index fingers, ventral side of thumb. 	- <u>Harness</u> hand gear (2-fingered style?): tapes fingers (knuckles of index finger and thumb) before donning. The tip of index/middle finger pocket interferes with racing (too long?). Harness lasts 3 to 4 months...no cost given. - Has had wrist and thumb injuries during racing. States that loose hand gear causes irritation. - Customized hand gear: tape not good for grip.
Subject 7 Male Quadriplegic T-2 Questionnaire	- dorsal side of the four fingers. 	- <u>Harness</u> hand gear (mitt style): No modifications stated. Replaces hand gear twice a year. No cost given. - Hand gear is initially stiff and requires break in period. Knuckles of index and middle fingers susceptible to irritations. - Customized hand gear: only lasted 2 to 3 weeks and was not efficient in the rain.

Athlete description and comments on current and past hand gear continued

Subject 8 Male Paraplegic T-4 Questionnaire	- dorsal side of index/ middle fingers; inside (dorsal) edge of thumb 	- Customizes hand gear: waterski gloves are taped with medical tape and aquaseal is applied for "traction". The first three fingers are taped together. Hand gear lasts 2 to 3 months. No cost given - Has not had any problems except the aquaseal is messy. The pinky finger can get in the way of racing
Subject 9 Female Cerebral Palsy CP-4 Questionnaire	- inside of index finger and thumb. 	- Customizes hand gear: waterskiing gloves are taped with hockey tape and ski clister is applied to inside knuckle of first finger on both hands to prevent slipping. Replaced every six months. Cost $50 (per 6 months???) - The major problems: the clister is messy, if tape unravels, its ends may interfere with racing; hand gear become uncomfortable and loses traction in rain. - Has had sprained fingers from catching in the wheel, inflamed wrist from overuse, blisters
Subject 10 Female Amputee T-4 Questionnaire	- dorsal side of index/ middle fingers, ventral side of thumb. 	- Manufactured hand gear (One Step Beyond). The only negative aspect of hand gear is the break in period. Lasts about three months, though rubber may need to be replaced before. No cost was given. - Customized hand gear was too heavy with tape build up and the push was not consistent between pairs of hand gear - Sprained joint in thumb and caught thumb in spokes while wearing customized hand gear.
Subject 11 Male Paraplegic T4 Questionnaire	- dorsal side of index/ middle fingers, ventral side of thumb. 	- Harness hand gear: tapes the two fingers and the thumb then donns glove liner. Has to get a shoe repair-shop to take out excess padding - only needs padding where he strokes the push-rim. Replaces them every two months. No cost given. - Old forms of hand gear not as effective as Harness.

Subject 12 Male Cerebral Palsy CP-3 Questionnaire	- edge of index finger and thumb. 	- <u>Customizes</u> hand gear: tapes baseball (batting) glove on all fingers, padding the thumb and index finger; the palm is taped; right hand needs more padding than the left. Uses sticky rubber tape and a sticky back foam. Fixes every week, and replaces completely every 2 months. $60 - gloves, $20 - tape. - Bruised thumb from excessive pushing; jammed fingers and thumb; the tops of index and middle fingers get in the way; hand gear slips in the rain.
Subject 13 Male Paraplegic T-4 Questionnaire	- thumb and edge of the index finger. 	- <u>Customizes</u> hand [illegible] es hand ball gloves - taping the thumb and index [illegible] 's glove with elastoplast tape, rubber sewn on parts th[illegible] [illegible] action (refer to plate 3). Fixes the hand gear every [illegible] weeks 25 Sterling (english money)...$50 ?? - Tips of fingers can interfere with racing; has only had irritations/ abrasions when breaking in hand gear.
Subject 14 Female Paraplegic T-3 Questionnaire	- dorsal side of first two fingers, and venatral side of thumb; fatty area below base of thumb for uphilll. 	- <u>Customizes</u> hand gear: tapes hand ball gloves with athletic tape (elastoplast). Tape built up on dorsal side of fingers, like a shield. Harness rubber is used on top of fingers and thumb (refer to plate 4). Will completely replace hand gear every year - $80. - Used to strain area underneath thumb (base of thumb), but this was due to stroking technique, not hand gear. If too much rubber is on thumb, will get into discs/spokes (of racing chair).
Subject 15 Male Paraplegic T-4 Questionnaire	- side of the index finger and the thumb. 	- <u>Customizes</u> hand gear: tapes hand ball gloves; builds up gloves with strapping tape (underneath for strength/solidness) and elastoplast (on top of strapping tape). Tape is built up on top of fingers to create a shield (like #13). Builds palm up to fit the fist (similar to #5 clenching a tube) (refer back to plate 5). Cost hard to say - about $60 for hand gear, plus weekly tape costs. Replaces entire hand gear every 6 mongths. - Strained back of hand (hence tape build up in palm); has had tingling at the end of long race; blisters on index finger common). Edge of tape will get in the way if it should pull off. - Replaces top layers every week; the rest lasts about six months.

Athlete description and comments on current and past hand gear continued...

Subject 16 Male Paraplegic T-4 Interview	- dorsal side of the index, middle and ring fingers. 	- Harness hand gear (mitt style): wears the glove liner underneath; will tape any blisters with elastoplast. The velcro strap which closes hand in fist increases the force pushed against the wheelchair push rim. - Sometimes gets blisters in between tips of index and middle fingers from pinching.
Subject 17 Male Paraplegic T-4 Questionnaire	- along the side of index finger and the thumb - uses mainly the thumb on hills. 	- Harness hand gear (two fingered style): does not wear the glove liner (refer back to plate 7). - Tried the mitt style Harness; was "too much" and did not like the velcro strap which closed hand into a fist. The two fingered style has less rubber, is not as big and clumsy. - Customized hand gear: tape came off.
Subject 18 Male Paraplegic T-3	- along the top/side of the index and middle fingers and the thumb. 	- Harness (2-fingered style). Orders hand gear with velcro strap at ends of middle/index finger which wraps around the wrist, holding the hand in a locked position for pushing. Wears a stretchy, acrylic/spandex glove as a liner (not one provided by Harness). - Has used pine tar for traction during rain and it has slowed him down, when he didn't work it into the hand gear properly. The inside of the glove is rough, if a liner isn't worn, the skin of the hand is irritated (not necessarily to the formation of blisters, just an uncomfortable rubbing sensation). - Has worn hand gear from One Step Beyond and found the rubber came off (would've ruined a race, happened during training). - Customized hand gear: used a baseball glove and tape; taping all four fingers together and then taping shut like the Harness Mitt-Style. Tape wore down, got hard, if any glue was used, it would make tape "gooey", he got a lot of blisters.

APPENDIX 5

Athletes' comments on "FIT"

Athletes' Comments on Fit.

Note. M = Male F = Female Q = Quadriplegic P = Paraplegic A = Amputee CP = Cerebral Palsy C = Customized hand gear H = Harness hand gear T-1, T-2, T-3, T-4, CP-3, CP4 = Athletic Classification

ATHLETE DESCRIPTION	COMMENTS ON FIT
1 - M, Q, T-2, C	- Fit is very important and athlete takes time to get hand gear to fit perfect so it feels good. Snug across fingers or blisters result. With Harness, thumb doesn't fit well, too bulky and sloppy.
2 - M, CP, T-4, C	- Loose gloves move around too much resulting in blisters Athlete likes hand gear tight around wrist for protection (from tendonitis)
3 - M, CP, T-3, H	- Likes fingers to fit firmly, but pliable - a snug fit (as opposed to tight) is desired to allow blood to circulate.
4 - F, P, T-4, H	- Fit is a very important aspect of hand gear. Gets hand gear fixed at a shoe repair-shop. Tight fit is comfortable.
5 - M, P, T-4, H	- Fit is a very important aspect of hand gear. Harness hand gear fits very well (felt that the 6 standard sizes allow for this). Requests 1/2" padding vs 1".
6 - M, A, T-4, H	- Fit is very important to athlete - fit important for a better grip. Harness has too much padding - takes it out where it isn't needed.
7 - M, Q, T-2, H	- Fit is a very important aspect of hand gear.
8 - M, P, T-4, C	- Fit is a very important aspect of hand gear. Can hurt self if gloves do not fit right Wears hand gear for awhile before taping to ensure proper fit.
9 - F, CP, CP-4, C	- Fit is a very important aspect of hand gear. If hand gear does not fit well, may cause blisters. Hand gear should be snug but not restricting.
10 - F, A, T-4, H	- Fit is a very important aspect of hand gear. Hand gear "should be part of you". Measurements of hands are taken to get good fit.
11 - M, P, T-4, H	- Hand gear taken to a shoe repair-shop to adjust the fit.
12 - M, CP, CP-3, C	- Fit is a very important aspect of hand gear; or hand gear might fall off during a race Likes a tight fit with no excess material.
13 - M, P, T-4, C	- Fit is an important aspect of hand gear; acquires desired fit by keeping fingers tight inside.

Athletes' comments on fit
continued ..

14 - F, P, T-3, C	- Fit is a very important aspect of hand gear. Hand gear must not mcve, or blisters will result. Buys good quality leather gloves and builds (hand gear) on hand; is currently rebuilding Harness ...H sizes seem to be (fit) general.
15 - M, P, T-4, C	- Fit is a very important aspect of hand gear - fit important to reduce chances of blisters. Acquires a good fit by knowing what gloves look like and going for some easy steady pushes before final taping.
16 - M, P, T-4, H	- Fit is important - Harness fits.. except it stretches and gets sloppy after 100km and if glove is too tight at base of thumb, will hurt. Liners help tighten the fit - hand gear mustn't be too tight across knuckles otherwise forming a fist is difficult.
17 - M, P, T-4, H	- No probs with current glove.
18 - M, P, T-3, H	- The leather molds to the shape of the hand without overstretching. Likes a snug (as opposed to tight fit) which allows the blood to circulate in the hands/fingers. Does prefer a tight fit in the wrist. Palm areas have some extra room; In general, hand gear is a little big without glove liner worn underneath.

APPENDIX 6

Athletes' Comments on "COMFORT"

Athletes' Comments on Comfort.

Note. M = Male F = Female Q = Quadriplegic P = Paraplegic A = Amputee CP = Cerebral Palsy C = Customized hand gear H = Harness hand gear T-1, T-2, T-3, T-4, CP-3, CP4 = Athletic Classification

ATHLETE DESCRIPTION	COMMENTS ON COMFORT
1 - M, Q, T-2, C	- Hot and humid weather most comfortable even though skin and callouses soften, increasing the chances of skin abrasions. Rubber of Harness hand gear rubs and abrades the skin off the knuckles - causing discomfort.
2 - M, CP, T-4, C	- Hand gear is comfortable except in the rain. Hot and humid weather conditions make hands (in hand gear) sticky from perspiration (but not comparable to problems encountered in the rain). If gloves weren't comfortable he wouldn't wear them as he may not perform as well. Weather and comfort - used to dry hot weather.
3 - M, CP, T-3, H	- In hot and humid weather, hands get hot and sweaty, but he does not notice this until he takes gloves off. Has problems with the wrist band creating uncomfortable sensations and blisters on wrist (so he wears wrist bands).
4 - F, P, T-4, H	- Comfort is important - must wear the hand gear everyday and they should feel part of your hand. A tight fit is comfortable.
5 - M, P, T-4, H	- Comfort is a very important factor for hand gear.
6 - M, A, T-4, H	- Comfort is a very important factor for hand gear. For better performance you need comfortable hand gear.
7 - M, Q, T-2, H	- Hand gear must be comfortable.
8 - M, P, T-4, C	- If you are not comfortable you will hurt your hands. Comfort is a very important factor for hand gear.
9 - F, CP, CP-4, C	- "being uncomfortable can cause improper pushing and can also affect concentration". Comfort is very important for hand gear. Current hand gear is comfortable because the fabric is soft and flexible.
10 - F, A, T-4, H	- Hand gear must be comfortable - "Should feel part of you so you don't focus on them". Made to measure hand gear guarantees comfort.
11 - M, P, T-4, H	- Comfort is very important for hand gear. He just has padding where he pushes to ensure comfort.
12 - M, CP, CP-3, C	- Comfort is very important for hand gear. "If they're not comfortable it will distract you from your race". Ensures hand gear is comfortable by adding enough padding in the right spots - tests it out then repads as needed.

Athlete's comments on
comfort continued....

13 - M, P, T-4, C	- Comfort is very important for hand gear and for pushing properly. To ensure comfort, athlete builds up outer tape so it feels right and puts on rubber patches.
14 - F, P, T-3, C	- Comfort is very important for hand gear - "If you 'feel' it you think about that and not pushing". Hand gear is built on hand and good padding is used to get comfortable hand gear.
15 - M, P, T-4, C	- Comfort is very important for hand gear. The racer becomes more uncomfortable with distance. Comfort is attained by knowing what to do, where to put tape and through careful and slow hand gear development.
16 - M, P, T-4, H	- Comfort is important and is well met by Harness glove.
17 - M, P, T-4, H	- Old Harness hand gear (mitt style) was too bulky creating a sense of discomfort.
18 - M,P,T-3, H	- Liner soaks up perspiration. Warm weather is comfortable, however hand gear is good in all conditions. Notices discomfort when liner not worn. Blisters are not necessarily forming - rather just an "abrasive" or "rubbing" feeling.

APPENDIX 7

Athletes' Comments on "PROTECTION"

Athletes' Comments on Protection.

Note. M = Male F = Female Q = Quadriplegic P = Paraplegic A = Amputee CP = Cerebral Palsy
C = Customized hand gear H = Harness hand gear T-1, T-2, T-3, T-4, CP-3, CP4 = Athletic Classification

ATHLETE DESCRIPTION	PROTECTION
1 - M, Q, T-2, C	- Most important aspect of hand gear, as you need protection every time you hit the rim. Must be aware of injuries which could ruin everyday and later life. Problem with injuries and wheelchair users is a shoulder or hand injury can never be fully rested as hands/arms/shoulders are needed to move wheelchair. It is necessary to cover all parts of hands all the time. Leather protection is needed everywhere, but rubber should end above knuckles (for flexibility). Using rubber coverage for protection is only necessary in specific areas (hand/pushrim contact).
2 - M, CP, T-4, C	- Must wear hand gear all the time or hands get beat up. All aspects of the hand are covered. Will apply just a couple layers of hockey to the middle, ring and pinky fingers, while the thumb and index finger need close to 25 layers of tape.
3 - M, CP, T-3, H	- Must always wear something on hands. The top part of hand needs protection from impact, though all parts of hand need coverage.
4 - F, P, T-4, H	- Protection is important for athletes as it would not be any good for the hands to get hurt from racing.
5 - M, P, T-4, H	- Protection is very important - Need the most protection at wrist, and fingers and thumb where hand contacts the pushrim.
6 - M, A, T-4, H	- Hand gear must protect hand - it is a very important aspect of hand gear. Says it is not fun pushing with blisters on fingers. Areas in need of protection are where athlete pushes the rim - middle and index fingers (dorsal side along knuckles) and thumb.
7 - M, Q, T-2, H	- Protection is an important aspect of hand gear. It is hard to stay focused on racing if hands are suffering. The dorsal side (top) of the four fingers need most protection.
8 - M, P, T-4, C	- Protection not indicated as athlete's primary concern. The tops of the index, middle and ring fingers and edge of the thumb need protection. Knows exactly where he hits and where to put extra tape on hand gear.
9 - F, CP, CP-4, C	- "Protection is the primary purpose of hand gear. However, stretching can also prevent injury". Inside of index fingers require the most protection and this is done by padding with tape.
10 - F, A, T-4, H	- Strongly agrees that hand gear must protect - "If injured you can't race". States that the way injury is avoided is from customized, made-to-measure gloves. Thumb and next two fingers require the most protection.

Athletes' comments on
protection continued...

11 - M, P, T-4, H	- Protection is very important and most needed where the hand contacts the pushrim (thumb, index and middle fingers). Harness hand gear has good padding for protection, though he will take excess padding out so only areas in need of protection have it.
12 - M, CP, CP-3, C	- Hand gear must protect hands as "you could seriously damage your hands". The areas where he strokes the push rim is where he needs the most protection. Gets enough protection by putting tape everywhere on the glove.
13 - M, P, T-4, C	- Strongly disagrees that hand gear must protect the hands from injury as the "hands are not the most vulnerable piece of the body when you have a crash". Yet, has stated that his index fingers and thumbs require the most protection and are protected by applying tape on top of glove to pad sufficiently.
14 - F, P, T-3, C	- Strongly agrees that hand gear must protect from injury. "If you don't feel pain you can push harder". The parts needing most protection are the knuckle areas of index and middle fingers. Hand gear is built slowly and tried out at several stages. Good (quality) tape and rubber sewn on top ensures protection.
15 - M, P, T-4, C	- Strongly agrees that hand gear must protect. The outer edge of the index finger and the tips of the thumb need protection. Blisters will form from movement and as he pushes further down on the thumb to go uphill. Needs protection from straining back of hand so he builds in ridge inside the palm of hand.
16 - M, P, T-4, H	- Protection is an important aspect of hand gear and Harness does a good job. Athlete likes all of the fingers at least encased in leather glove - covered just incase. When blisters form, will put elastoplast on them, and then put on glove liner.
17 - M, P, T-4, H	- No problems with protection. No injuries yet.
18 - M, P, T-3, H	- Harness has rubber right where he pushes (index and middle finger, and outer edge of the thumb. Inside of glove gets rough and the sweat inside hands plus roughness creates blisters. Protection necessary for all aspects of the hand. No injuries yet.

APPENDIX 8

Athletes' Comments on "WEIGHT"

Athletes' Comments on Weight.

Note M = Male F = Female Q = Quadriplegic P = Paraplegic A = Amputee CP = Cerebral Palsy
C = Customized hand gear H = Harness hand gear T-1, T-2, T-3, T-4, CP-3, CP4 = Athletic Classification

ATHLETE DESCRIPTION	WEIGHT
1 - M, Q, T-2, C	- The Harness glove wastes a lot of rubber which makes it bulky and adds weight. Hand gear shouldn't be too heavy for fast races (sprinting) where the racer must stroke the pushrim 2 times per second.
2 - M, CP, T-4, C	- Once, when too much tape was applied, hand gear was too heavy. Had tried a coated cotton glove as a base, and this glove got heavier when wet (more so than the batting glove).
3 - M, CP, T-3, H	- Harness not heavy. Did find that customized hand gear got heavy from tape build up.
4 - F, P, T-4, H	- The lighter the better. Harness hand gear is light enough.
5 - M, P, T-4, H	- Hand gear must be light in weight.
6 - M, A, T-4, H	- Strongly agrees that hand gear must be light weight - "You can't push with a boxing glove".
7 - M, Q, T-2, H	- Athlete indifferent to light versus heavy hand gear.
8 - M, P, T-4, C	- You don't want to be bearing any extra weight...so it is important for hand gear to be light weight. Athlete will not put on a lot of tape and instead of taping up a hole, he will remove the old tape first, before applying new tape.
9 - F, CP, CP-4, C	- Light hand gear is important for quick hand movement.
10 - F, A, T-4, H	- Hand gear must be light in weight. Could develop sore wrists if not light. The made to measure hand gear is light weight.
11 - M, P, T-4, H	- Athlete's answer difficult to understand - believe he feels that his hand gear is not heavy, but weight is not important.
12 - M, CP, CP-3, C	- Hand gear must be light in weight. "If they are heavy it will be hard to move your hands and it will slow you down". Uses lightweight foam for padding.
13 - M, P, T-4, C	- Agrees that hand gear must be light in weight, though it does not seem to be a very important aspect of hand gear.
14 - F, P, T-3, C	- Seems indifferent to weight - "If it works weight is not such a factor". Athlete does not worry about weight.

Athletes' comments on
weight continued...

15 - M, P, T-4, C	- Seems indifferent (neutral) on weight subject. "Depends! Heavy gloves can add to momentum, but (I) suppose lightweight would be ideal". The athlete likes them heavier...heavy means solid - or at least gives him a sense that the hand gear is solid.
16 - M, P, T-4, H	- Harness is pretty light, but could still be lighter...the lighter the better. Once you are racing, you don't notice them.
17 - M, P, T-4, H	- No problems or comments with weight.
18 - M, P, T-3, H	- Harness hand gear light - not heavy.

APPENDIX 9
Athletes' comments on "FLEXIBILITY"

Athletes' Comments on Flexibility.

Note. M = Male F = Female Q = Quadriplegic P = Paraplegic A = Amputee CP = Cerebral Palsy
C = Customized hand gear H = Harness hand gear T-1, T-2, T-3, T-4, CP-3, CP4 = Athletic Classification

ATHLETE DESCRIPTION	COMMENTS ON FLEXIBILITY
1 - M, Q, T-2, C	- Athlete dislikes the how far down on the hand the rubber of Harness hand gear goes as it abrades the skin (on the knuckles) and makes it more difficult for him to make a fist with hand. Customized hand gear allows for him to place rubber ONLY on areas of contact with the push rim.
2 - M, CP, T-4, C	- Too much tape decreases the amount of flexibility which makes the hand gear stiff. Athletes needs flexibility in hands, but support in the wrist.
3 - M, CP, T-3, H	- No direct comments on flexibility - except Harness hand gear must be "broken" in for a week or so to get the movement needed in the fingers and hand.
4 - F, P, T-4, H	- Strongly agrees that hand gear must be flexible - not too much padding provides the athlete with the amount of flexibility needed across fingers.
5 - M, P, T-4, H	- Once the hand gear is on the hand, it must be firm, otherwise the power is lost when the push rim is struck. Athlete does not believe hand gear must flexible (except for enough flexibility for donning). Athlete does note flexibility is important across knuckles to get hand into fist - however, once the velcro strap is closed, hand gear must be solid.
6 - M, A, T-4, H	- Relates flexibility to tiredness...hand gear must be sufficiently flexible so hands don't get tired. Needs flexibility along push areas (index and middle fingers and thumb).
7 - M, Q, T-2, H	- Hand gear needs to be flexible in the lower part of the fingers.
8 - M, P, T-4, C	- Athlete likes to feel the push rim, stating hand gear should be flexible. The index (dorsal side) and bottom of thumb need flexibility. Athlete trains in them before racing to ensure they are flexible.
9 - F, CP, CP-4, C	"Hand movement is what propels the chair - if your hands are restricted your chair is restricted". The second knuckles on fingers must be able to make a fist. If the hand gear is taped too tightly, then it becomes restricting.
10 - F, A, T-4, H	- Strongly disagrees that hand gear must be flexible. "Want to have a consistent push"...so once hand is in pushing position, athlete does not seem to want any sort of flexibility.
11 - M, P, T-4, H	- The athlete strongly agrees with flexible hand gear. He must always take the hand gear to the shoe repair-shop to get rid of excess foam which exists in areas that he doesn't need protection. The extra padding interferes with flexibility.

Athletes' comments on
flexibility continued...

12 - M, CP, CP-3, C	- Strongly disagrees that hand gear must be flexible. "You want the gloves to remain the same so you get the same push". Needs flexibility in last three fingers and palm; ensures appropriate flexibility by keeping tape at proper tension.
13 - M, P, T-4, C	- Strongly agrees that hand gear must be flexible. States that the thumb and the fingers must be flexible enough to bend into the palm.
14 - F, P, T-3, C	- Strongly agrees that hand gear must be flexible "So I can move my fingers to release tension". The top parts of the fingers and the crease of the thumb must be flexible. Only tapes part used to push on.
15 - M, P, T-4, C	- "If inflexible, can lead to hand fatigue. It's nice to stretch your fingers every now and then during a long race". Nice to open and close hands, wrists need movement, but would be nice to give support to the wrist, while allowing for some flexibility.
16 - M, P, T-4, H	- The glove becomes a solid entity/unit, but he can still feel the rim when stroking. It is not that flexible, except across the knuckles (to make the fist). Important to have some give as hand gear tightens across the knuckles when making a fist. Harness is now making hand gear thinner across the top (less bulky along the outer seam edge at the finger tips - ??relates [illegible] better than flexibility??).
17 - M, P, T-4, H	- Thumb needs to be "solid" as the thumb of Harness hand gear is.
18 - M, P, T-3, H	- Rubber allows for flexibility and "gripping" (rubber on rubber). Velcro strap at wrist gives support and keeps fist/push in locked position.