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# The Design of a Seating Device for Ice Sledging

by

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A Master's Degree Project

submitted to the Faculty of Environmental Design
in partial fulfillment of the requirements for the degree
of Master of Environmental Design
(Industrial Design).

Faculty of Environmental Design
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Supervisor: Professor Dale Taylor

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FACULTY OF ENVIRONMENTAL DESIGN

The undersigned certify that they have read, and recommend to the Faculty of Environmental Design for acceptance, a Master's Degree Project entitled "The Design of a Seating Device for Ice Sledging" submitted by Velva Lea Craig in partial fulfillment of the requirements for the degree of Master of Environmental Design.

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# ABSTRACT

"The Design of a Seating Device for Ice Sledging"

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prepared in partial fulfillment of the requirements of the M.E. Des. degree in the Faculty of Environmental Design, (Industrial Design), The University of Calgary.

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This project focuses on the human factors considerations and design criteria for a seating device for ice sledging, specifically suited to mobility-impaired recreationists. An examination of ice sledging activities and existing equipment showed that the seating and lower body anchoring provided in the existing ice sledge were inadequate.

The background research included a literature review of seating research, the nature of mobility impairment and adaptive seating devices. A set of general seating principles was compiled to address basic seating considerations and offer a systematic approach for seating the disabled recreationist.

Original human factors research was undertaken involving twenty individuals who regularly ice sledge. An adjustable test sledge was built to examine the specific seating and positioning requirements of a range of participants. Design criteria for a new seating device were developed and a working prototype was built which illustrated the design concepts in a concrete form for trial and evaluation.

The new adjustable seating device allows individuals to optimize their positioning and provides a close ergonomic fit in the lower body. It offers a range of support components providing options for the backrest, torso and head.



Keywords: seating design, physically handicapped, mobility-impaired, sledge hockey, ice picking, ice sledging equipment, ice sledge racing, human factors research, recreation.

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## 1. INTRODUCTION

Physically disabled individuals have limited recreational opportunities. Their participation is restricted by the recreational environment, the absence of appropriate facilities and a lack of adaptive equipment. Lynn Phillips, the research director of Paralyzed Veterans of America, states

> "The availability of adaptive equipment for re-creating within existing sports as well as the development of adaptive recreational equipment creating new sporting activities need to be made available. Designers of recreational equipment need to be encouraged to design products usable by people with various needs and abilities." [1]

The project's focus on a seating device for disabled athletes arose from an interest in the design of products for the disabled and an understanding of their desire to participate in leisure activities. Informal interviews were conducted in the Calgary area with professionals in the field of rehabilitation and recreation, and with representatives of various clubs and associations for disabled recreationists. Seating and positioning were highlighted in the interviews as problems common to a number of activities pursued by mobility-impaired individuals. These activities include downhill pulking (a form of downhill skiing), cross-country sledging (a form of cross-country skiing), floor hockey, sledge hockey (a form of ice hockey), ice picking (a form of figure skating), ice sledge racing (a form of racing on ice), rafting and boating. Other research has also suggested that seating has a significant effect on the abilities of disabled individuals and their potential for participation [2], but very little work has been done on the seating and positioning requirements of the physically disabled for dynamic

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[1] Lynn Phillips, "Research Review," Paraplegia News, (January 1985): 29.

[2] Adrienne Falk Bergen and Cheryl Colangelo, Positioning the Client with Central Nervous System Defects: the Wheelchair and Other Adapted Equipment (Valhalla, N.Y.: Valhalla Rehabilitation Publications Ltd., 1982), p.1

recreational activities [3].

A brief investigation into the nature of the activities listed previously led to the conclusion that each sport had a unique set of problems which were particular to the participants, the recreational environment, the hazards, the facilities, the equipment, the techniques, and the rules and regulations of the sport. Due to the number and the complexity of problems associated with each sport I chose to focus on the seating and positioning requirements for ice sledging activities. Conversations with the coaches and members, and a preliminary examination of the ice sledging equipment showed that this equipment was still in the very early stages of development and suggested that the seating and positioning provided was inadequate. The following objectives were established for the project:

1. To briefly review current research on seating and positioning of physically disabled individuals and establish a set of general seating principles for the disabled recreationist.

2. To examine S.H.I.P. (Sledge Hockey and Ice Picking Association), activities, techniques, and existing equipment to develop an understanding of the recreational environment and the range of sledging activities.

3. To conduct human factors research on the seating and positioning requirements of the users, thus obtaining a framework of information for the design of a new seating device for ice sledging.

4. To develop design parameters for a seating device to be used by ice sledging participants, specifically suited to mobility-impaired recreationists.

5. To design and construct a working prototype which would illustrate the design concepts and seating principles in a concrete form for trial and evaluation.

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[3] J.S. Menton, "An Overview of Research on Seating," Engineering in Medicine, Vol. 17, no. 3, p. 108.

The seating design cannot be viewed in isolation from the other aspects of the sledge design, such as the ice picks and the runner characteristics for hockey, racing, and ice picking. However, the design of these components was not undertaken in this project. An investigation of the application of the seating design to other activities, a detailed market analysis, and costing, were beyond the scope of the project and the resources available to the author.

## 2. BACKGROUND RESEARCH

### 2.1 The Background

The Paraplegic Society of Sweden created the game of sledge hockey in 1978. Ice sledging was introduced as a new activity in Canada in 1980 when the Alberta Sledge Hockey and Ice Picking Association (S.H.I.P.) was founded in Medicine Hat, Alberta. Since then a number of other clubs have also been organized across Canada, and two have been established in the United States. At the present time, relatively few people take part in this sport. However, interest in the activity is growing. The prime objectives of individuals involved in the sport are participation, recreation and integration. Most of the individuals who ice sledge are members of S.H.I.P. However, some people recreational ice sledge outdoors.

#### 2.1.1 The Participants

Sledge hockey and ice picking are integrated recreational activities which provide the opportunity for adults and children, both able-bodied and disabled, to participate together each according to their own ability and skill. These activities provide an opportunity for them to meet new friends, build physical fitness, acquire new skills and improve their self esteem. Individuals with a broad range of disabilities take part. Some of their disabilities include: paraplegia, tetraplegia, quadraplegia, amputation, congenital hip deformities, cerebral palsy, muscular dystrophy, polio, spina bifida, blindness, developmental handicaps and multiple handicaps. The participants are male or female, aged four to sixty. Any person with upper body mobility can participate in either sledge hockey or ice picking contributing at a level consistent with his or her particular ability.

### 2.1.2 Levels of Participation

During ice sledging activities, participants sit close to the ice surface in ice sledges and propel themselves with short picks using a plant, pull and push, follow-through action (see Figure 2-1). Individuals can take part in a range of activities, once the basic skills are acquired. These include sledge hockey, racing, ice picking, recreational sledging, and tandem sledging.

The following information on ice sledging activities was obtained through conversations with club executive, coaches and members. The "Official Sledge Hockey Rules and Regulations Manual" and the "Official Ice Picking Methods and Techniques Manual" were also used as sources of information.

#### 2.1.2.1 Sledge Hockey

Canadian sledge hockey is usually played at indoor arenas. The games consist of two, twenty-minute periods and are regularly organized between teams of neighbouring cities.

The teams are typically composed of skilled teens and adults with limited to excellent upper body mobility. Presently most hockey players are male but the teams do include some women. A team consists of twelve members, including two goalies. Each team is allowed to have six players, including a goalie, on the ice at any one time.

Figure 2-1.  Sledge Propulsion - Plant, Pull, Push.

The players are required to wear hockey helmets, face guards, elbow pads and gloves. These devices protect the upper body relatively well, but the existing sledges leave the lower body vulnerable to injury from the puck, other players' picks, collisions between sledges, and impacts with the arena boards. The goalies wear standard protective equipment and sit in a sledge in a regular hockey goal net [4].

For optimum performance, the hockey player's lower body must be firmly anchored in the sledge while the upper body is free to manoeuvre quickly, reach for, control, and shoot the puck. The game regulations state that the rear runners should be short (23 cm long) to facilitate turning and manoeuverability [5].

### 2.1.2.2 Racing

The first European Ice Sledging Racing Championships were held in Heerenveen, Holland in 1985 on the Thialf ice track. Male and female adults from Finland, England, Norway, and Austria competed in 100, 300, 500, 700, 1000 and 1500-metre events [6].

A much less competitive form of racing exists in Canada. Adults, teens and children with poor to excellent upper body mobility participate individually or in relay teams. Races usually take place at indoor hockey arenas.

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[4] Ryan Becker et al., Official Sledge Hockey Rules and Regulations Manual (Medicine Hat, Alberta: Sledge Hockey and Ice Picking Association, 1984), p.4.

[5] Ibid, p. 1

[6] Tim Marshall, "Ice Sledge Racing Championships," Sport 'n' Spokes, Vol. 11, No. 1 (May-June 1986):25.

The racers wear lightweight winter clothing. For optimum picking efficiency, the racer's lower body must be firmly anchored in the sledge. Specialized long runners are used to increase speed and make the sledge track in a straight line. Racers have varied support needs, depending on their torso strength. Some require back and torso support which does not interfere with sledge propulsion.

2.1.2.3 Ice Picking

Ice picking is an activity similar to figure skating, except that it is done in an ice sledge. Both sexes, all ages, and individuals with a broad range of disabilities take part. Participants practise individual and group routines using costumes, props and music. Consistent with competitive figure skating, programs are 6 minutes in length, and are judged in terms of compulsory moves, music, interpretation and artistic composition. Practices and performances usually take place in indoor hockey arenas. Participants' upper body mobilities range from poor to excellent. Because of this, they have varied back and torso support needs.

2.1.2.4 Recreational Sledging

Like recreational skating, recreational sledging can be done alone or in groups with family and friends, outdoors on rinks, rivers, lakes, or indoors at arenas. Enthusiasts wear appropriate winter clothing. They may engage in a variety of games including medicine ball, red light-green light, follow-the-leader and Simon Says. Once again, the participants in recreational ice sledging have poor to excellent upper body mobility, a range of support needs and may require upper body torso support.

### 2.1.2.5 Tandem Sledging

Tandem sledging is a form of recreational sledging which provides the opportunity for severely disabled individuals to participate in and enjoy ice sledging. Two sledges are hooked together to form one tandem unit, allowing a participant with excellent upper body mobility to propel a non-mobile passenger. The severely disabled individual who participates as a passenger will likely require lower body support, full back support, torso support and may also require neck and head support.

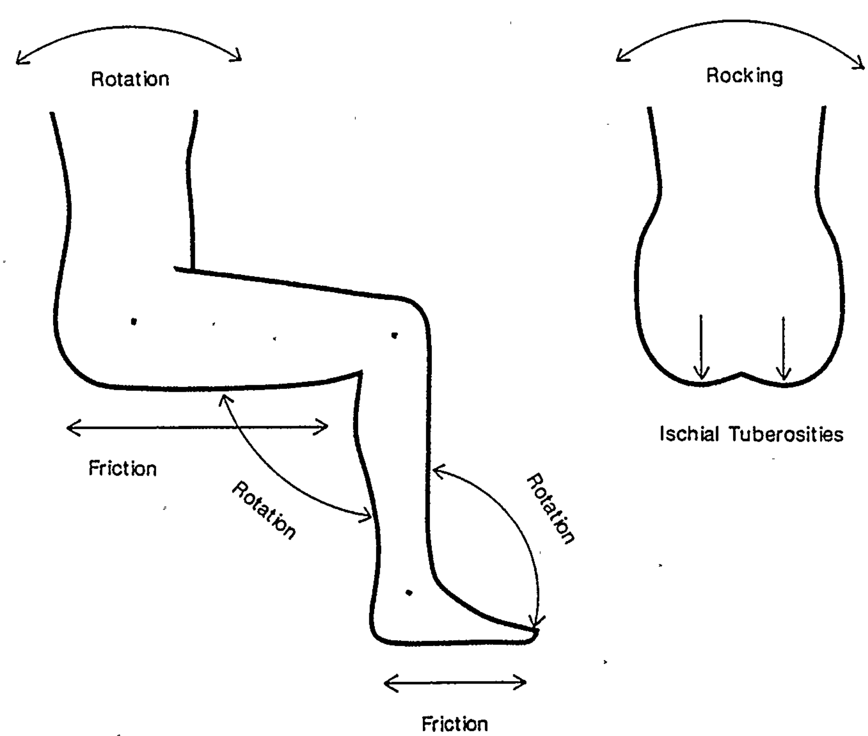


Figure 2-2. The Mechanics of Sitting

## 2.2 The Mechanics of Sitting

The body can be seen as an open chain of links and pivots with the leg and torso muscles working to stabilize action at the ankle, knee and hip joints. The lower body has 4 degrees of freedom to move: the pelvis can rock on the ischial tuberosities, the thigh can rotate in relation to the pelvis, the lower leg can rotate both at the knee and in relation to the foot (see Figure 2-2). A stable position is achieved when the degrees of freedom at these pivot points are limited by the internal workings of muscles or the external influence of a support structure [7]. According to Panero,

> "One of the major difficulties in a design of seating is that sitting is, quite frequently, viewed as static activity while, in actuality it is rather a dynamic one. Accordingly, the application of static two-dimensional data, alone to solve a dynamic three-dimensional problem, involving biomechanical considerations is not a valid design approach.... The dynamics of sitting can be more clearly illustrated by studying the mechanics of the support system and general bone structure." [8]

## 2.3 General Seating Principles: A Systematic Approach

Adrienne Falk Bergen and Cheryl Colangelo stress the importance of following a systematic approach in the evaluation of the positioning and support requirements of disabled individuals. They focus on the complex problems of seating individuals with central nervous system dysfunction. Proper positioning is imperative for all disabled individuals regardless of age or diagnosis. The general principles they discuss hold for

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[7] P. Branton, "Behavior, Body Mechanics and Discomfort," in Etienne Grandjean, ed., Proceedings of the Symposium on Sitting Posture (London: Taylor and Francis, 1976), p. 204.

[8] Julius Panero and Martin Zelnik, Human Dimension and Interior Space (New York, N.Y.: Whitney Library of Design, 1979), p. 57.

"clients of all ages with disabilities such as multiple sclerosis, stroke, cerebral palsy, acquired head injury, post encephalitis, spinal cord injury, etc. Many of the principles can and should be applied to handicapped clients with orthopedic disorders." [9]

The following guidelines for seating and positioning are largely based on Bergen and Colangelo's systematic approach. Other sources including "Humanscale" seating guidelines developed for able-bodied populations and current research on cushioning and pressure distribution were also used to compile a set of basic principles for the seating and positioning of disabled individuals for recreational activities. The principles discussed are by no means exhaustive, individuals with severe seating problems require careful assessment by a team of professionals who work in the field.

### 2.3.1 Alignment of the Pelvis

The first step in establishing a support base for upper body movement is the alignment of the pelvis on the sitting surface. "Correction of pelvic alignment alters body posture, often resulting in improved function." [10] The pelvis is properly aligned when it is not tipped forward, backward, or to one side or the other, and the natural lumbar curve is maintained. A positioning belt drawn across the hips at a 45 degree angle can be used to pull the pelvis back into the seat and prevent the pelvis from tilting backwards. Lateral hip support will help prevent the hips from slipping to one side.

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[9] Bergen, p.1.

[10] Ibid, p. 6.

### 2.3.2 Provision of a Firm Sitting Surface

A firm sitting surface under the thigh and buttock helps to distribute body weight and minimizes pressure on the ischial tuberosities. Hammocking or sagging as seen in the seats of collapsible wheelchairs should be avoided in the seating surface because it forces the hips and knees to rotate inwards. According to Bergen and Colangelo,

> "When a person with abnormal tone sits on this type of surface, any tendency towards asymmetry usually becomes exaggerated and the person is in great danger of developing deformities in the hips and spine. Therefore, a firm sitting surface is recommended unless medically contradicted." [11]

The seat depth is also important. A seat which is too deep will pull the hip forward causing posterior pelvic tilt and pressure at the back of the knee [12].

### 2.3.3 Provision of a Firm Back Support

To maximize their stamina and minimize fatigue over time, individuals with disabilities often require higher levels of back support than able-bodied people. A number of factors determine the level of back support necessary for upper body stability. These factors include: the level of the spinal cord injury; the degree of neurological involvement; the degree of muscle deterioration; and torso strength. As a minimum requirement, the sacro lumbar joint should be supported to prevent rocking of the pelvis. Hammocking should be avoided in the backrest because it causes the shoulders to rotate inwards and allows the pelvis to tilt backwards [13]. The back support should be firm and have a very

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[11] <u>Ibid</u>, p. 7.

[12] <u>Ibid</u>, p. 10.

shallow radius (105 cm) to promote centre line orientation of the torso [14].

### 2.3.4 Assessment of the Attitude in Space, Seat and Backrest Angles

For individuals with central nervous system deficits, functional control, abnormal movement, and comfort may vary depending on the body's orientation in space. "The pull of gravity can interfere with the client's ability to utilize available abdominal control." [15] Wherever possible, an upright symmetrical sitting position should be encouraged. Some individuals, however, have improved functional abilities in a reclined position with an angled seat. The attitude in space should be changed to a more upright position as skills, strength and fitness improve.

By adjusting the seat angle from horizontal to between 5 and 20 degrees, the pull of gravity can be used effectively to push the hip back into the seat and prevent the pelvis from tilting backwards. A tilted seat prevents individuals who have weak torsos from sliding and slumping down in their seat, and helps them maintain a more upright position [16].

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[13] Ibid, p. 8.

[14] Niels Diffrient, Alvin R. Tilley and David Harmer, Humanscale 1/2/3 (Cambridge Massachusetts: MIT Press, Massachusetts Institute of Technology, 1981), p. 20.

[15] Bergen, p. 10.

[16] Ibid, p. 10.

For many individuals, the torso is stable when the required level of firm back support is provided. For others, a reclined back angle may improve functional control of the head and upper extremities and prevent slumping forward, as gravity acts to stabilize the weak torso.

Diffrient et al. recommend an angle of 95 to 115 degrees between the seat and the backrest, since the lumbar curve flattens and the pelvis tilts backwards if the angle is less than 90 degrees [17].

2.3.5 Stabilization of the Torso

Lateral thoracic supports which fit close to the torso can be used to limit slumping to the side and to help align the trunk over the hips. The thoracic supports should be positioned so that arm movement is not inhibited [18]. A two finger allowance should be left below the axillae (armpits) to ensure that the thoracic support will not cut into the axillae. In some cases forward slumping can be minimized by providing an "H" configuration torso restraint over the shoulder and across the chest [19]. The restraints should be 5.08 cm wide so they will not cut into the shoulders. Tight restraints should be avoided because they may induce spasms, cause nerve damage, and easily restrict breathing.

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[17] Diffrient et al., p. 18.

[18] Bergen, p. 10.

[19] Ibid, p. 19.

### 2.3.6 Stabilization of the Feet and Legs

Foot position can affect the closeness of fit in the pelvic area. Panero, in his discussion of seating principles says,

> "If, through improper anthropometric design the chair did not allow the majority of users to in fact have foot or back contact with other surfaces, body instability would be increased and additional muscular force would have to be introduced in order to maintain proper equilibrium." [20]

The feet must be stabilized in relation to the hips or the hips will be free to slip forward [21]. Individuals with mobility impairments are often unable to maintain or control their foot and leg positions and require special positioning considerations. The footrest should provide weight support, predominantly in the heel and through the ball of the foot [22]. The feet should be aligned with the knees wherever possible. Restraints which cross the ankles at 45 degrees and side support can also be provided to maintain the alignment of the feet [23].

Leg position will contribute to the maintenance of proper pelvic alignment and comfort. Individuals with mobility impairments may require support high on the calf and at the sides of the legs to align their legs and prevent splaying of the knees. In some cases, a pommel between the thighs will help reduce inward rotation of the knees [24]. Support should not be provided directly behind the knee to avoid constriction of the major artery and nerve which lie close to the surface at the back of

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[20] Panero, p. 60.

[21] Bergen, p. 13.

[22] Diffrient _et_ _al_., p. 13.

[23] Bergen, p. 13.

[24] Bergen, p. 13.

the knee.

### 2.3.7 Provision of Head Support

Diffrient et al. recommend that head support should be provided when the angle of recline is less than or equal to 60 degrees from horizontal [25]. Individuals with severe physical disabilities may be unable to maintain an upright position and may require head support to prevent their necks from hyperextending or their heads from rolling to the side [26]. If the problem of head control is slight the backrest can simply be extended up high enough to support the head. A 0 to 10 degree correction angle should be incorporated in the headrest to bring the head forward and improve visual orientation [27].

Lateral support should be provided for individuals who are unable to hold their heads upright. Neck rings or collars contoured to fit around the neck can be used, with or without head supports, to provide lateral stability [28]. In various handicapping conditions, the occiput (back of the skull) is enlarged. The headrest can be recessed to accommodate individuals with this condition [29].

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[25] Diffrient et al., p. 21.

[26] Bergen, p. 21.

[27] Diffrient et al., p. 21.

[28] Bergen, p. 22.

[29] Bergen, p. 21.

2.3.8 Distribution of Pressure

In the upright seated position, over half the body weight is supported by 8% of the seated contact area directly under the ischial tuberosities [30]. Postural changes reduce this pressure and help to prevent tissue breakdown. When able-bodied individuals sense discomfort due to pressure concentration they shift their weight naturally to allow blood to circulate and ventilation to occur. Depending on the degree and nature of the disability, a disabled individual may not sense discomfort or may be physically unable to shift his own weight to relieve pressure. As a result, disabled individuals easily develop pressure sores and sensitivities. Cushioning can be effectively used to improve the relative distribution of skin pressure.

An able-bodied person will experience discomfort within one hour on a hard flat seat. A disabled individual will be affected even sooner. The ideal seat design provides cushioning over a firm base and results in no concentrated pressure. To quote Panero,

> "If cushioning is not properly designed, it is possible that relief from compressive stress may be obtained at the expense of body stability." [31]

Very deep soft cushioning will result in tension in the hip muscles from rotation in the greater trochanters of the thigh bones and should be avoided [32]. Current research on the prevention of pressure sores in individuals with spinal cord injuries suggests that pressure can be reduced and redistributed along the lower thigh by providing a cut out in

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[30] Grandjean, p. 207.

[31] Panero, p. 67.

[32] Diffrient et al., p. 20.

the cushioning directly under the coccyx and ischia [33].

To reduce the possibility of pressure sores developing, cushion coverings should dissipate moisture and should breathe. Folds, creases and cavities where foreign objects can collect should be avoided.

2.3.9 Provisions for Change and Growth

Like able-bodied sports enthusiasts, disabled recreationists improve their physical fitness, strength and skills through practice and training. Body weight and size change rapidly in growing children and adolescents. Progressive disabilities result in deterioration of the physical condition. Due to all of these factors, seating and positioning should be monitored on a continuing basis and modified to respond to changing needs.

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[33] M. Ferguson-Pell, I.C. Wilkie, J.C. Barbenel, "Pressure Sore Prevention for the Wheelchair User," Proceedings of International Conference on Rehabilitation Engineering (Toronto 1980), p. 167.

# 3. ANALYSIS OF THE EXISTING PRODUCT

The existing product analysis was based on the following: (a) informal conversations with the coaches and club members who participate in ice hockey, racing, ice picking and recreational sledging, (b) the observation of games and activities over a season, (c) the review of a demonstration video, (d) the examination of the Association's "Official Sledge Hockey Rules and Regulations Manual" and "Official Ice Picking Methods and Techniques Manual", and (e) the examination of club sledges which had been in use for four seasons. A systematic analysis of functional characteristics and limitations revealed a number of problems with the current design. These problems are discussed generally in Section 3.1 below, followed by an analysis of the specific problems in the design of the existing product.

## 3.1 Problem Areas

The problems with the current design fall generally into the areas of user fit, user efficiency, comfort, safety, and product life.

### 3.1.1 User Fit

To achieve a good ergonomic fit, variations in body size must be accommodated and reflected in the size, configuration, and shape of product components. In recreational activities such as pulking, kayaking, and wheelchair racing, a recreationist can most effectively propel himself and manoeuvre if a glove-like fit exists between athlete and equipment. Good fit is essential for user efficiency.

3.1.2 User Efficiency

In addition, the design of recreation equipment must also respond to the physical capacities, limitations, strengths, stamina, and skill levels of the people who will use the equipment. The center of gravity and relative body position will influence stability and affect ranges of movement and endurance. The weight of the equipment and ease of operation will also influence how independently an individual will be able to use the equipment and the amount of assistance he/she will require.

3.1.3 Comfort

Discomfort is, to a large degree, the result of poor ergonomic fit, pressure build up from poor pressure distribution, restricted circulation, poor control of temperature, and the stress accumulated in a particular body position over time. In seating for recreational equipment, as in any other kind of seating, poor ergonomic fit, and inadequate cushioning and support will cause user discomfort after a short time.

3.1.4 Safety

Player injuries in recreational activities can be kept to a minimum if careful consideration is given to the elimination of sharp projections and the protection of body parts vulnerable to injury. The dynamics of the activity and the interaction between players, equipment, and the environment must be assessed to determine protection needs.

### 3.1.5 Product Life

Well designed products stand the test of time. To ensure that a product functions as it should and that its appearance and operation will not deteriorate, the environmental and activity-related demands to which it will be subjected should be considered. Maintenance can be minimized through the selection of durable materials and finishes. Demountable parts and simple adjustment mechanisms which can be replaced or repaired easily, help to ensure that a product will work as it should without breaking down. Inventory and storage requirements can be kept to a minimum through careful consideration of the number, size, and configuration of parts.

## 3.2 Functional Analysis

In the following section, the problems with user fit, user efficiency, comfort, safety and product life are discussed according to a breakdown of the existing ice sledge design into its basic elements and parts. The ice sledge is made up of a running base, a support system, a propulsion system and a tandem attachment option.

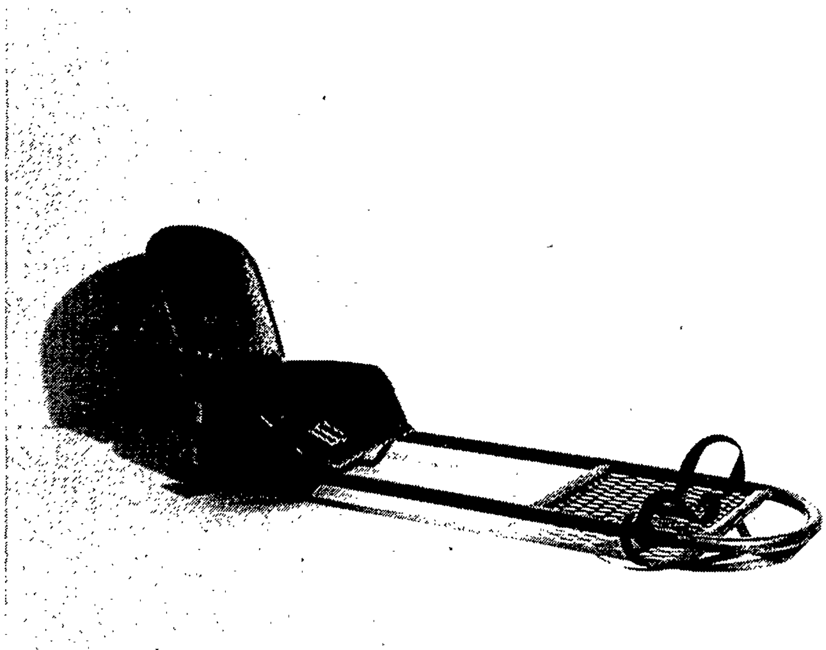

Figure 3-1. The Existing Ice Sledge with Optional Backrest

3.2.1 Running Base

The running base consists of a tubular frame, a seat frame that slides on the tubular frame to provide length adjustment, two rear runners fixed directly under the seat, and a front skid (see Figures 3-1 and 3-2).

In the current design it is possible to adjust the sledge length from a minimum length of 55 cm to a maximum of 107 cm. Observation of club activities and hockey games demonstrated that large adults rest their feet on the crossbar at the front of the footplate with their toes protruding over the front of the tubular frame. In this position, their feet are vulnerable to injury. When the sledges are adjusted to

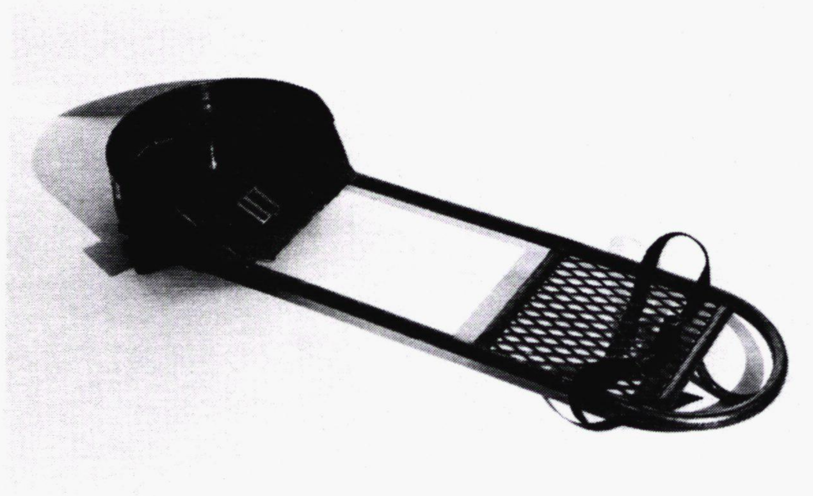

Figure 3-2. The Existing Ice Sledge Without Backrest

accommodate children or small adults, two long tubes stick out behind the seat (see Figure 3-3). These projections have the potential to cause serious injury when moving sledges tip over sideways on the ice. The frames are bare metal tubing. Thus, when sledges collide, fingers and knuckles are often pinched and injured.

The adjustment of sledge length is an awkward procedure because the sledge must be turned upside down to access and loosen the clamp bolts under the seat frame. Other than the tubular frame itself, which structurally withstands collisions well, there are no protective bumpers at the front or rear of the sledge to absorb shock or reduce impacts. Consequently, the frame dents upon repeated impact and paint chips off badly, leaving the steel tubing exposed to rust. Due to this rust and

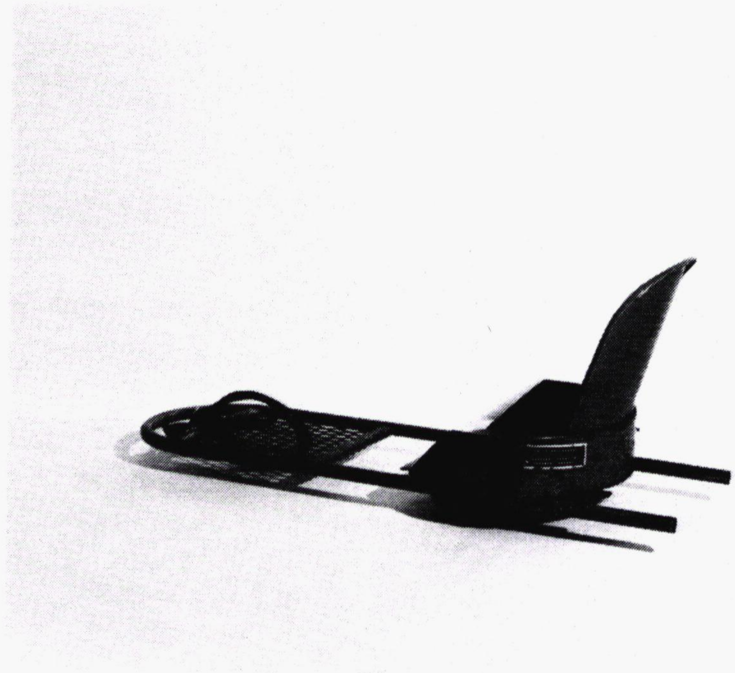

Figure 3-3. The Existing Ice Sledge Showing Protruding Tubing

bends in the frame, it becomes very difficult to slide the seat frame on the tubular base to adjust the sledge length. Even if sledges are painted on an annual basis, the chipping, rusting, and denting of the frame adversely affects the appearance and operation of the product.

In a number of the sledges examined, the blades were damaged and bent. Blade maintenance and repair is laborious because the blades are not removable and must be sharpened by hand with a file.

Heavy gauge metals are used in the running base. As a result the sledge is heavy and this makes it difficult to transport it to and from the ice. As well, it is difficult for children or individuals with limited arm strength to manoeuvre it on the ice.

### 3.2.2 Support System

The support system consists of a flat fiberglass seat and detachable backrest bolted to the seat frame, and a horizontal foot plate welded to the tubular frame.

The seating and positioning features in the current design do not meet the range of player needs, achieve optimal anchoring of the lower body, nor provide adequate support. Individuals are forced to sit straight legged or with unsupported bent legs, and to stabilize themselves by strapping their hips and feet tightly to the sledge. The tight restraints restrict circulation and create a number of pressure points. After short periods of use, players experience lower back fatigue, sore buttocks, and pain and stiffness in the back of the legs (see Figure 3-4).

No contouring or cushioning is provided in the flat, pancake-shaped seat or in the backrest to help distribute pressure or absorb shock. The fiberglass seat offers very little thermal insulation from the cold ice, less than 10 cm below. Individuals with mobility impairments often have circulation problems and their tissues easily break down when exposed to pressure and friction. Frostbite, freezing, and hypothermia can easily occur when there is inadequate protection from the elements [34]. Players sometimes use pieces of foam slab on their seats to reduce discomfort and these loose pieces of foam slip out of position, and get wet, dirty, torn and lost.

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[34] Philip Hage, "Wilderness Inquiry II: New Challenge for the Disabled," The Physician and Sports Medicine, Vol. 12, No. 1. (January 1984): 173.

Figure 3-4. Player Seated in Existing Ice Sledge

The seat in the current sledge is too wide for children, making it difficult to firmly anchor their hips in the sledges. As a result, children tend to slide in the seat when they propel themselves on the ice, energy is not effectively transferred into propulsion, and manoeuverability is adversely affected. The circular metal rim of the seat frame turns inwards causing pressure points on the hips of large adults.

The current sledges are most effectively used by recreationists who have good upper body mobility and do not require much back support. The optional backrest does not provide optimal support for all the players and does not suit all the player activities. The fixed 70 degree back rest angle does not support all players in an optimal position for

Figure 3-5. Child Seated in Existing Ice Sledge

efficient picking action.

The backrest configuration does not provide adequate arm clearance for hockey players. During competitive hockey games the arms of individuals using the optional backrest can easily be pinned between their backrest and the boards. As a result, hockey players, in order to improve their puck access, often choose to leave the backrest off the sledge. This leaves their backs exposed to injury from opponents' picks and sledges. The shock of sudden impact in this unsupported position could easily result in serious back injury.

No provision has been made for lateral hip or torso support or head support which would allow an individual with limited upper body strength to sit comfortably while propelling the sledge themselves or while being pushed by another player in a tandem sledge. As a make shift measure a strap of 2.54 cm webbing is drawn tight around the chest and backrest of players who require additional support to sit up. This strap tends to slide down the backrest, cuts into the torso and does not provide adequate lateral support. As a result, players with limited torso strength slump in the seat and slide down as their pelvis rotates forward.

Lower leg and calf support is not provided for players who are more comfortable with their knees bent or who are unable to fully straighten their legs. Players again place pieces of foam slab behind their knees or calfs to reduce discomfort. These loose pieces of foam have the same problems as those used on the seat.

The flat footplate does not stabilize foot position relative to the hip position. The feet can easily slide forward on the horizontal surface allowing the players' hips to rotate forward in the seat and the lumbar curve to flatten.

The tight restraints which must be applied at the hip, foot, and sometimes the legs, can easily restrict circulation. These restraints align the legs, and prevent feet from falling off the foot plate and players from falling off sledges when they tip. People wearing winter gloves find the D-ring fasteners and the buckle on the hip belt difficult to fasten and unfasten. These restraint systems would be dangerous in the event that a sledge broke through soft ice and quick escape was essential in an outdoor environment on lake or river ice.

### 3.2.3 Propulsion System

While seated in the sledges, players propel themselves and shoot the puck with special ice picks. The ice picks are used in plant, pull and push-through action. It is difficult to make good ice contact with the existing 4-point pick configuration and a lot of strength and arm control is required to plant the picks sharply into the ice. In competitive games, the sharp pick ends can cause injuries between players. The current design does not provide a surface for controlling the puck and players are forced to slide their knuckles on the ice while shooting.

Braking is achieved by forcing the picks under the frame and lifting up, jamming the picks into the ice below. Due to the momentum and weight of the sledge, a great amount of force must be applied to the picks to slow the sledge down at top speeds. These picking and braking techniques are the cause of a lot of ice surface damage. As well, the paint on the length of the underside of the tubular frame is worn away by abrasion from the picks while braking.

### 3.2.4 Tandem Attachment

Non-mobile individuals and those with very limited upper body strength are able to participate in ice sledging via a tandem attachment which fastens two sledges together. An able-bodied or strong player sits in the rear sledge and propels both sledges, allowing the passenger in the front to enjoy the feeling of movement and participate in the excitement of the activity. The existing backrest is not high enough, however, to provide support for adults needing thoracic support. No lateral support is provided for torso or hip. Neck and head support are also absent. As a makeshift solution a commercially available seating device called a "Tumble Form Seat" is propped up and tied to the existing sledge seat to provide support for small children with poor upper body stability. By about 12 years of age children outgrow this seat and, consequently, they are unable to continue sledging. The existing seating is simply not adequate for many individuals with moderate to severe disabilities. In the existing seating, the additional weight of the attached sledge and passenger, and poor manoeuverability due to a very long turning radius, make tandem sledging very tiring for the person propelling the sledges.

# 4. PRELIMINARY DESIGN BRIEF

## 4.1 Design Objectives

Based on an understanding of ice sledging activities, the range of users, the recreational environment, and the problems with the existing sledges, the following design objectives were developed for the new seating device:

1. Design a versatile seating system suited for ice sledging activities which would enable a wider range of disabled individuals to participate in the activities.

2. Provide a support system which would accommodate changing positioning requirements due to growth or improved physical fitness and skill development.

3. Provide an improved support system which would accommodate variations in sitting postures and enable players to position themselves in a manner which would allow them to maximize their unique abilities.

4. Provide improved lower body anchoring which would allow the players to optimize their picking efficiency and improve their performance in recreational and competitive activities.

5. Provide improved: ergonomic fit, cushioning, contouring, and restraint. This would reduce discomfort and enable players to use their sledges for extended periods to train and build personal fitness.

6. Improve the safety during recreational and competitive sledging by: eliminating dangerous projections and providing improved impact resistance and protection.

7. Design a product that is non medical in appearance and has the durability to stand up to the demands of the range of ice sledging activities.

## 4.2 Constraints

The constraints influencing the design of the ice sledge fall into two broad categories: those which are user/activity related and those which are technology related.

### 4.2.1 User/Activity Related

Ice sledging is a new sport in Canada. Clubs typically have 5 to 20 members with volunteers acting as coaches and officials. There is a large turnover of players from season to season. New members are encouraged to come out and try the sport.

Games and activities are regularly set up with able-bodied hockey teams, church groups, and businessmen playing against S.H.I.P. members. In this context a single sledge must accommodate a broad range of players. Since competition is not yet highly sophisticated, the standard sledge must have the flexibility to adapt for the range of sledging activities.

The new seating device for ice sledging cannot be so radically different from the existing sledge that the activity itself is changed. Game regulations specify that the player must sit close to the ice surface and the sledges must provide clearance for passing the puck under the frame.

The existing sledges are distributed through the founding club in Medicine Hat. When a club starts up, approximately 12 sledges are purchased with financial assistance from the government, local social clubs or churches. In a few instances individuals have purchased sledges for their own personal use.

The clubs own and maintain their own equipment. To facilitate upkeep, the major components should be easy to disassemble for repair and maintenance. Interchangeable parts and spare components can be kept on hand for use while damaged parts are repaired.

Disabled people do not like to be seen as different. Specialized equipment for people with physical handicaps often looks functional or medical. Their appearance sets them apart from able-bodied people. Ice sledging is an active sport and the new seating device should look like a fun piece of recreational equipment.

### 4.2.2 Appropriate Technology

Although participation in ice sledging has the potential to grow substantially with improvements in the sledge design current demand for ice sledges is very low. Since 1981 only about 300 Canadian-manufactured sledges have been sold. The international market has yet to be explored.

Considering current demand, the new seating device should incorporate materials and fabrication processes appropriate to low volume production. The fabrication should involve simple jigging methods. Expensive molding processes, involving costs that must be amortized over large production runs to be cost-effective, should be avoided.

Anticipating the potential for increased demand, the fabrication processes should allow the flexibility to vary the size of the production run, producing from one to approximately fifty units at a time. Options should also be considered for upgrading and automating the technology when increased demand warrants higher volume production. Ways of modifying the design, to reduce the production cost, should also be considered.

## 4.3 Performance Criteria

The wheelchair was first conceived when wheels were attached to a chair so that a disabled person could be pushed around the home. Today disabled individuals lead much more active lives. Only recently, with the development of sports wheelchairs, has the seating of disabled individuals been considered in relation to a recreational activity [35]. Sledge hockey and ice picking are dynamic recreational activities which use an ice sledge as the recreational transportation device. Seating and positioning specifically suited to these activities must consider the dynamic movements involved in the activities; propulsion, puck access, puck control, steering, turning, stability, manoeuverability and braking.

The following performance criteria for the new seating device were generated to satisfy the basic design objectives and to respond to the problems of the original sledge.

### 4.3.1 User Fit Criteria

1. The new device should accommodate body size variations of male and female players, aged 8 to 60 who weigh between 50 to 225 lbs.
2. The support system should have the flexibility to accommodate a range of sitting positions from upright to semi-reclined postures.
3. Anchoring and support should be provided for the lower body, hips, buttocks, thighs, lower legs and feet.
4. A range of back support should provide for players with excellent, good, limited, and poor upper body mobility.
5. Lateral hip and torso support should be provided for individuals

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[35] Cynthia Burk, "Maximizing the Positive-Adjustability in Lightweight Wheelchairs," Sports 'n' Spokes, Vol. 11, no. 6. (March/April 1986), pp. 12-16.

with poor upper body mobility, and head support should be made available for non-mobile passengers.

4.3.2 User Efficiency Criteria

1. Support options should be provided for the range of player activities, namely, sledge hockey, racing, ice picking, recreational sledging and tandem sledging.

2. The back, hip, and torso support should not interfere with picking action.

3. Adequate lateral stability should be provided in the running base to ensure that the device will not tip easily when players brake, turn, shoot or reach for the puck.

4. Simple adjustment mechanisms and fastening devices should be located for easy access and operation.

5. The support elements should not interfere when players transfer into or out of the sledge.

6. The device should be compact and dismantle for ease of transport.

4.3.3 Comfort Criteria

1. Cushioning and contouring should be provided to distribute pressure evenly and reduce pressure points.

2. The seating device should provide insulation for the buttocks from the cold ice below.

3. The restraint systems, for the torso and hips, should not restrict circulation.

### 4.3.4 Safety Criteria

1. Dangerous projections should be eliminated in the configuration of the frame and support system.

2. Protective bumpers should be provided to reduce impacts and absorb shock.

3. To reduce injuries from the puck, picks, and collisions, protection should be provided for the sides of the hips, lower legs, ankles, and feet.

### 4.3.5 Product Life Criteria

1. Durable materials should be selected that are moisture-resistant and perform well in cold temperatures.

2. The product should dismantle to facilitate maintenance, replacement and repair, and minimize storage requirements.

3. The new device should be non-medical in appearance.

## 4.4 Conceptual Approach

The new seating device for ice sledging is not intended as therapeutic seating. Rather, its purpose is to allow broader participation in a recreational activity. Three basic approaches were considered in relation to the design objectives, performance criteria and constraints. They were customized seating molds, formable and reformable support systems, and modular seating systems. These options are reviewed below. The modular seating system approach was chosen and the subsequent human factors investigation addressed the information necessary to detail the specific modular seating for this activity.

### 4.4.1 Customized Seating Molds

There are a number of methods currently used in rehabilitation to produce customized seating molds for therapeutic use. An indirect method involves taking a mold of the disabled person's body and then casting a rigid shell from the mold, adding layers of softer foam for comfort and pressure reduction [36]. Another direct molding process uses an elastic bean bag seat which is filled with styrofoam beads. In this technique the individual is positioned in the soft bean bag seat and epoxy resins are then added and allowed to set [37].

While these custom seating techniques have been developed for individuals with severe seating problems, there are a number of disadvantages associated with them. Ideally, a customized seating mold should be completely personalized, and require no further adjustments for the individual. However, it is very difficult to determine optimal positioning the first time a mold is made. The major weakness of these methods is that they rely on the individual's position at the instant the mold is made [38]. Thus, these custom seating molds do not respond to changing positioning needs, nor do they accommodate growth, improved fitness and skills or, conversely, the deterioration of physical condition. If an individual's needs change, the seating molds must be remade or modified, and new seats are required on a regular basis.

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[36] M.J. Forbes et al., "A Comparison of Three Custom Seating Techniques," Proceedings of International Conference on Rehabilitation Engineering (Toronto, 1980), p. 147.

[37] Sandy Moore et al., "The DESEMO Customized Seating Support - Custom-Molded Seating for Severely Disabled Persons," Physical Therapy, Vol. 62, No. 4 (April, 1982), p. 461.

[38] Forbes, p. 152.

Sledge hockey and ice picking clubs are run by loosely organized volunteers who do not have the time or expertise to coordinate the provision of customized seating molds for every new player who comes out to try the activity. Customized seating molds are expensive, require expertise in their assessment and fabrication, as well as special facilities for molding.

Since the current sledges are owned by the clubs, more than one person may use a sledge during a game or practice. Customized seating would prohibit participation by church groups, able-bodied hockey teams, and individuals who only wish to participate occasionally. Furthermore, it would be very difficult to provide customized seating molds for ice sledging since new players are unfamiliar with the activity, and initially they are unaware of their own positioning needs for participation.

### 4.4.2 Formable and Reformable Support Systems

Formable and reformable seating technologies have been developed to respond to the needs of individuals with moderate to severe seating problems. One of the systems which has been developed is a pliable body support which may be wrapped around the body and made rigid when air is evacuated [39]. Interlocking pieces that can be joined to form a mesh-like surface have also been developed for constructing modifiable support structures [40]. Although these systems offer a high degree of

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[39] O.W. Newmark, "Beaufort Vacuum Bead Device Chair Posture Controller," Seating Systems for the Disabled (London: The Biological Engineering Society, 1979), p. 63.

[40] D.G. Cooperf and E. Hawkes, "Shapeable Matrix Support Surface for Chil-

adjustability, the technologies involved are quite complicated and the processes are time-consuming. The seated individual must be supported in the correct position while the support is made rigid and care must be taken or poor positioning will result.

The vacuum support system in particular, does not lend itself well to a recreational environment. The pump required to evacuate the support would be inconvenient to use in a hockey arena or outdoor environment. Further, the vacuum supports are subject to puncture in sledging activities, and once punctured are difficult to repair.

### 4.4.3 Modular Seating Systems

In a modular seating system the range of basic support components are prefabricated. The components may be selected, combined, adjusted and assembled to meet the needs of a broad range of individuals. The Rehabilitation Centre for Children in Winnipeg, developed a modular seating system because they found that many custom inserts tailored for individual children were similar in style and size [41]. The modular system allowed desirable features needed on a regular basis to be incorporated as standardized components.

The modular seating system has a number of advantages for ice sledging applications. It would enable a club to have a range of support options available to accommodate a broad range of mobility impaired recreationists. The system of modular components could be specifically

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dren and Adults," Proceedings of the Second International Conference Rehabilitation Engineering (Ottawa, 1984), p. 475.

[41] I.T. Paul et al., "Factors Influencing the Design of a Modular Insert System for Disabled Children," Proceedings of International Conference on Rehabilitation Engineering (Toronto, 1980), p. 160.

tailored for particular activities offering more or less support and protection when needed. For example, short backrests and calf protection could be provided for hockey players, while high backrests, torso and head support could also be made available for individuals who require more upper body support.

Nelham suggests that a single seating system will not meet the needs of all disabled individuals [42]. Modular seating systems work well for individuals with mild to moderate disabilities. However, due to the complexity of their needs, some severely disabled individuals do require custom molded seating inserts for daily activities. The flexibility to integrate specialized modifications can be built into a modular system. A footrest can be specially adapted or, in the case of an extreme seating problem, a customized mold can be substituted for the seat and backrest. The components can be adjusted, added, or changed as positioning needs change over time.

## 4.5 Required Information

The only ice sledges in Canada are those sold commercially by S.H.I.P. Although the sledges are durable and innovative in concept, preliminary examination of the sledges demonstrated reasonable cause to suggest that the seating and positioning provided is inadequate.

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[42] R.L. Nelham, "Review of Seating Systems in North America," Seating Systems for the Disabled (London: The Biological Engineering Society, 1979), p. 49.

The medical community and current research indicate that seating and positioning significantly affect the functional abilities of physically disabled individuals [43]. Unfortunately, little human factors data has been generated on the seating and positioning requirements of the disabled which can be applied readily to the design of specialized recreational equipment.

> "A recognition of the need for postural support, function, and mobility devices other than the traditional wheelchair has stimulated applied research and device development.... Review of the literature, however, finds that anthropometric data required for knowledgeable design for specific populations of non-ambulatory individuals does not exist, and what data does exist is not in a form usable by designers of seating and mobility systems." [44]

By definition, individuals with physical disabilities are the extreme case in a continuum of ability [45]. A responsible product designer should have a good understanding of the people who use the products they design. Many products for the disabled are poorly conceived because the designers have inadequate information and base their decisions on assumption rather than orderly consideration of user needs and performance requirements. A non-disabled subject, or researcher, cannot accurately anticipate the needs of a disabled person without adequate information. Due to combinations of factors including muscle weakness, limited ranges of movement, spasticity, sensitivities to pressure, sensation loss, etc. disabled individuals have unique needs

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[43] Bergen, p. 1.

[44] Michael J. Heinrich and Susan Johnson-Taylor, "A Practical Method for Data Collection for Seating Mobility Design," Proceedings of the 2nd International Conference on Rehabilitation Engineering (Ottawa, 1984), p. 477.

[45] Selwin Goldsmith, Designing for the Disabled, third revised edition (London: RIBA Publications Limited, 1976), p. 17.

which differ from those of able-bodied individuals.

To proceed with the design task the following human factors information on the specific seating and positioning requirements of disabled individuals for ice sledging was required:

1. Obtain the limiting dimensions and the variations in body sizes of the range of players.
2. Identify the critical measurements for the configuration and shape of support elements.
3. Determine the required adjustments and ranges of adjustments.
4. Verify assumptions regarding the number and location of support surfaces.
5. Confirm assumptions regarding cushioning, contouring and pressure distribution.

## 5. HUMAN FACTORS RESEARCH AND DATA ANALYSIS

By examining available data on able-bodied and disabled populations, it was found that no data on seating and positioning the disabled has previously been generated for ice sledging or similar recreational activities. To quote J.S. Menton,

> "...there has been comparatively little research on the special problems of seating for the disabled, especially if wheelchairs are excluded from this review." [46]

To compile a body of information regarding the specialized seating and positioning requirements of the range of disabled recreationists who participate in ice sledging, a human factors investigation was undertaken which falls into the category of exploratory research. The Alberta S.H.I.P. agreed that their members could be contacted to ask for volunteers for the human factors research. Due to the limited numbers of individuals involved in the sport, only a very small sample of recreationists could be recruited. Twenty individuals who regularly ice sledge were selected to represent the range of users, the range of user activities, and the broad range of disability related limitations. No attempt was made to generate a statistically verifiable sample; rather the seating and positioning requirements of each subject were carefully examined. The data collection and analysis were directed to provide a framework of information upon which to base decisions regarding design specifications for an improved recreational seating device for ice sledging.

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[46] Menton, p. 108.

5.1 Information on Subjects

Subjects for the study were carefully selected as twenty individual case studies. To adequately represent the types of players, the range of capacities, and disability related limitations, the following cases were included: competitive players with excellent upper body mobility, recreational and competitive players with good upper body mobility, recreational players with limited upper body mobility, and individuals with poor upper body mobility who participated as passengers in tandem sledges. Subjects were male and female, between ten and fifty years of age.

Some S.H.I.P. members have developmental handicaps and some are multiply handicapped. Individuals with severe physical limitations and multiple handicaps often require specialized seating to provide additional back and torso support for daily living activities [47]. I felt it was important that some players with multiple handicaps be included in the study as these players were likely to have specialized needs that should be addressed in the new seating design. These individuals are unable to use the existing sledge comfortably and stand to benefit most from the new design.

The medical and scientific community has well-established ethical procedures which protect adults, juveniles and the mentally handicapped while enabling them to participate in research studies. In accordance with these guidelines, the subjects and the parents/guardians of the subjects who were under eighteen years of age, and/or mentally or multiply handicapped had the research methods, risks and benefits of the

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[47] Bergen, p. 1.

study explained to them via a letter. Written consent was obtained prior to the test sessions via a consent form (refer to Appendix A.1). As well, the parent/guardian or aide was invited to attend the test sessions to act as an interpreter and monitor the individual's well-being throughout the test sessions. The S.H.I.P. coach and a registered nurse were on hand to perform these functions if the parent, guardian or aide had given consent but was unable to attend the test sessions.

Permission was obtained from some participants/parents/ guardians to publish selected photographs in the master's degree document and to use slides and video-taped sequences in presentations to groups of individuals interested in the health and rehabilitation of disabled individuals and to the manufacturer(s) interested in producing the new seating device (refer to Appendix A.2). The anonymity of subjects who had agreed via a photographic release form (refer to Appendix A.3) to the release of photographs, slides and video could not be guaranteed.

## 5.2 Test Sledge Design

The adjustable test sledge was designed to investigate seating and positioning for ice sledging, and to respond to individual needs and preferences. To ensure that all players would be accommodated, the dimensions and configurations of its' components were based on an analysis of available anthropometric data on able-bodied and disabled populations [48].

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[48] Selwin Goldsmith, pp. 117-127.

Niels Diffrient, Alvin R. Tilley and David Harman, Humanscale 1/2/3 (Cambridge Massachusetts: The MIT Press, Massachusetts Institute of Technology, 1981).

The test sledge was designed to accommodate able-bodied and disabled players from age 8 to 60, male and female, and weighing from 50 to 225 pounds. It was built to permit a wide range of sitting postures from upright through semi-reclined and reclined positions. The seating system provided support for buttocks, back, calves and feet, as well as torso and head. Restraint was provided for hips, legs, feet and torso.

The test sledge was designed to help narrow down the basic elements for the new seating device and to identify critical dimensions and required ranges of adjustment (see Slides 1 through 5). Sitting length, seat height and angle, back height and angle, foot rest position and angle could be adjusted independently over a wide range. Table 5.1 summarizes the variability of components in the test sledge. The measurements and variables are defined in Figures 5-1, 5-2 and 5-3.

Table 5.1 Test Sledge Design Summary

| Positioning Variable | Adjustment Range |
|---|---|
| sitting height | 11.5, 13.5, 15.5, 17.5 cm |
| sitting length | 50 to 120 cm |
| seat angle | 0 to 20 degrees from horizontal |
| back angle | 45 to 90 degrees from horizontal |
| hip support width | 22 to 50 cm |
| backrest height | 20 cm (sacrum support)<br>38 cm (lumbar support)<br>60 cm (thoracic support) |
| footrest/calf support | 0 to 45 degrees from horizontal |
| thoracic support width | 22 to 50 cm |
| thoracic support height | 22 to 60 cm |
| headrest height | 40 to 80 cm |

The device was built to test and verify a number of incorporated assumptions regarding cushioning, contouring, restraint, and clearance. The front edge of the seat was given a 2.5 cm radius to avoid pressure behind the knee and a short seat length (30 cm) was used to accommodate small children. To minimize interference with picking action, a narrow backrest width of 26 cm was used, and hip and torso supports were designed to hug the body closely. In an attempt to minimize the impact of external factors and to focus on seating and positioning requirements, the weight of the test sledge and the runner configuration were kept comparable to the existing sledge. To avoid constriction of a major nerve and artery, a judgement was made that a support directly under the back of the knee should not be incorporated in the design. High density cushioning 1.27 cm thick was used on the three optional backrests, the seat, and the hip, thoracic, head, and foot supports to provide minimal pressure relief and thermal insulation. Additional high and medium density foam was used to make modifications to the cushioning provided in the test sledge.

## 5.3 Test Session Methodology

The safety and comfort of all subjects was a prime consideration in the development of the test procedures and the design of the testing device. Subjects were tested individually on an indoor rink and were not engaged in competitive activity. The normal risks involved in competitive games include incidents where sledges crash into one another or the side boards, sledges tip over on the ice, and ice picks injure legs, arms, or backs.

The research approach involved a structured testing process, structured observation and data collection, and unstructured questioning of participants. Careful attention was given to the design of test equipment and procedures to ensure that test sessions could be administered simply and procedures could be understood easily by the subjects. To check the feasibility of test procedures and to ensure that the test equipment would operate safely, a pilot test was run. The subject data was systematically recorded on subject data sheets (for a sample see Appendix A.4 and A.5).

At the beginning of the test sessions, the subject and/or parent/guardian was informed that participants were not required to perform any task in the session they did not wish to undertake and that they should inform the researcher immediately if they felt something was too difficult, uncomfortable or unsafe.

In the first sequence of human factors data collection, player activities, age, sex, and special conditions related to disability were noted and some basic anthropometric measurements were taken to compile important information regarding user fit. The length of the thigh and lower leg were taken to determine seat and calf support lengths. Sitting length was measured to determine the required range of length adjustment between seat and footrest. Sitting height, eye and shoulder level were taken to define the maximum backrest height and the range of head support needed. Measurements of torso and hip width were taken as a basis for the seat width and the configuration of the lateral support. The required length of restraints for the torso, thigh and ankle were taken as reference for the arrangement of restraints and the configuration of the hip and torso supports. The measurements are defined in Figures 5-1, 5-2 and 5-3, and Table 5.2 summarizes the measurements taken and their relevance to the sledge design.

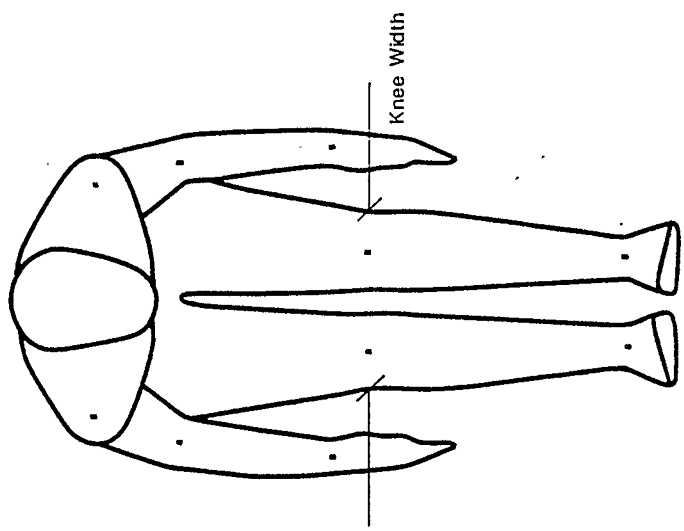


Figure 5-1. Anthropometric Measurements

The seating and positioning needs of each subject were examined in a second sequence of testing using the adjustable test sledge. The anthropometric measurements taken in the first sequence of testing were used to roughly adjust the test sledge to comfortable position for the subjects. At the beginning of the test sledge fittings, the researcher explained how the measurements would be taken and how the adjustments to the seating device would be made. The participants were asked to sit in the adjustable test sledge and indicate when the device had been adjusted to an optimal position for participation. A series of finer adjustments were systematically made to seat height, back height and angle, seat angle and hip support width and footrest position until an optimal position for each subject was found.

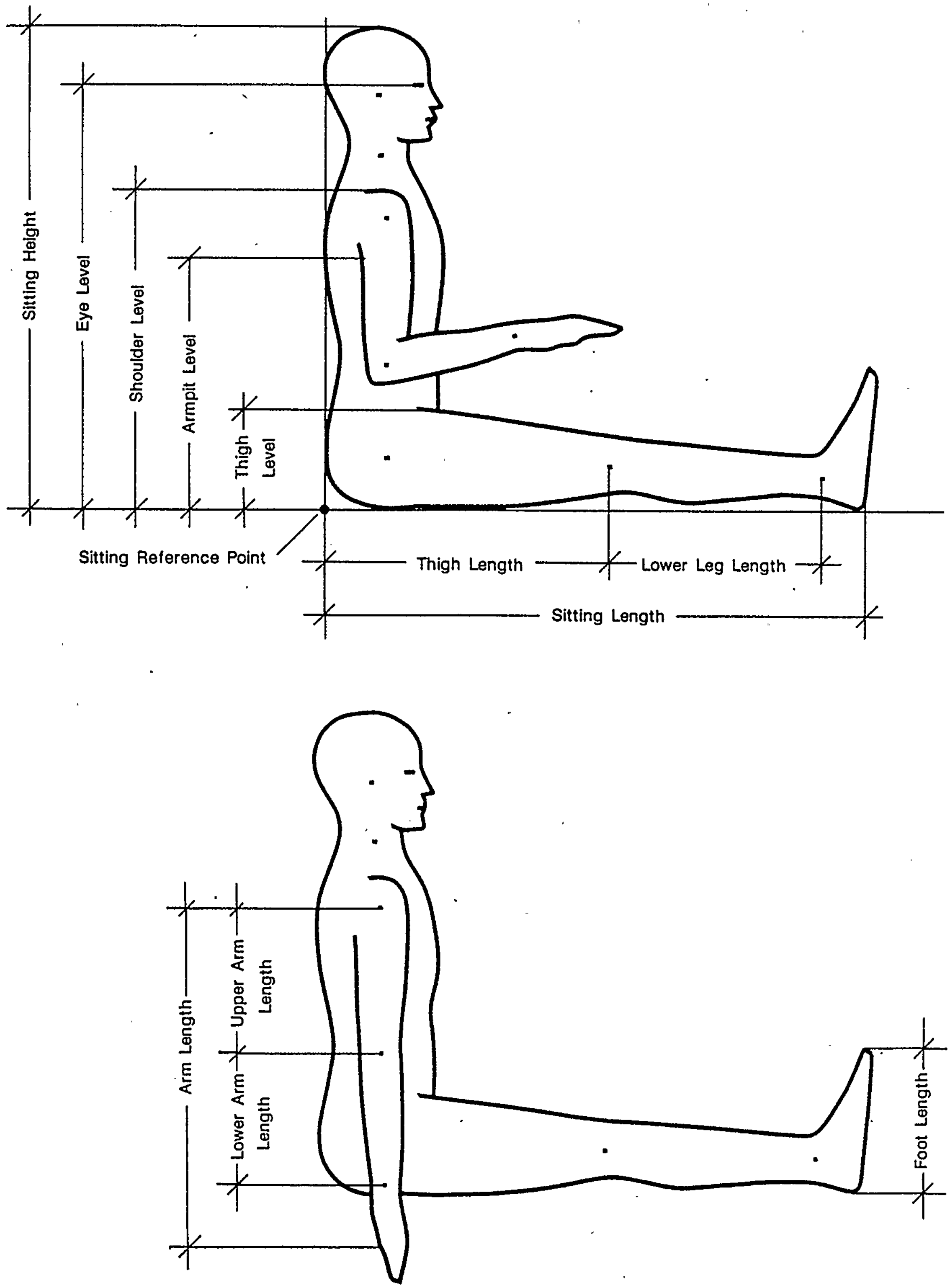


Figure 5-2. Anthropometric Measurements, (cont'd)

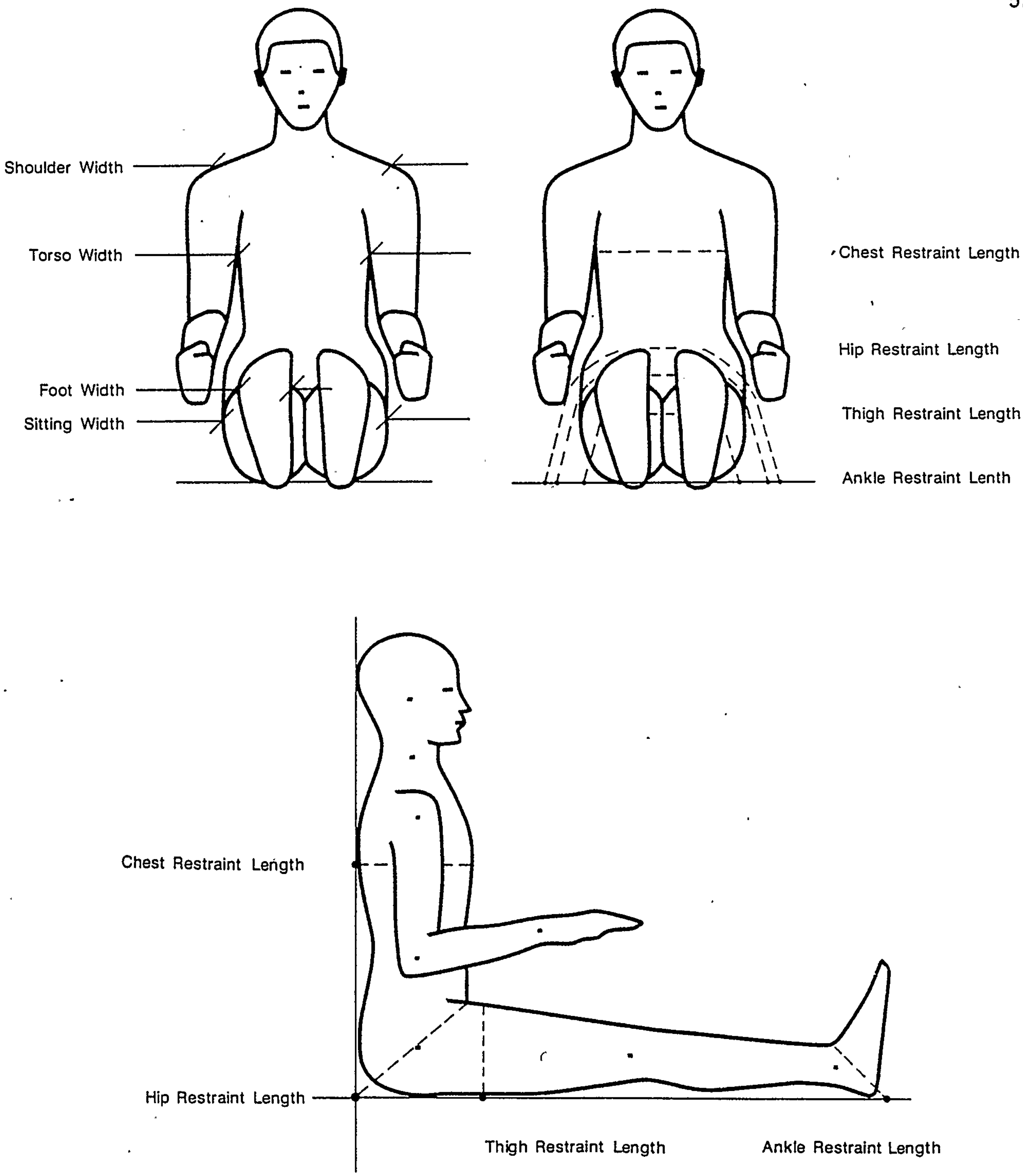


Figure 5-3. Anthropometric Measurements, (cont'd)

Table 5.2: Applicability of the Measurements to the Sledge Design

| Anthropometric Measurement | Design Parameter |
|---|---|
| Sitting height | Head support height adjustment range |
| Eye level | Head support configuration |
| Shoulder level | Full back support height and the adjustment range of neck support height |
| Armpit level | Range of thoracic support height adjustment |
| Thigh length | Seat length |
| Lower leg length | Calf support length adjustment range |
| Thigh height | Hip support height |
| Sitting length | Range of sitting length adjustment between the seat and footrest |
| Sitting width | Seat width |
| Knee width | Calf support width |
| Shoulder width | Back support width |
| Torso width | Back support width and torso support width adjustment |
| Upper arm length<br>Lower arm length<br>Extended arm length | Taken for future pick design |
| Torso restraint length | Torso support and restraint adjustment range |
| Hip restraint length | Hip restraint adjustment range |
| Ankle restraint length | Foot restraint adjustment range |
| Foot length | Foot support length |
| Foot width | Foot support width |

Table 5.2: Applicability of the Measurements to the Sledge Design (cont'd)

| Test Sledge Measurement | Design Parameter |
|---|---|
| Level of back support<br>1. Sacrum (20 cm)<br>2. Lumbar (38 cm)<br>3. Thoracic (60 cm)<br>4. Head (20 cm extension) | Range of back support height options required |
| Back angle | Range of required adjustment for back angle |
| Seat height | Required range of adjustment for seat height |
| Seat angle | Range of required adjustment for seat angle |
| Hip support width | Range of required adjustment for hip support width |
| Calf support angle | Range of required adjustment for calf support angle |
| Thoracic support height | Range of required adjustment for thoracic support height |
| Thoracic support width | Range of required adjustment for thoracic support width |
| Head support height | Range of adjustment for head support height |
| Restraint<br>Torso<br>Hip<br>Leg/knee<br>Foot | Restraint provision requirements |
| Cushioning<br>Seat<br>Hip<br>Back<br>Head | Cushioning provision requirements |

The adjustable seating device used in the test session was designed to be more comfortable than the existing sledge. To reduce the possibility of injury, helpers and a qualified nurse were on hand to assist participants while they transferred into and out of the seating device. These helpers also provided support for torso and limbs while the device was being adjusted.

The interaction between the seating device and the user was examined in the third sequence of testing. Participants were asked to perform some of the basic manoeuvres they regularly perform while ice sledging. According to their ability, participants were asked to grasp the ice picks, push off with the picks, move forward, turn right and left, and brake. Subjects then repeated the manoeuvres again in the test sledge adjusted to the settings identified in the second sequence of testing.

The Sledge Hockey and Ice Picking Association safety regulations and game rules do not require members to take a medical examination to participate in S.H.I.P. programs. In light of the proposed test methods, participants were not required to have a medical exam prior to the test sessions. As S.H.I.P. members, they regularly ice sledge and were familiar with the activity.

Physically disabled adults are as aware of their physical limitations and capabilities as any able-bodied person. They are capable of expressing their needs and judging what they can safely undertake. Some of the participants in the study were under eighteen years of age, developmentally or multiply handicapped. Prior to the on-ice test sequence, a helper demonstrated the basic manoeuvres the participants were asked to perform. Subjects performed the basic manoeuvres according to their own abilities and limitations. Any task deemed too difficult was omitted from the session. As a precautionary measure against any fall on the ice, the participants were required to wear hockey helmets during the sessions.

During the on-ice test sessions, each subject was photographed and video-taped. The videos and photographs were later used in the data analysis and design development.

Table 5.3: Summary of Testing Procedures

Test Session One

a) Record subject information - age, sex, mobility, player activities, special conditions/disability related limitations.

b) Record anthropometric measurements.

Test Session Two

a) Roughly adjust the test sledge seat width and sitting length according to the anthropometric data. Set back angle to ninety degrees and footrest to zero degrees.

b) Determine preferred seat height through discussion with subject, based on upper body mobility and subject's size and skill.

c) Determine level of back support required through discussion with subject and assist subject in transferring to test sledge.

d) Adjust backrest to preferred angle.

e) Adjust seat angle based on preference and pelvic stability.

f) Adjust the footrest to preferred angle and fine tune the adjustment to avoid a pressure point under the calf.

g) Refine adjustments to compensate for any changes.

h) Fasten hip restraint and foot restraint. Fasten leg restraint if required.

i) Locate height of thoracic support if required for upper body stability and adjust width based on anthropometric data. Fasten chest strap.

j) Locate height of headrest if subject has reclined seating position and requires support.

k) Use high and medium density foam, duct tape and plywood boards to achieve any specialized modification.

l) Record all test sledge settings so that the positioning can be duplicated for the on-ice trials and data analysis.

Test Session Three

a) While the subject is being tested in the existing sledge, adjust test sledge for subject according to the setting recorded in test session.

b) Assist subject in transferring into the existing sledge.

c) Have the subject grasp the picks, push off and travel past the camera, break, turn around and travel back across to where he started.

d) Have the subject begin in front of the camera and turn right at the marker and brake. Repeat and have the subject turn left and brake.

e) Assist the subject in transferring into the test sledge.

f) Repeat (c) and (d) in the test sledge.

g) Assist subject while leaving the ice.

## 5.4 Implications of the Subject Data

The subject data collected during the human factors test sessions were analyzed to determine the optimal size, configuration, and required ranges of adjustment for the new seating device components. Frequency distributions for relevant measurements were considered in light of the activity dynamics and other influencing factors. Normally in human factors analysis, only a specified percentage of the potential user population is considered in a design solution. Since accommodating a wider range of disabled is one of the primary objectives for the new design, all the measurements including extreme cases were considered to be relevant to the design. To ensure that able-bodied as well as disabled recreationists would be accommodated, the anthropometric data were checked against data on able-bodied populations.

### 5.4.1 Range of Disabilities Represented and Special Conditions

The 20 subjects were selected to represent a broad range of disability related limitations. Table 5.4 summarizes the disabilities represented in the study, and Table 5.5 summarizes the disability-related conditions.

### 5.4.2 Age

The subjects ranged from 10 to 46 years of age. Eight were under 18, 6 were between 19 to 30 years of age, and 6 were between 31 and 46 years of age.

### 5.4.3 Sex

Due to the fact that the large majority of individuals who participate in sledge hockey and ice picking are male, 16 of the subjects in the study were male and only 4 were female.

Table 5.4 Breakdown of the Disabilities Presented in the Study

| Disability | Number of Cases |
|---|---|
| Muscular dystrophy | 1 |
| Cerebral palsy | 5 |
| Visual impairment | 3 |
| Congenital hip dislocation | 1 |
| Arthritis | 2 |
| Paraplegia (polio) | 1 |
| Quadraplegia | 1 |
| Hymoparaplegia (paralyzed on one side) | 1 |
| Spina bifida | 1 |
| Aperts syndrome | 1 |
| Amputee (single at the hip) | 1 |
| Club foot | 1 |
| Multiple disabilities | 3 |
| Developmental handicap | 3 |

Table 5.5 Summary of Disability-Related Conditions

| Condition | Number of Cases |
|---|---|
| Limited ankle flexibility | 5 |
| Limited knee flexibility | 3 |
| Limited hip flexibility | 3 |
| Leg braces | 2 |
| One shorter leg | 3 |
| Portion of spine fused | 3 |
| Back brace | 1 |
| Scoliosis | 2 |
| Limited sensation in lower body | 4 |
| Spastic movement | 3 |
| Lack of coordination | 2 |
| Limited wrist and finger flexibility | 3 |
| Enlarged skull | 2 |

### 5.4.4 Upper Body Mobility

As mentioned in Section 4.1, the subjects selected had varying degrees of upper body mobility. Two individuals had excellent upper body mobility, 7 had good upper body mobility, 5 had limited upper body mobility, 4 had poor upper body mobility and 2 individuals were non-mobile (were unable to functionally control and move their upper bodies).

### 5.4.5 Player Activities

The subjects were involved in a range of sledge hockey and ice picking activities. Three boys played junior hockey, and 5 male adults played senior hockey. Three adult females, 6 boys and 1 girl participate in ice picking. Eleven out of the 20 participants indicated that they enjoyed non-organized recreational sledging. Seven individuals were involved in racing. Two individuals participate as passengers in tandem sledges, while 3 individuals regularly propel passengers in tandem sledges.

### 5.4.6 Sitting Length

A stable foot position plays a critical role in maintaining pelvic alignment and establishing a firm base upon which to build upper body control. The test sledge fittings seemed to indicate that lower body anchoring will be improved if the sitting length can be adjusted so that hip and foot position can be supported in an optimal relationship for each individual. The sitting length adjustment range should permit players who wear leg braces to sit straight legged. Control and

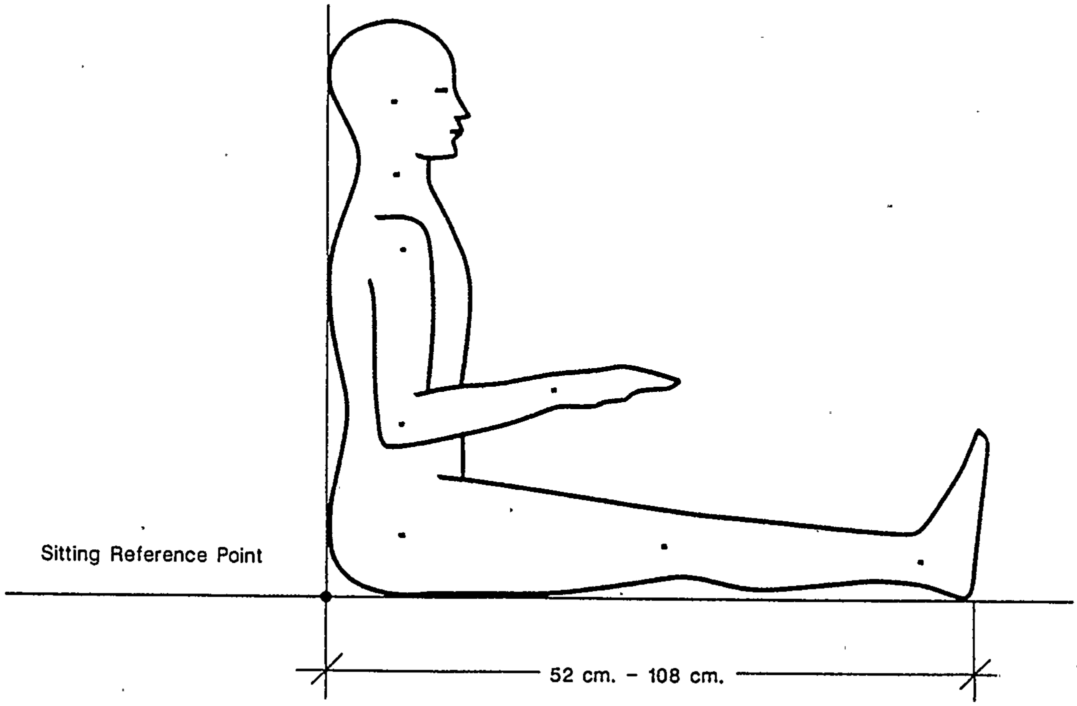


Figure 5-4. Sitting Length Adjustment Range

manoeuverability is maximized when the overall sledge length is close to the sitting length of the player. The subject data for sitting length indicates that distance between the seating reference point and the heel should adjust from 52 cm to 108 cm (see Figure 5-4).

5.4.7 Seat Width

The seat width must not interfere with the picking action of small players but it must be wide enough to support the buttocks of a large adult, adequately distribute pressure and avoid pressure build up on the ischial tuberosities. A visual analysis of photographs of picking from the rear suggests that a seat approximately 5 cm wider on either side than a player's hips impedes picking action and turning. Since the minimum measurement for player hip width was 25 cm, the seat width should not exceed 35 cm. A seat width of 35 cm will accommodate children and small to medium sized adults while very large adults may require a wider seat width of 46 cm (see Figure 5-5).

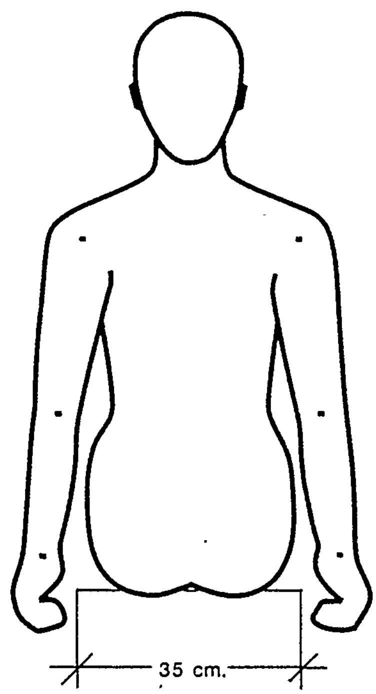


Figure 5-5. Seat Width

5.4.8 Hip Support, Width and Configuration

The subject fittings indicated that hip support should be incorporated in the seat design to help prevent the hips from rotating to the side, improve lateral stability and pelvic anchoring. The hip support must also be kept low and fit close to the body so that it will not interfere with picking action, puck access or the transfer of players into or out of the sledges.

To provide lateral stability but not interfere with arm or torso movement, the hip support should conform to body size variations and shapes. Thigh height and hip support width were used as anatomical reference points for the hip support configuration. To determine the required adjustment range of the hip support, the smallest and largest players' sitting widths were plotted (see Figure 5-6). The data indicates that the hip support should accommodate hip widths from a minimum of 25 cm to a maximum of 45 cm and thigh heights from a minimum of 8 cm to a maximum of 19 cm. The measurements for the length of the hip restraint indicate that the hip restraint should adjust from 53 to 95 cm. The measurements for thigh restraint length indicate that support or restraint over the thigh should adjust from 42 to 77 cm.

5.4.9 Seat Length

The seat should provide firm support under the buttock and thigh to help prevent the hips from rotating backwards and knees from rotating inward. Body weight should be distributed over the length of the thigh to help limit pressure on the ischial tuberosities. The range of players can not optimally be accommodated with one seat length if it is located

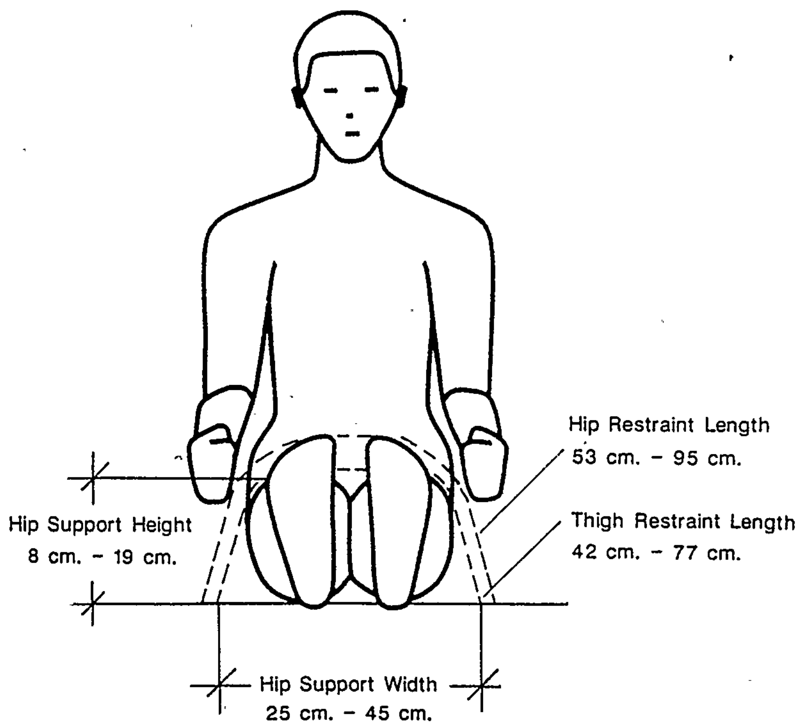


Figure 5-6. Hip Support Configuration

in a fixed position. A seat long enough to support a large player will be too long for a small player, causing a pressure point behind the knee. A seat short enough for the smallest players will not adequately support the thigh of the largest player and will cause pressure build up on the ischia. The data suggested that seat lengths of 32 cm and 37 cm should be provided. To optimally support very large adults a longer seat length of 42 cm could also be made available. One seat can accommodate the range of players if it can be moved forward to better support the thigh of large players (see Figure 5-7).

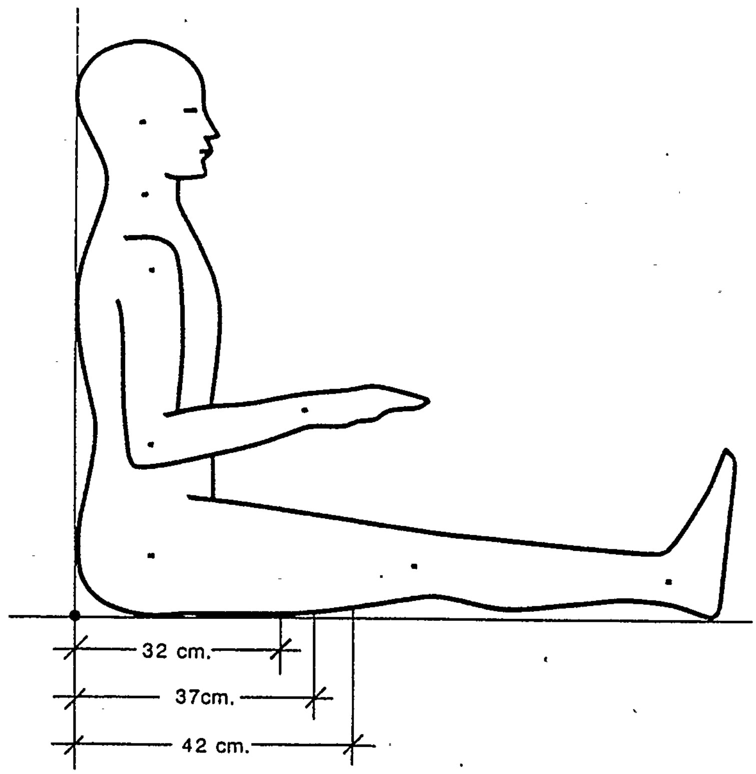


Figure 5-7. Seat Length

5.4.10 Seat Height

Based on the test sessions, the sitting height should be kept low at approximately 11.5 cm (see Figure 5-8). Theoretically, a higher sitting height with feet lower than the hips would not stretch the hamstrings at the back of the legs as much, would put less stress on the lower back, and would reduce discomfort. In this case, particularly for players with poor torso strength and limited upper body control, optimum comfort has to be traded off in favor of stability.

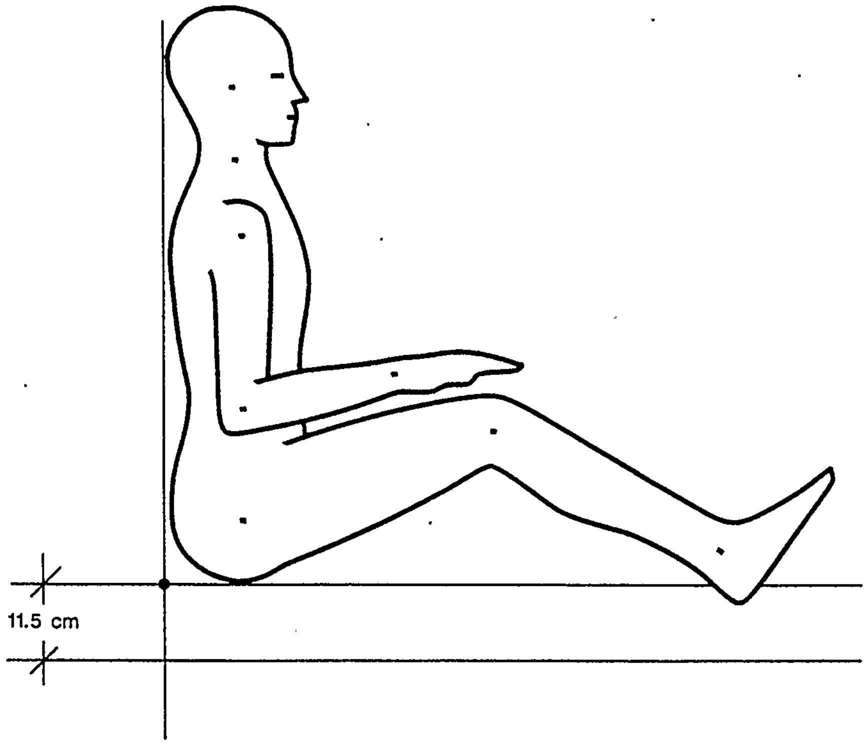


Figure 5-8. Seat Height

5.4.11 Seat Angle

The subject data seems to substantiate the principle that an angled seat can be used to improve pelvic anchoring and stability. Four of the subjects slid down and could not maintain a comfortable position on a flat seat. Ten out of the twenty subjects preferred a seat angle greater than or equal to ten degrees. The test sledge had a very short seat length and as a result large players felt little benefit when the seat was angled, thus choosing to leave the seat flat. It is reasonable to assume that some of these players would have preferred to angle the seat if a longer seat length had been provided. Two individuals wore leg braces and had to sit straight legged on a flat seat. The subject fittings indicate that the seat angle should adjust from 0 to 20 degrees (see Figure 5-9).

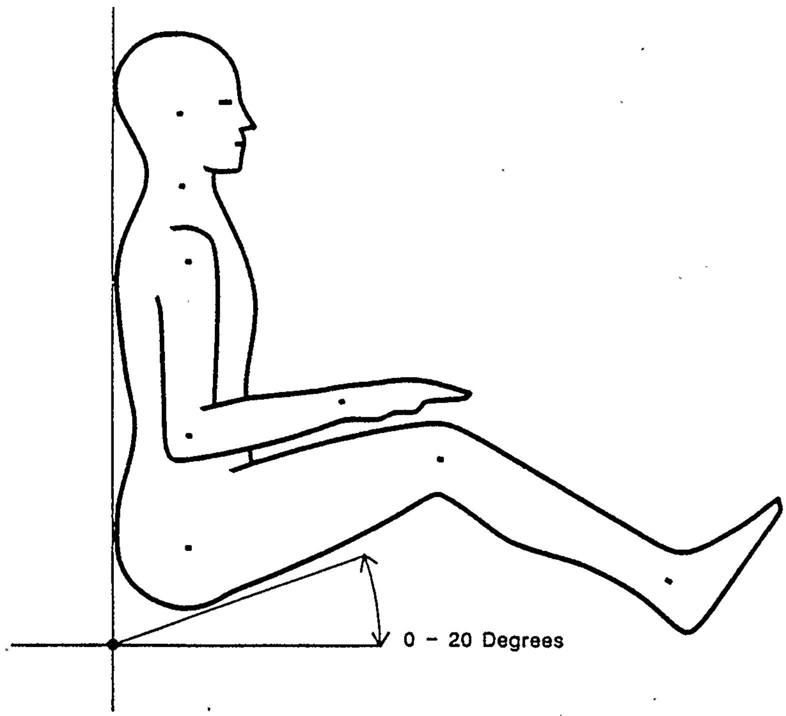


Figure 5-9. Seat Angle Adjustment Range

5.4.12 Height of Back Support

The range of backrest heights offered in the test sledge were based on data on able-bodied populations [49], the range of player activities, and anticipated support requirements. The low 20 cm backrest height was designed to minimize interference with upper body movement for hockey players while still supporting the sacro lumbar joint, and preventing shearing due to rocking of the pelvis. The lowest backrest was also

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[49] Diffrient et al., Humanscale Seating Guide 2a.

intended to provide back support for small children. The 38 cm backrest offered sacral and lumbar support, but was low enough so that it would not interfere with arm and shoulder movement of adults. The 60 cm backrest provided a full back and shoulder support for the large adult.

The subject data suggest that three backrest heights should be provided. While 11 out of 20 participants preferred the 38 cm backrest, three individuals who required a reclined seating angle also required full (60 cm) back support. Six highly mobile players preferred a low backrest height between 20 cm and 29.5 cm. A backrest 26 cm high should accommodate these highly mobile players (see Figure 5-10).

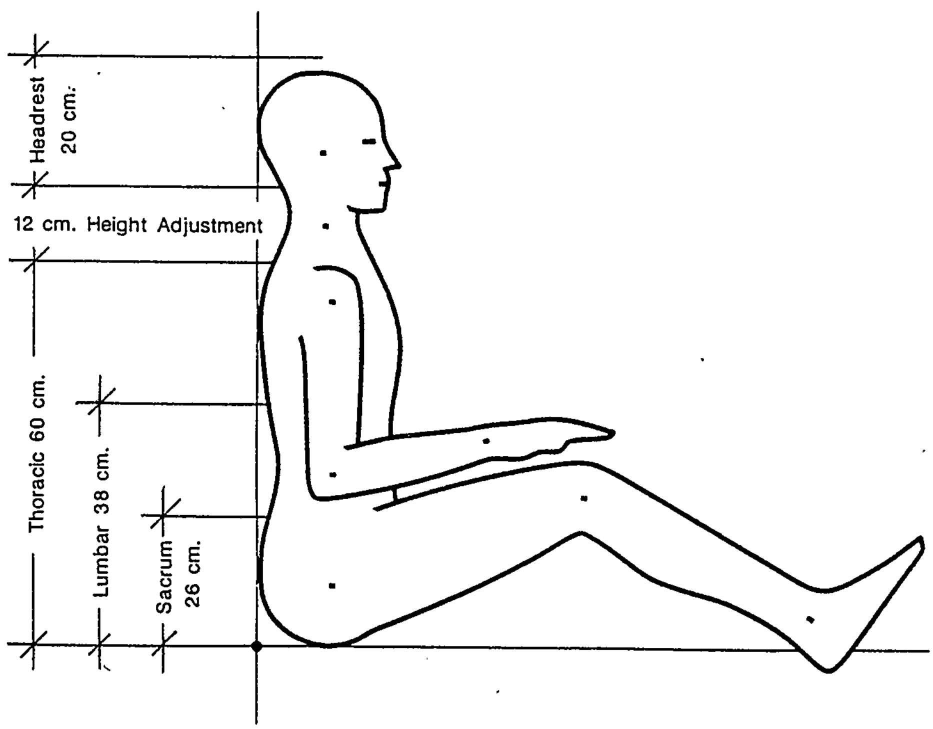


Figure 5-10. Backrest Height Options

5.4.13 Backrest Angle

Five out of 20 participants required a backrest angle between 45 and 65 degrees (greater than or equal to 5 degrees more reclined than the existing sledge). A reclined backrest angle seemed to help individuals with limited torso strength improve their upper body control and stability. Individuals with strong upper bodies preferred an upright sitting position which enabled them to maximize the picking efficiency and forward reach. Ten out of 20 participants preferred a backrest angle between 85 and 75 degrees (greater than or equal to 5 degrees more upright than the existing sledge). To respond to the range of player support needs, the backrest should adjust from 45 to 90 degrees, offering a range of support for reclined, semi-reclined and upright postures (see Figure 5-11).

5.4.14 Seat to Back Angle

The angle between the seat and the backrest was calculated for each player from the backrest angle and seat angle measurements. It is important to note that a player who has a reclined backrest angle typically also requires an inclined seat angle. The maximum seat to back angle was 115 degrees and the minimum was 87.5 degrees. Eighteen out of twenty cases fell between 95 degrees and 115 degrees, supporting the seating guidelines in Humanscale [50]. The data suggest that the angle between the seat and the backrest need not exceed 115 degrees (see Figure 5-12).

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[50] Diffrient et al., Humanscale 1/2/3/, p. 22.

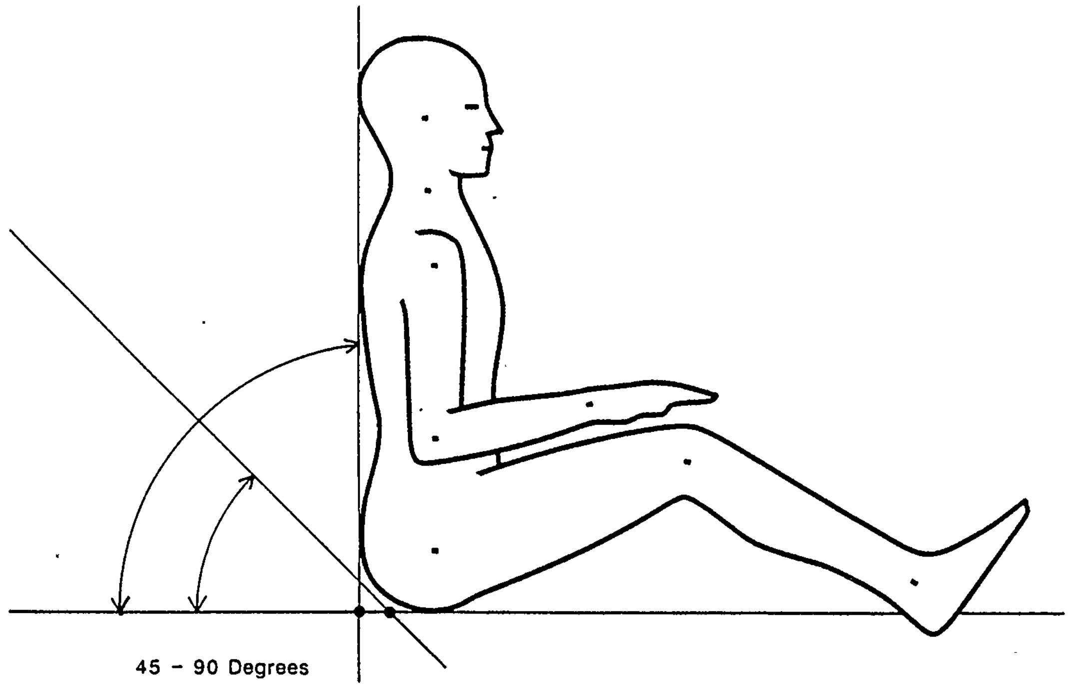


Figure 5-11. Back Angle Adjustment Range

5.4.15 Length of Calf Support

The calf support on the test sledge was too short to provide lateral support for the lower legs of most of the adult players. The short seat length of the test sledge did not adequately support the thighs of large players. The combination of the short calf support and the short seat length meant that nine cases required cushioning under their knees to support their legs adequately. Since pressure must be avoided on the nerve and artery running close to the surface at the back of the knee, the calf support should adjust to support the lower leg and accommodate the range of player lower leg lengths. The minimum measurement for lower

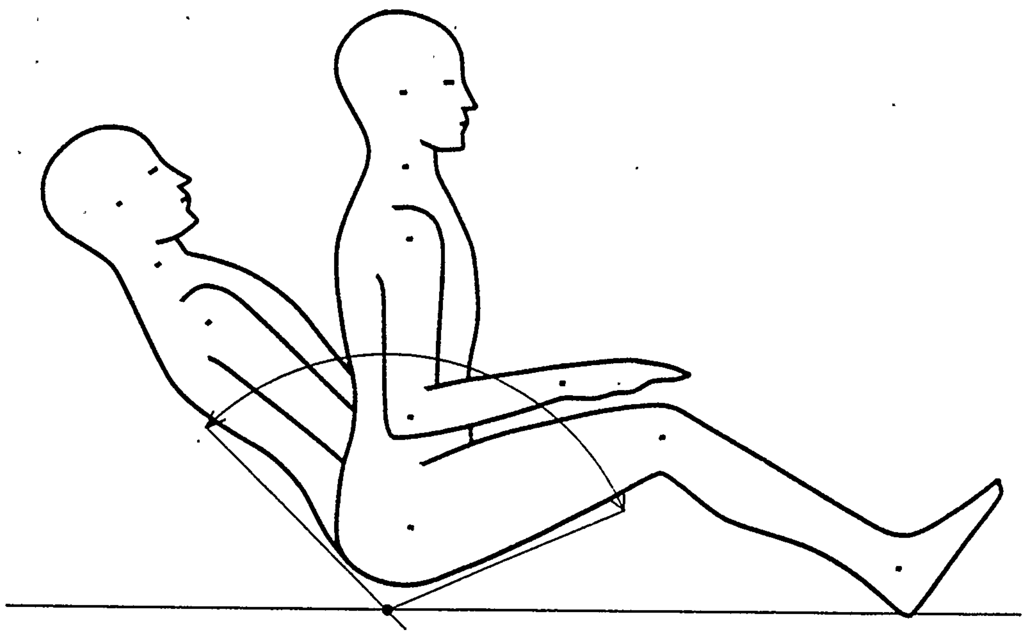


Figure 5-12. Seat to Back Angle

leg length was 24.5 cm. Adding 6 cm for the distance from the sole of the foot to the ankle bone, the calf support should adjust to a minimum length of 30 cm for the smallest player. A calf support height of 42 cm will come up high enough to support the calf of the largest player. Therefore, the calf support should adjust from a length of 30 cm to 42 cm (see Figure 5-13). The calf support should be soft, as opposed to rigid, since pressure behind the calf and tight foot restraints can induce extension and spasms in individuals with spinal cord and neurological disorders.

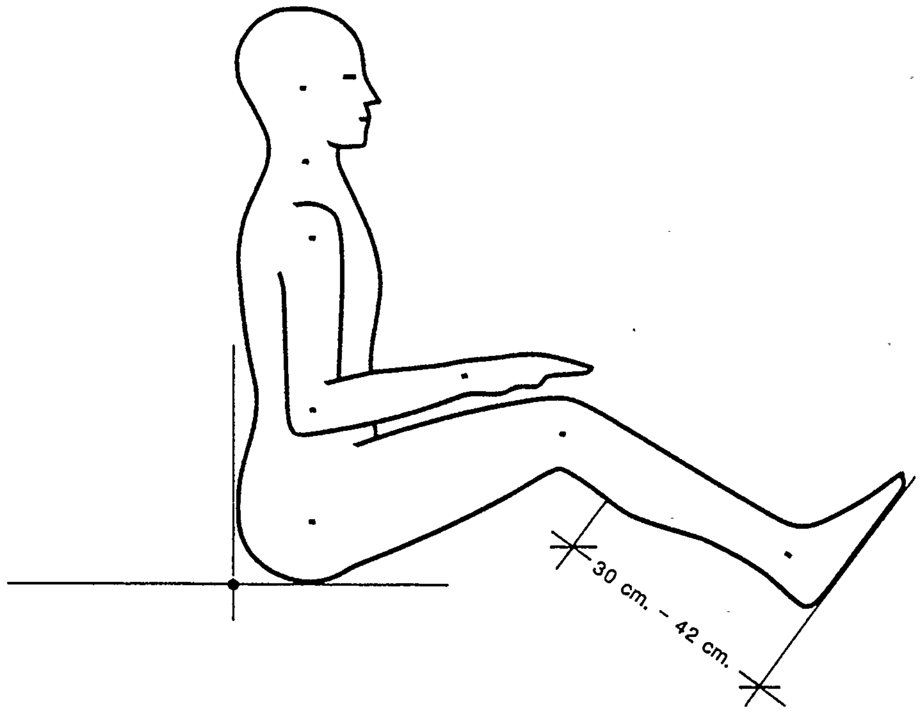


Figure 5-13. Calf Support Length Adjustment Range

Conversations with players and an analysis of player activities suggest that the calf support should help stabilize the legs laterally and provide protection for the sides of the lower legs and ankles. Knee width was used as a reference for the calf support configuration and width. One individual only had one leg and one individual sat with very splayed legs due to a spinal deformity. Including these two extreme cases, knee widths ranged from a minimum of 15 cm to a maximum of 53 cm. So that it will not interfere with picking action, the calf support should not exceed the 35 cm seat width (see Figure 5-14).

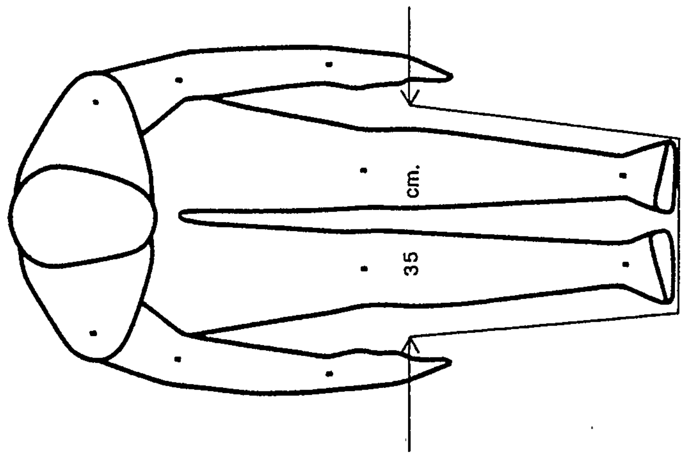


Figure 5-14. Calf Support Width

5.4.16 Footrest Angle

The subject data indicated that the footrest and calf support should stabilize the feet relative to the hips to optimize lower body anchoring and provide a high degree of positioning flexibility. One individual only had one foot and four individuals had very limited ankle flexibility, as well as extended and twisted foot positions. Three individuals required an open foot to calf angle between 110 and 112 degrees. In the subject fittings, the angle between the ice surface and the calf support on the test sledge ranged from 3 degrees to 36 degrees. The calf support should adjust through this range. The foot plate should pivot to accommodate variations in ankle flexibility (see Figure 5-15). A foot restraint should be provided that adjusts from 33 to 54 cm.

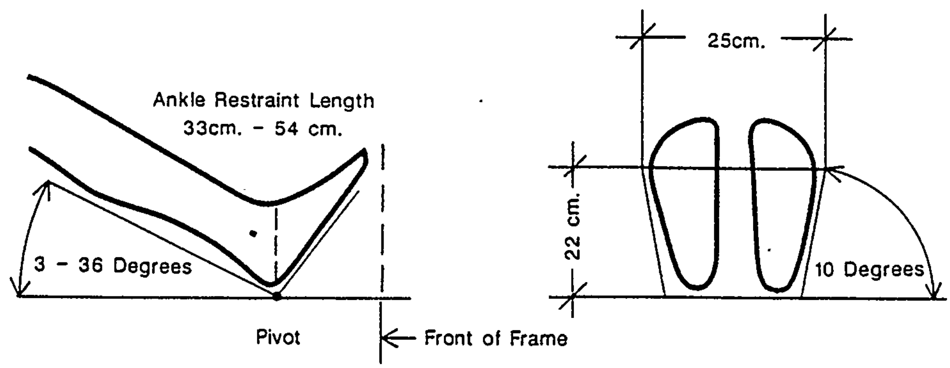


Figure 5-15. Calf Support Angle and Footrest Length and Width

5.4.17 Footrest Length

Based on available human factors data, the footrest should support the length of the foot from the back of the heel to the ball of the foot [51]. Looking at the subject data and anthropometric data on able-bodied populations, one footrest 22 cm in length will adequately accommodate the range of player foot lengths. The footrest pivot should be located far enough from the front of the frame (approximately 12 cm) to protect feet when sledges collide with the arena boards or each other (see Figure 5-15).

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[51] Diffrient et al., Humanscale Hands and Feet 6b.

### 5.4.18 Footrest Width

The footrest must be wide enough to accommodate the largest foot in winter footwear. The feet of able-bodied individuals naturally splay outwards about 10 degrees. Due to spasticity and contractures, some disabled players have very different foot positions and they may be unable to keep their feet firmly planted on a footrest. Since the maximum foot width was 11 cm, with an allowance for foot splaying, the footrest should be 25 cm wide across the ball of the foot (see Figure 5-15).

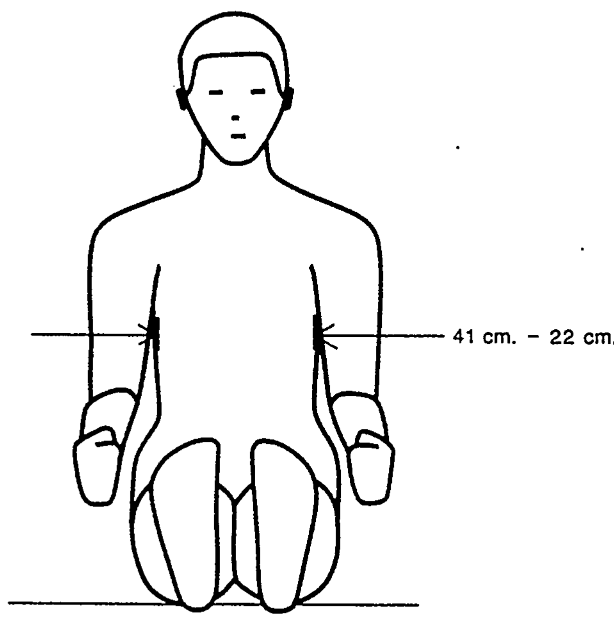


Figure 5-16. Thoracic Support Width Adjustment Range

5.4.19 Thoracic Support Width

The thoracic support must provide firm lateral support for individuals with limited torso strength and help align the torso over the hips. It should fit closely to the torso so that it does not inhibit arm movement, but also allow room for chest expansion in breathing. Four out of 20 cases required thoracic support. The thoracic support on the test sledge worked adequately for small players, but did not provide adequate support for a large male adult. Lateral stability could be improved if the torso support incorporated an over-the-shoulder configuration of restraint and a wide support around the chest. The torso restraint should adjust from 48 to 92 cm (see Figure 5-17). Based on the subject measurements and data on able-bodied populations, the torso support must accommodate torso widths from 41 cm to 22 cm (see Figure 5-16).

5.4.20 Thoracic Support Height

The thoracic support should support the torso just under the axillae (armpits). It should be cushioned so that it will not cut into the armpits or hip bones. To accommodate the full range of players, the thoracic support should work in conjunction with the 60 cm backrest and provide a height adjustment range from 28 cm to 53 cm (see Figure 5-17).

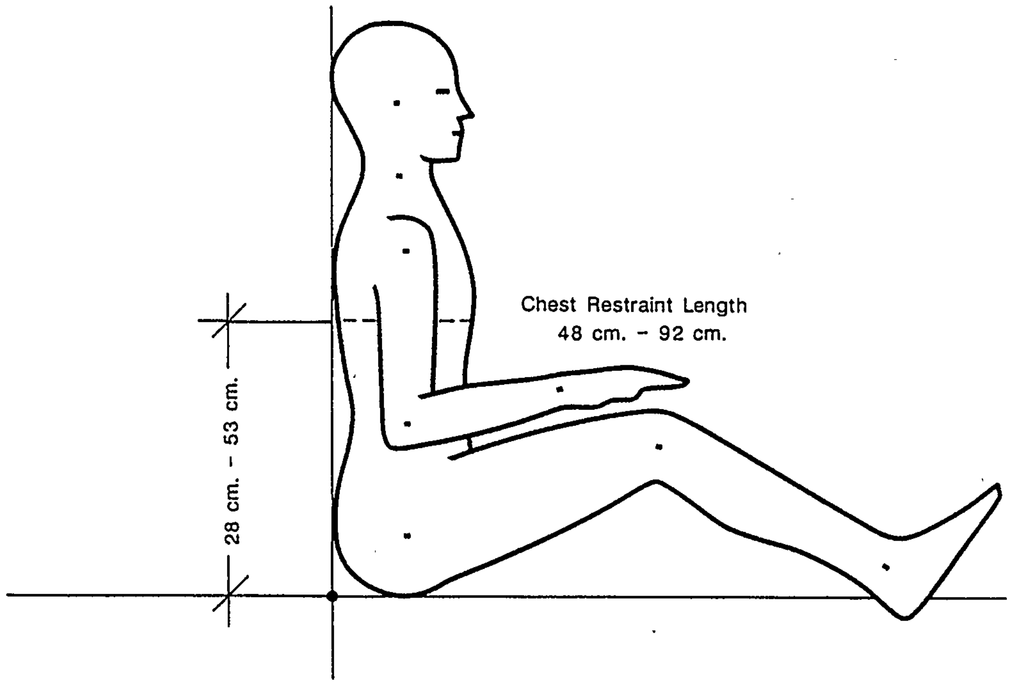


Figure 5-17. Thoracic Support Height Adjustment Range

5.4.21 Head and Neck Support

Two subjects out of 20 required head support. Both were children and the 60 cm backrest was high enough to provide head support. For larger players, a head support extension should be provided that works on the 60 cm backrest. The head support extension should adjust from 60 cm to 91 cm. The 2 individuals who needed head support also required lateral support to prevent their head from falling to the side (see Figure 5-18). A neck support should be provided to stabilize the head since the lateral support should not interfere with vision or hearing. Assuming that the neck support will rest on the shoulders, the measurements for shoulder level indicate that the neck support should have a height adjustment range of 39 to 62 cm.

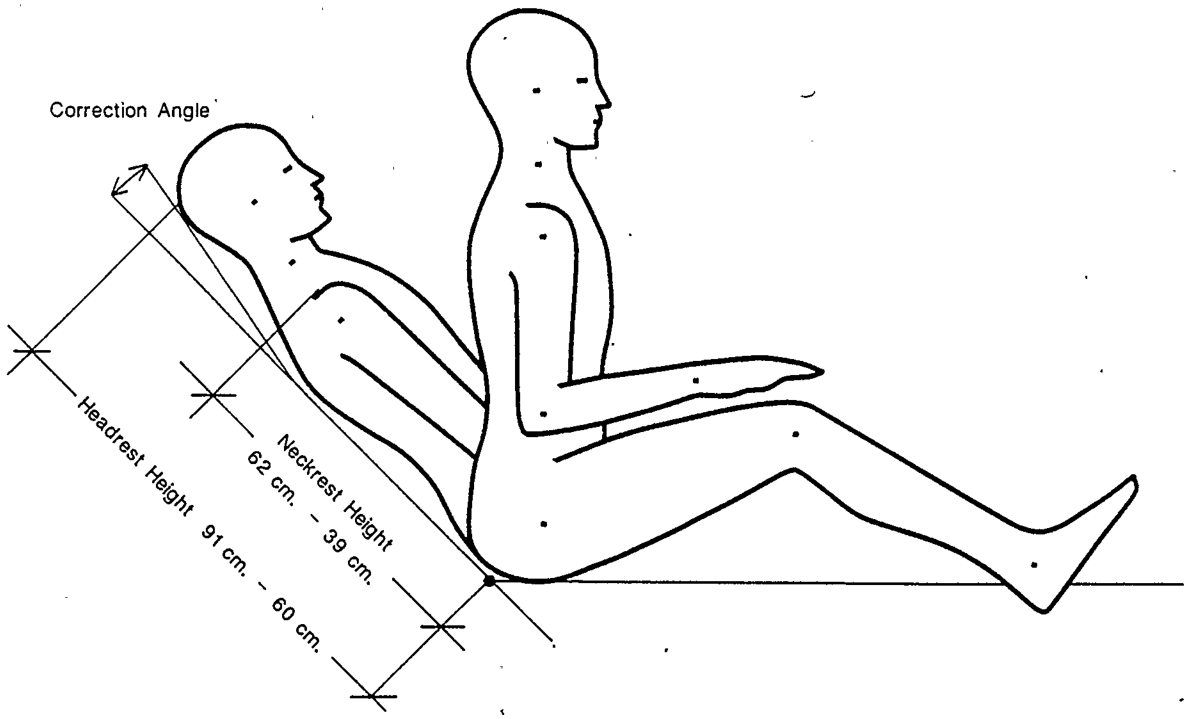


Figure 5-18. Head Support Adjustment Range

5.5 On-Ice Sessions

The on-ice sessions where the subjects tried out the new seating system and the existing sledge were useful in determining a number of design details. The participants were not familiar with the new test sledge so it was not possible to make any valid comparisons of performance.

Videos and photographs provided useful visual references. Photographic records of participants in the test sledge and in the existing sledge were used to confirm the shortcomings of both. They also provided useful information for verifying the configuration of the components.

Photographs of large players revealed that the 30 cm seat length provided in the test sledge was too short to adequately support the thighs and distribute pressure. Players who slumped in the existing sledge appeared to be more stable and sit in a more upright position in the test sledge when the seat and back angle were adjusted. This supported the assumption that seat and back angle adjustment should be provided.

Photographs also showed that the rigid calf support provided in the test sledge was too short to support the calf of adults, caused a pressure point, and indicated that a great deal of flexibility should be provided in the footrest and calf support.

Action photographs of the players' picking and turning action from the rear established that the back width used in the test sledge provided adequate arm clearance while not interfering with propulsion. Other photographs from the rear of players in the existing sledge showed that the picks pass very close to the body during the picking and turning action. This was taken into consideration when designing the frame width, seat width and hip support configuration.

## 5.6 Factors Affecting the Runners

The S.H.I.P.'s hockey rules and regulations specify that for hockey tournaments, the rear runners can be no longer than 23 cm. Runner length and sharpness also affect the manoeuverability of the sledge. A long sharp blade makes it easier to propel the sledge in a straight line and is optimal for racing, while a short blade makes it easier to turn and manoeuvre in hockey skirmishes. In theory, optimal manoeuverability would be achieved on a single centre rear runner. On a single runner the participant would need much more balance and skill to manoeuvre the sledge effectively without tipping sideways. The maximum distance between the blades should be no wider than the seat so that they will not interfere with picking action.

With the runners positioned just behind the hips, the sledge will not tip backwards easily and it will be more stable for players in a semi-reclined position. Theoretically, the front skid should be directly under the foot. A front skid position far in front of the feet increases the radius required to turn, and reduces manoeuverability.

# 6. DESIGN CONCEPT FOR THE NEW SEATING DEVICE FOR ICE SLEDGING

## 6.1 Functional Characteristics

The design for the new seating device was developed from the preliminary design brief and the analyses of the human factors data. Conceptually, the new sledge is made of a running base, propulsion system and modular support system. The new design will be discussed according to a breakdown of the basic components and their parts.

### 6.1.1 Running Base

The running base is composed of a two-part, adjustable tubular frame, two rear runners, a front skid, and front and rear bumpers (see Figure 6-1).

#### 6.1.1.1 Frame

The general seating principles and human factors analysis suggested that the pelvic anchoring would be improved if the foot position was stabilized relative to the hip. The new two-part tubular frame has the length adjustment occurring between the seat and footrest (see Slide 6). With this new configuration safety is improved because the exposed tubing ends are eliminated. The adjustment clamps are located for easy access below the player's knees on the upper inside edge of the frame (see Slides 7 and 17). In accordance with game rules puck clearance is provided below the frame.

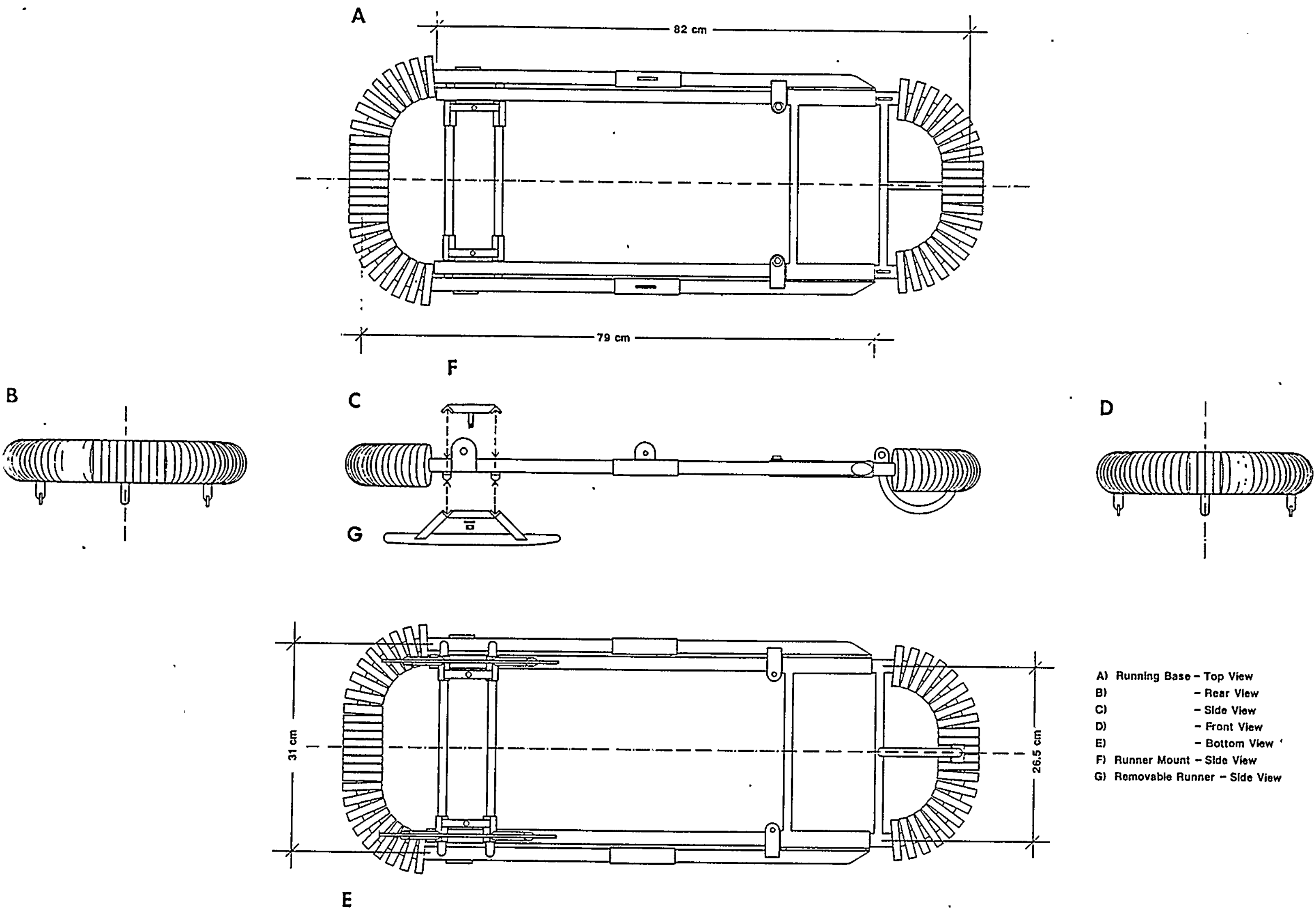


Figure 6-1. Prototype - Running Base.

To protect the participants against collisions and minimize possible damage, a closed cell, medium-density, impact dampening rubber bumper is provided at the front and back of the sledge. The dampening material reduces point impacts and helps to protect the surface finish from chipping and denting. It also allows the use of lighter weight tubing in the frame construction.

The new frame is made of Chrome Moly, a high-carbon steel tubing. Chrome Moly is much stronger than mild steel tubing. It is possible to use thinner material and obtain a very strong lightweight structure. To lighten the frame and avoid increasing the total weight, the tubing diameter has been reduced from 2.54 cm to 1.9 cm and the wall thickness is reduced from 0.162 cm to 0.09 cm. Crossmembers in the new construction provide torsional stability and the strength to withstand collisions. To minimize scratching and chipping, the tubular frame is sprayed with a two-part epoxy paint.

6.1.1.2 Rear Runners

Runners are welded to the seat in a fixed position in the existing design. The new design replaces these with removable runners (see Slide 8). This facilitates sharpening, and maintenance and provides the flexibility of changing blade lengths for different activities. To ensure stability and keep the front of the sledge down when players assume a reclined position, the rear runners are mounted slightly behind the hips. In order to reduce the possibility of injury, the runners do not protrude behind the sledge.

### 6.1.1.3 Front Skid

The front skid configuration was not changed from the existing sledge because the present skid facilitates turning and manoeuverability.

## 6.1.2 Propulsion System

### 6.1.2.1 Picks

The redesign of the propulsion system was not undertaken in this project. The research and analysis formed a basis for some basic design parameters. Conceptually, the picks would be composed of a hand grip, stick, shooting surface, and ice contact point. A rough visual analysis of players' picking action shows that picks are planted at an angle of less than 90 degrees - maximum force appears to be applied between 90 and 45 degrees - and the picks leave the ice at approximately 5 degrees. The ice pick configuration should maintain and maximize ice contact through this range of motion while minimizing potential injury.

Players with limited grip strength could benefit from a grip configuration which would include a firm surface for the base of the hand to push against. In order to minimize player injuries, the hand grips and pick ends should be shaped so that they cannot go through a hockey face mask.

A shooting surface should be incorporated in the new pick to improve puck control. The stick's configuration should lift the shooting hand up so that it does not rub on the ice. The picks should be lightweight and available in several lengths since players vary in size, strength and stamina, and longer picks may improve performance in competitive racing.

The existing picks damage the paint on the outside of the frame badly when they are used to break momentum and stop the sledge. A new pick should also incorporate a protective material to minimize paint abrasion and protect the frames from damage.

6.1.3 Support System

The modular system of support is composed of: (a) an adjustable seating frame, (b) one of three optional backrest heights, (c) a seat and hip support, (d) a footrest and calf support, and (e) torso, neck, and head support options for those individuals who require additional upper body support. The footrest and calf support provide support and protection for the lower leg (see Figure 6-2).

6.1.3.1 Adjustable Seat Frame

The seat frame interfaces the running system, backrest, and seat (see Slide 10). Independent seat angle and back angle adjustment are provided in the seat frame so that a wide range of sitting postures and preferences can be accommodated. The seat angle adjusts from 0 to 20 degrees and backrest angle adjusts from 90 to 45 degrees. The adjustment mechanisms are simple, easy to use and are located so that they can be accessed readily by the participant or a person assisting.

Some disabled individuals with very severe seating problems cannot be safely transferred or function outside of their own personalized seating mold, therefore specialized seating molds can be attached to the adjustable seat frame by bolting through the seat and backrest mounting

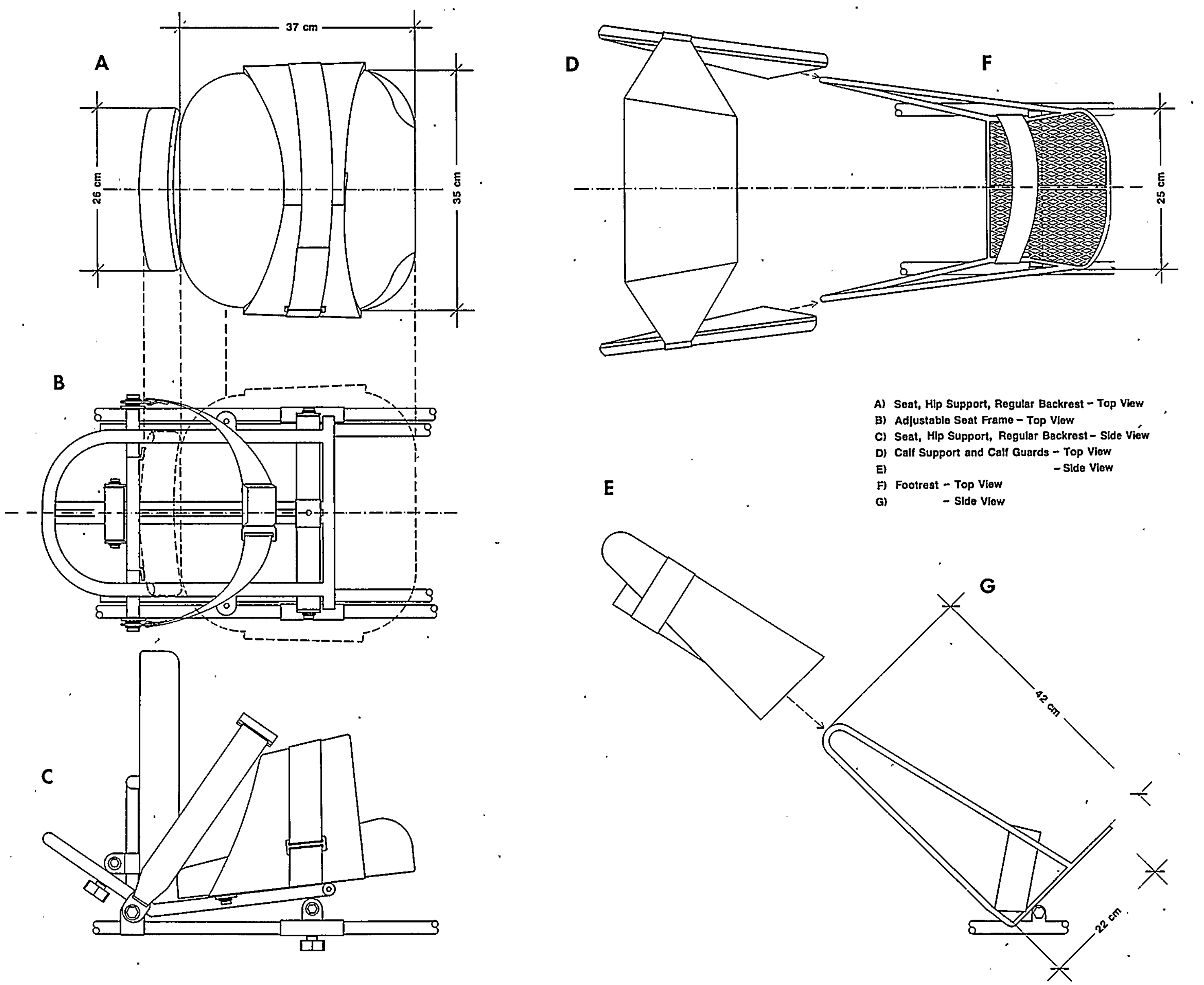


Figure 6-2. Prototype - Adjustable Seating Frame, Seat, Hip Support, Regular Backrest, Footrest and Calf Support.

tabs.

6.1.3.2 Seat and Hip Support

In order to keep the player's center of gravity close to the ice and maximize lateral stability, the relative seat height is kept low. The cushioned seat bolts to two seat mount tabs on the adjustable seat frame. The seat may be bolted in the rear position for a child or moved ahead 5 cm and bolted in a forward position to support a large adult's thighs and buttocks (see Slide 13).

The wedge-shaped seat cushion forms a sitting pocket which helps stabilize the pelvis using gravity to push the hip back into the seat.

The cushion is a laminate of low and high density foam to distribute pressure and reduce pressure points. Directly under the ischial tuberosities and coccyx 3 cm of low density cushioning and 2.54 cm of high density cushioning are provided. In order to avoid a pressure point behind the knee, the front edge of the cushion is curved with a radius of 5.08 cm. Thermal insulation from the cold ice, below the seat, is also improved by the seat cushioning. The removable seat cover is made of cordura, which is a durable, breathable, and water repellent material.

The hip support works in conjunction with the seat to increase lateral stability, improve lower body anchoring, and protect the hips from injury. It is made of flexible, high density foam which wraps over the hips, conforms to the body, and accommodates the range of players' body sizes and shape variations. The soft support does not interfere when players transfer in or out of the sledge and hugs the body closely so it does not obstruct picking or turning actions. The foam support also provides additional thermal insulation. Velcro strips anchor the hip support to the base of the seat so it can be removed for cleaning. Lycra, a stretchy breathable material, covers the inside surface of the foam support to avoid creases and ridges that could cause irritation. Cordura is used on the outside of the support, and it is fastened with 5.08 cm of webbing and velcro for easy adjustment. A hip restraint of 5.08 cm of webbing is also provided to help hold the hips back in the sitting pocket. An automotive seat belt buckle ensures that the hip restraint can be easily adjusted, fastened, and unfastened.

#### 6.1.3.3 Footrest and Calf Support

The footrest and calf support offer lower leg support and positioning flexibility (see Slide 9). The footrest pivots freely about the heel of the foot, allowing the player's feet to naturally come to rest in a comfortable position. The foot plate supports the length of the foot from the back of the heel to the ball of the foot and provides clearance to allow for winter footwear. The front edge of the footplate is rounded to reduce potential injuries to other players and the pivot point is set back from the front of the frame so that player's toes are not vulnerable to injury when sledges collide.

Lower leg guards of high density foam fit over the side supports, extending off the footplate to protect the sides of the lower legs when contact is made with the arena boards or other sleds. A soft calf support hangs over the side supports to support the underside of the lower legs (see Slide 12). The cloth calf support can be moved along the side support to accommodate variations in lower leg length. The back and sides of the lower legs are supported and aligned by the calf support. To

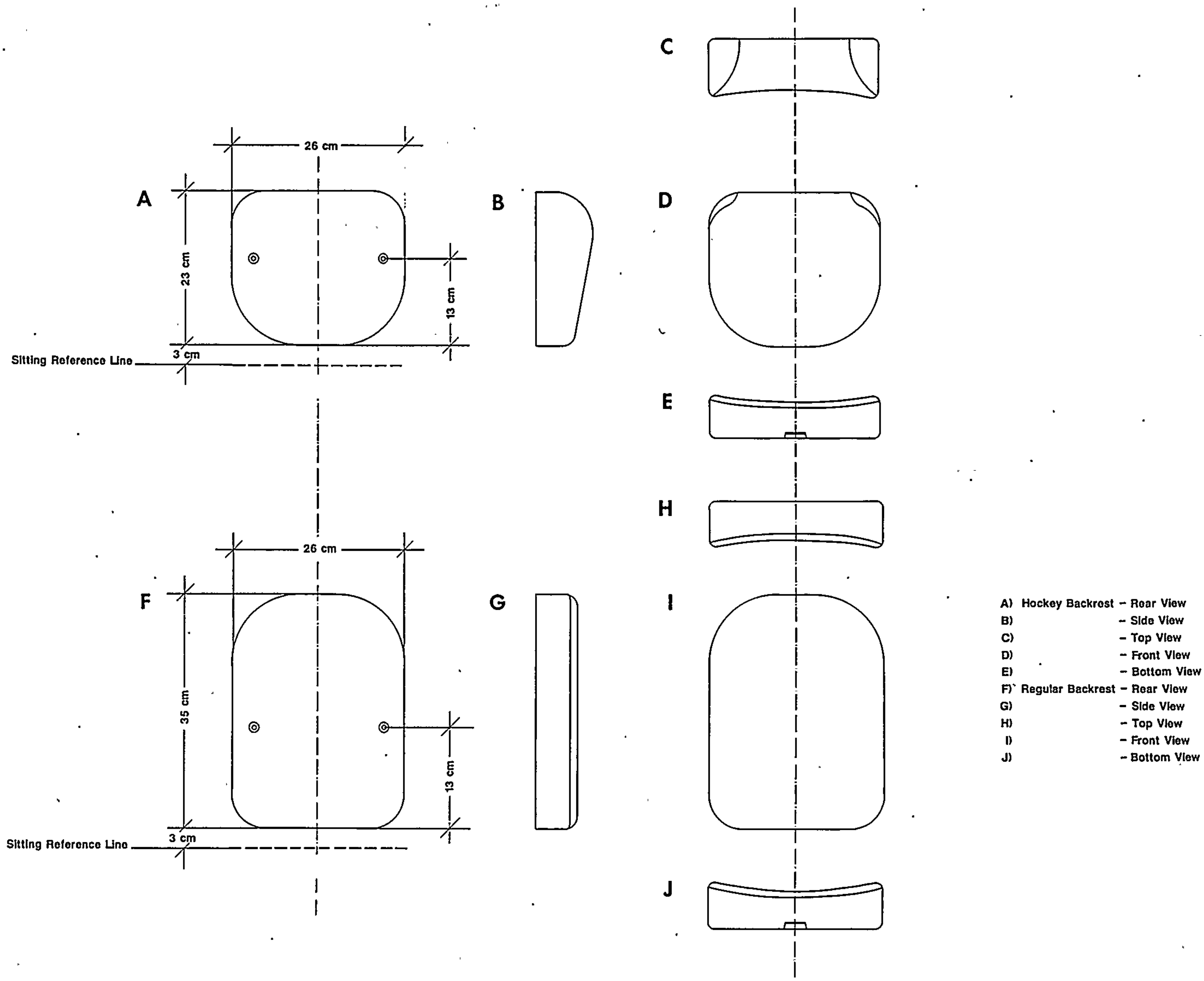


Figure 6-3. Prototype - Regular Backrest and Hockey Backrest Options.

minimize pressure on the back of the calf, the calf support is made of cordura padded with low density foam. A foot restraint of 5.08 cm webbing is located in such a way that it crosses the ankles at 45 degrees. The new footrest and calf support eliminate the danger of feet sliding off the sledge and the foot restraint does not have to be drawn as tightly as on the existing sledges.

#### 6.1.3.4 Backrest Options

The new positioning system has three backrest height alternatives (26 cm, 38 cm and 60 cm) to provide basic sacral, lumbar and thoracic support for the range of players and player activities (see Slides 14-16). The two shorter backrests have a 26 cm back width to permit uninhibited picking action by children and adults. The short 26 cm backrest height reduces the possibility of arms being pinned between the backrest and arena board during hockey games. The backrests are contoured with a horizontal radius of 105 cm to promote centre line orientation. The top corners of the backrests are rounded so they will not interfere when players turn and reach for the puck behind their sledges. The high backrest option is 30 cm wide and provides better lateral stability for individuals who require additional support.

The backrests consist of cushioning over a plywood base. This firm base will help to prevent shoulders from rotating inwards and the pelvis from rotating forward. A lamination of 3 cm of low density foam cushioning over 1.27 cm of high density foam is provided in the backrests to improve pressure distribution and thermal insulation. Backrest covers are made of cordura and can be removed for cleaning.

6.1.3.5 Thoracic Support

The materials and construction of the hip support are also used in the thoracic support (see Slide 17). The flexible high density foam support accommodates varying torso widths, wraps around the chest and fits the torso closely in a manner which does not inhibit arm movement. It straps around the high backrest and can be used with or without a headrest. The support may be positioned at varying heights to prevent it from cutting into the axillae or hip bones. To maximize lateral stability the thoracic support incorporates a chest strap and two adjustable shoulder straps of 5.08 cm webbing.

6.1.3.6 Headrest

A height adjustable headrest extension is provided which attaches to the high backrest. The headrest is 20 cm in height and provides a 12 cm adjustment range to accommodate the range of adult players (see Slide 18). A 10 degree correction angle is incorporated in the headrest to bring the head forward to improve the visual orientation in semi-reclined and reclined positions.

6.1.3.7 Neck Support

A neck support of high density foam was developed to provide lateral support for the head without interfering with vision or hearing. The firm support fits around the neck and rests on the player's shoulders. It may be strapped onto the high backrest or the headrest extension at varied heights (see Slide 18).

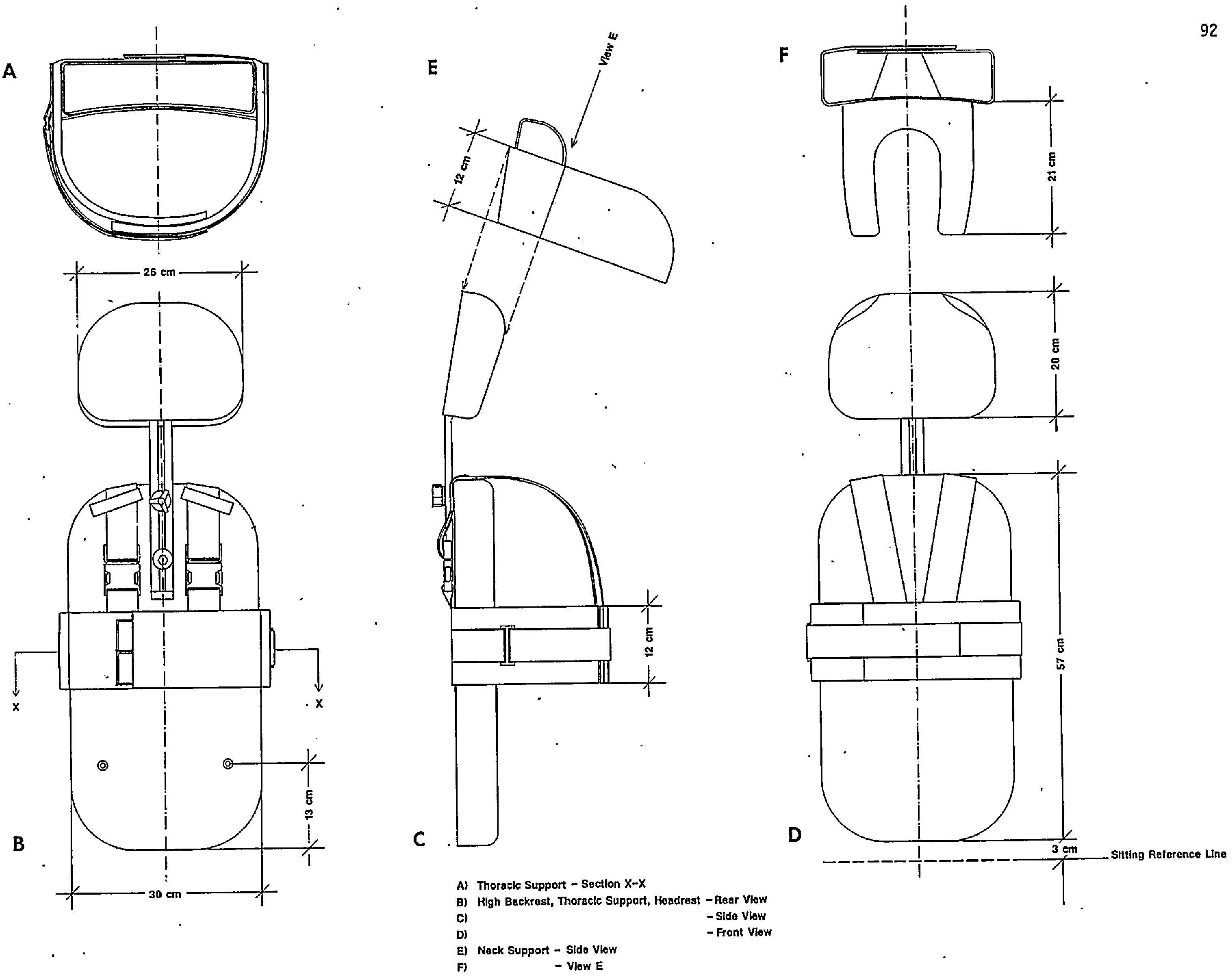


Figure 6-4. Prototype - High Backrest, Thoracic Support, Headrest and Neck Support Options.

### 6.1.4 Tandem Sledging

The method of tandem sledging in the existing sledges is very tiring for the person propelling both sledges. The improved support system, in the new design, enables a person propelling tandem sledges to optimize his or her positioning, thus reducing fatigue. It provides improved torso, neck and head support for the individual who participates as a passenger in tandem sledges. The backrest and seat adjustment allow an individual with poor upper body stability to assume a reclined attitude. The angled seat and hip supports help to stabilize the pelvis and prevent slumping in the seat. The footrest and calf support provide improved support, alignment and protection of the lower legs and feet.

## 7. PROTOTYPE EVALUATION

The new sledge was designed to improve positioning and meet the needs of a specialized market of disabled recreationists. In product design, working models and prototypes are typically field-tested prior to commercial production. The prototype of the new seating device for ice sledging should be evaluated in both recreational and competitive conditions prior to commercial production.

At present, no commercial firm sponsors or is materially interested in this project other than S.H.I.P. It is anticipated that S.H.I.P. would be interested in field testing the prototype for one to two seasons. An evaluation should be done prior to production in order to determine which design features are economically viable and which trade-offs may be made to reduce costs.

### 7.1 Evaluation Methodology

The prototype evaluation should be structured to answer the following questions regarding the acceptability of the new design.

1. Does the prototype for ice sledging allow participation by a broader range of disabled recreationists than the existing sledge?
2. Does the prototype function better for the range of sledging activities than the existing sledge?
3. Does it provide better support and flexibility in positioning than the existing sledge?
4. Does the range of support options provided in the prototype meet the needs of the range of users? Are all the components necessary?
5. What changes should be made prior to production?
6. What design features should be eliminated to reduce the cost?

The two-part evaluation process should include structured observation of participants using both the prototype and the existing ice sledge, and a user survey. To ensure that the evaluation is objective, the structured observation sessions and user survey should be administered by a person trained in these methods.

### 7.1.1 The Sample

Ideally, the sample of members selected for the prototype evaluation would not include the individuals who participated in the human factors research. These individuals have already been sensitized to the new design. However, due to the small numbers who participate in the activity, it is not reasonable to exclude individuals who participated in the human factors research from the evaluation process. If financial resources permit, members from clubs across Canada should be involved in the evaluation. Even a small sample of a minimum of twenty Alberta members will provide useful information. As large a sample of members as possible should be selected and these should represent the range of activities and users. The sample should include a balance of males, females, children, teens, adults, and disabilities.

As in the previous human factors research, the sample should represent the range of users and the range of user activities. To represent the range of users, the evaluation should include individuals with:

- o excellent upper body mobility
- o good upper body mobility
- o limited upper body mobility
- o poor upper body mobility
- o non mobile.

To represent the range of activities the evaluation should include individuals who participate in

- sledge hockey
- ice picking
- racing
- recreational ice sledging
- tandem sledging

### 7.1.2 Structured Observation

Club members should be given the opportunity to use and become familiar with the prototype over a period of two to three months. A record should be kept of the time each participant spends in the new sledge to ensure that all subjects have equal time. After this introductory period, structured observation sessions should be scheduled at an indoor hockey arena and also in an outdoor environment such as a rink. Sessions should be set up for competitive and recreational activities, namely: sledge hockey, ice picking, racing, recreational, and tandem sledging. Participants should be observed during regular games, practices and activities.

To allow comparisons between the sledges, each participant should be observed using the prototype as well as the existing sledge. The information obtained from the structured observation will establish the range of users accommodated by the new and the existing design. When the data is analysed the level of mobility and player activities can be cross-referenced to determine which participants prefer and use which design features. A record of how the sledges are used will substantiate whether all the components and adjustments are necessary in the new design. To obtain an indication of which sledge participants find more comfortable, the participants should be asked to use each sledge only as long as they find it comfortable to do so.

The following checklist was generated to provide the structure for observation.

## Observation Checklist

### Subject Information

- o age, sex
- o disability
- o upper body mobility
- o activity being observed
- o experience in the activity
- o skill level in the activity.

### Sledge Utility

Which of the adjustments are used?

| Sledge X (Prototype) | | Sledge Y (Existing Sledge) | |
|---|---|---|---|
| o sitting length adjustment | ___ | o sitting length adjustment | ___ |
| o seat angle adjustment | ___ | | |
| o back angle adjustment | ___ | | |
| o seat in forward position | ___ | | |
| o seat in backward position | ___ | | |

Which modular components were used?

| Sledge X (Prototype) | | Sledge Y (Existing Sledge) | |
|---|---|---|---|
| o 26 cm backrest | ___ | o optional backrest | ___ |
| o 38 cm backrest | ___ | o torso strap | ___ |
| o 60 cm backrest | ___ | o foam cushioning | ___ |
| o hip support | ___ | | |
| o footrest/calf support | ___ | | |
| o calf guards | ___ | | |
| o torso support | ___ | | |
| o head support | ___ | | |
| o neck support | ___ | | |

What length of time did the participant spend in each sledge?

| | Sledge X | Sledge Y |
|---|---|---|
| 0-15 min | ___ | ___ |
| 16-30 min | ___ | ___ |
| 31-45 min | ___ | ___ |
| 46-60 min | ___ | ___ |
| 61-75 min | ___ | ___ |
| 76-90 min | ___ | ___ |
| 91-105 min | ___ | ___ |
| 106-120 min | ___ | ___ |
| over 120 min | ___ | ___ |

### 7.1.3 User Survey

The physical performance of the sledges and aspects of user fit, user efficiency, and comfort may also be addressed with a user survey. The prototype evaluation will not provide absolute answers regarding the performance of the new sledge design. The purpose of the questions on the user survey is to establish if the new design is sufficiently better than the existing sledge to warrant commercial production. If the user survey shows that the prototype is preferred over the existing sledge there is a basis for deciding to go into commercial production. If attributes of the new design are found to be undesirable or unnecessary they can be eliminated or changed. The same user survey that is given to adults should also be orally administered to children with verbal explanations of terms to aid their comprehension. At the end of the observation session the participant who has just finished using the prototype should be asked to complete a user survey similar to the following.

## User Survey

1. Which sledge do you prefer for the following attributes?

| | Sledge X | Undecided | Sledge Y |
|---|---|---|---|
| ease of transfer | ___ | ___ | ___ |
| ease of picking | ___ | ___ | ___ |
| ease of turning | ___ | ___ | ___ |
| ease of braking | ___ | ___ | ___ |
| accessing the puck | ___ | ___ | ___ |
| controlling the puck | ___ | ___ | ___ |
| shooting the puck | ___ | ___ | ___ |
| stability in turning | ___ | ___ | ___ |
| stability in braking | ___ | ___ | ___ |
| stability in collisions | ___ | ___ | ___ |
| ease of adjustment | ___ | ___ | ___ |

2. Rate the new seating device against the existing sledge by scoring each on the following features (+2 is the highest or best score; -2 is the lowest or poorest score).

| | Sledge X | Sledge Y |
|---|---|---|
| lower body fit | +2 +1 0 -1 -2 | +2 +1 0 -1 -2 |
| positioning versatility | +2 +1 0 -1 -2 | +2 +1 0 -1 -2 |
| support | +2 +1 0 -1 -2 | +2 +1 0 -1 -2 |
| comfort | +2 +1 0 -1 -2 | +2 +1 0 -1 -2 |
| protection | +2 +1 0 -1 -2 | +2 +1 0 -1 -2 |
| suitability to the range of activities | +2 +1 0 -1 -2 | +2 +1 0 -1 -2 |
| durability | +2 +1 0 -1 -2 | +2 +1 0 -1 -2 |
| aesthetics | +2 +1 0 -1 -2 | +2 +1 0 -1 -2 |

3. Which features of the sledge would be most important to keep if some had to be eliminated to reduce cost? Rank the features listed below so that 10 is the most important feature to keep and 1 is the least important quality.

| | Rank out of 10 points |
|---|---|
| sitting length adjustment | ______ |
| back angle adjustment | ______ |
| seat angle adjustment | ______ |
| backrest height options | ______ |
| hip support | ______ |
| torso support | ______ |
| head support | ______ |
| cushioning on the seat and backrest | ______ |
| front and rear protective bumpers | ______ |
| footrest/calf support | ______ |

At the end of the season the data collected from structured observation sessions and user surveys should be compiled and analyzed.

The prototype should also be thoroughly examined after two months, four months and after a full season of use. The club should keep a record on wear and tear, repairs and failures for each of the following components:

- frame
- sitting length adjustment clamps
- bumpers
- runners
- seating frame
- back angle adjustment mechanism
- seat angle adjustment mechanism
- seat
- hip support
- 26 cm backrest
- 38 cm backrest
- 60 cm backrest
- foot rest
- calf support
- leg guards
- thoracic support
- neck support
- head rest

The results of the evaluation should indicate whether any changes should be made to the new design and provide a framework of information for decisions regarding trade-offs for cost reduction. Prior to commercial production, the selected manufacturer should be required to produce a pre-production prototype which incorporates the design modifications and changes in production technology, materials or manufacturing processes. After the new seating device has gone into commercial production, customer follow-up should be incorporated to provide feedback on the product's performance.

## 7.2 Trade-offs

Products for the disabled have high costs associated with them for a number of reasons. The products are often highly specialized and the market demand is limited so the products are produced in low volumes. Low volume production usually prohibits the use of mass production technology and as a result the manufacturing process is labour-intensive.

The existing sledge is produced by a small manufacturer in Medicine Hat who sells the product at a price barely covering his own material and labour costs. The founding club in Medicine Hat promotes and distributes the sledges across Canada.

The prototype for the new design was designed and constructed using optimal materials. Cost restrictions were considered in the choice of a modular concept, as well as the choice of the production technology and fabrication processes. There are a number of trade-offs which should be considered to reduce the cost of the product for commercial production:

1. Chrome Moly (4130) is a very expensive material. The cost of the product could be reduced if the frame, seat frame and footrest were made of mild steel tubing instead of Chrome Moly. However, mild steel is not as strong as Chrome Moly and the wall thickness would have to be increased to 0.162 cm in the frame and seat, resulting in a heavier product.

2. The upholstery costs could be reduced by simplifying and changing the expensive removable slip covers to permanent, non-removable covers.

3. To reduce the cost of fabrication, the production of custom parts including the bumpers, frame clamps, adjustment components, and mountings tabs could be contracted out, and purchased in volume. The primary manufacturer would keep an inventory of these parts on hand for production runs.

4. Various aspects of the production could be contracted and done in shops with specialized manufacturing facilities. The seat, optional backrests, hip, thoracic, and head and neck supports could be contracted to an upholstery manufacturer. The tube bending could be contracted to a manufacturer with computerized tube bending equipment.

5. It may be determined through the prototype evaluation that it is too costly to offer the full range of components. Components such as the head rest, neck rest or thoracic support may be eliminated as options, but the club may provide the individuals with the basic design so they can produce the item themselves or have one made for them on a specialty basis. It may be decided that adjustment features can be eliminated to reduce the number of parts and production time.

## 7.3 The Product Cost

The following formula is commonly used in marketing research to estimate the cost of mass produced products [52].

| | | |
|---|---|---|
| material cost: (detailed list of all materials) | $ | ____ |
| labour cost | $ | ____ |
| Total | $ | X |
| administration and general overhead | $ | X |
| price to wholesaler | $ | 2X |
| distribution cost | $ | 2X |
| price to consumer | $ | 4X |

In this case, however, the cost to the consumer should not be as high as 4X and may approach 2X. If the new sledges continue to be produced in low volume by a small manufacturer, the administration and general overhead can be assumed to be lower than X. The Sledge Hockey and Ice Picking Association is a non-profit organization with a mandate to provide opportunities for participation in ice sledging activities. Presently there is no secondary distributor. The Medicine Hat club sells the sledges to clubs and individual consumers. If the club's main concern is increasing participation in the sport the price to the consumer should only increase by the amount the club wishes to recoup for the promotion and distribution of the sledges.

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[52] Fernd Van Engelen, "Trike: Design of a Practical Human Powered Vehicle," The University of Calgary, Faculty of Environmental Design, M.E. Des. Project, 1986, p. 59.

The following is a rough breakdown of the cost of producing the entire seating device prototype including the full range of modular seating components and the running system exactly as it was done in the prototype. Although detailed costing was not done, the revised second estimate shows the expected cost reduction for the full support system and running frame using mild steel instead of Chrome Moly (4130), simplified upholstery, contract production of custom parts, and less expensive paint.

Estimate for production

| | Prototype | Production Models |
|---|---|---|
| o metals and hardware | $ 250.00 | $ 80.00 |
| o custom parts | $ 00.00 | $ 80.00 |
| o metal fabrication | $ 315.00 | $ 250.00 |
| o welding | $ 315.00 | $ 250.00 |
| o spray painting and materials | $ 80.00 | $ 20.00 |
| o upholstery materials | $ 200.00 | $ 100.00 |
| o sewing and upholstery labour | $ 315.00 | $ 150.00 |
| Total | $1375.00 | $ 930.00 |

It should be noted that a club would not purchase the full range of modular components for each sledge. For example, when a new club purchases twelve sledges they may purchase twelve frames and adjustable seating frames, twelve seats and hip supports, but only six hockey backs, four regular backs, two high backs, two torso supports, one headrest extension and one neck support.

It may be possible to further reduce the production costs if the demand warrants larger volume production runs. The cost reduction will vary depending on the volume of production, material costs, labour costs, overhead, distribution costs, and profit margin.

### 7.4 Further Research

A number of areas requiring further research were identified but were beyond the scope of this project. They include the runners, propulsion system, protective equipment, and tandem sledge.

#### 7.4.1 Runners

The prototype provides the option for removing the runners allowing specialized blades to be used for different activities. Further research and experimentation is required to determine the optimal characteristics of runners for hockey, ice picking and racing. In order to enable players to extend their activities and play floor hockey through the summer months a means of attaching small wheels in the place of the rear runners and front skid could also be investigated.

#### 7.4.2 The Picks

The ice picks currently used for sledging are very primitively constructed. Further research on the dynamics of picking and propulsion should be undertaken to develop a new pick which contacts the ice more efficiently, and provides an improved grip, shooting surface and configuration. A number of disabled players currently involved in ice sledging only have the use of one arm and they would benefit from a specialized pick configuration suited to one-armed propulsion.

With the current sledging equipment, braking is achieved by forcing the picks under the frame, lifting up, and jamming the picks in to the ice below. Due to the momentum of the sledge, a great amount of force must be applied to the picks to slow the sledge down at top speeds. These picking and braking techniques are the cause of a lot of ice surface damage. A new braking system could be developed integral to the sledge to reduce ice damage.

### 7.4.3 Protective Equipment

Sledge hockey players with limited upper body mobility and strength would benefit from the development of lightweight protective equipment for shoulders, knees and hands.

### 7.4.4 Tandem Sledge

A special frame configuration could be developed for a new tandem sledge. Maneouverability would improve if a second seating frame were located towards the front of a longer sledge frame. This would bring the weight of the passenger closer to the person picking and facilitate propulsion. A single sledge would be easier to propel as it would have a shorter turning radius than two sledges joined in tandem. A footrest could be incorporated for the pusher on the sides of the passenger's seat.

### 7.4.5 Application to Other Activities

Research should be undertaken to determine if the seating and positioning system developed for ice sledging is applicable to other recreational pursuits including downhill pulking, mono skiing, cross country sledging, and land yachting.

## 7.5 Conclusion

The design concepts for the new seating device for ice sledging were based on current seating research and a human factors investigation of the range of needs of the disabled recreationist who ice sledges. The human factors investigation assessed the individual's needs and provided a framework of information for the design development. The results of the human factors analysis were applied to a particular design problem. A new seating device for ice sledging specifically suited to the needs of mobility-impaired individuals was designed and a prototype was built.

The adjustable seating system provides improved support and accommodates variations in sitting postures. A modular system of components provides improved support for the hips, legs, feet, back, torso, neck and head. The new design provides improved protection and impact resistance, and should improve safety conditions in competitive activities.

It is anticipated that a wider range of disabled individuals will be able to participate in ice sledging activities according to their own abilities. The flexible system enables individuals to optimize their positioning for the range of sledging activities. Improved cushioning and contouring enables the players to comfortably use the sledges for extended periods of time for training and building personal fitness and skills.

This project provided useful human factors data on the special seating and positioning requirements of mobility-impaired recreationists for designers and other professionals who are concerned with the health and rehabilitation of disabled individuals. A set of general seating principles were compiled and a systematic approach is outlined for responding to the positioning needs of disabled recreationists. The design concepts and general principles used in the new seating device can be applied in part, if not directly, to the design of equipment for other recreational pursuits.

# Appendix A: Human Factors Materials

## A.1 Explanatory Letter

Dear Recreationists and Parents/Guardians:

We would like to invite recreationists and/or parents/guardians to give permission for minors/wards to participate in a study on the seating and positioning requirements of physically disabled and able-bodied people who participate in ice sledging. The study will carefully analyze each individual's seating and positioning needs. Factors affecting comfort, support, control and safety will be examined.

Vel Craig, the researcher and designer undertaking this study, is a master's student in the Faculty of Environmental Design at the University of Calgary. She has concentrated three years of graduate study on the design of products for individuals with special needs and has a background in production technology, prototyping and fabrication methods. She has also worked as a contract designer for the Vocational Rehabilitation and Research Institute (Calgary) , and as a technical aids specialist for Transitional Services for Physically Disabled Adults (Calgary).

The purpose of this study is to gather information on the special seating and positioning requirements of mobility-impaired recreationists. The research will be used to design a new recreational seating device for ice sledging that is specifically suited to the needs of physically disabled individuals.

As a result of the research and new seating design, a wider range of disabled will have the opportunity to participate in ice sledging. The new seating design will attempt to provide better support, accommodate variations in sitting postures, and improve safety in competitive activities. By optimizing their positioning, players will be able to improve their performance in recreational and competitive activities. The new seat will permit players to comfortably use the sledges for extended periods of time to train and build personal fitness.

The principles of the new seating design can be applied to other recreational pursuits such as pulking (a form of downhill sled skiing for mobility-impaired), cross country sledging, ice sailing and floor hockey. The information gained from the study will be published in a master's degree document, making valuable information on the positioning and seating available to designers and recreation professionals.

As subjects participating in the study, you and/or your ward will be tested on the ice rink of an indoor arena. In the first sequence of testing the following body measurements will be taken while you are fully clothed: the length of the thigh, lower leg, foot, upper arm and lower arm; total height seated; eye and shoulder level; width of torso and hip when sitting; and the circumference of the torso, thigh and lower leg. Your reach up, forward, downward and backward will be measured. In the second sequence of testing, you will be asked to sit in an adjustable seating device and asked to indicate your preferences for seat height, angle and width; back height and support angle; knee and foot-rest position. The need for any additional support, restraint, cushioning or protection will also be examined. In the third sequence of testing, you will be asked to perform some of the basic movements you regularly perform while ice sledging. If you are able, you will be asked to: transfer into the sledge, grasp the ice pick, push off with the picks, move forward on the ice, move backwards on the ice, turn to the right and left, shoot with the ice picks, break with the picks, and transfer out of the sledge.

Participants in the study will not be involved in competitive activity and will not be exposed to any unusual risks. It is possible, though highly unlikely, that a subject may experience a quick change of position during the adjustment of the seating device. To reduce the possibility of injury or discomfort, qualified helpers and a registered nurse will be on hand to assist participants as they transfer into and out of the seating device and provide support for torso and limbs while the device is being adjusted. As a precautionary measure against a fall on the ice, all participants will be required to wear hockey helmets which will be provided during all test sessions. Parents, guardians and aides are invited to attend the test sessions to monitor the sessions and interpret on the participants' behalf.

A final session will take place later in the season after the data on seating and positioning has been analyzed. At this time you will be asked to evaluate the new seating device. You will be given the opportunity to try out a working model of the new device and evaluate whether it meets your needs. Your comments on the merits of the design and any suggestions you have for improving the product will be welcomed and discussed.

We are looking forward to having you participate in this study and are confident that with your cooperation and input, a seating device can be designed that will meet specialized seating needs and improve opportunities for participation. If you and/or your ward choose to participate in the above study, you have the right to withdraw from the study at any time. The investigator also has the right to terminate the subject's involvement.

If you are interested in participating in the study, indicate your interest and give your written consent by signing the attached Participant Consent Form. A parent or guardian must also sign for participants who are under eighteen years of age, mentally or multiply handicapped. Subjects will be chosen to represent the types of players and range of abilities of individuals who ice-sledge. In the event that you are not selected for this study, we appreciate your interest. Your advice and comments on the design of the new seating device will be gratefully received.

As a separate request, we ask as many participants as possible to agree to be video-taped and photographed during the test sessions. These visual records will enable us to compile the raw data, verify its accuracy and examine important details.

Sincerely,

Dale Taylor, Industrial Design Program Director
Faculty of Environmental Design,
University of Calgary
and

Ms. Velva Lea Craig
Graduate Student

## A.2 Participant Consent Form

- I/we the undersigned hereby consent to the participation of __________________________________ in study on seating and
(participant's name)
positioning requirements for ice sledging.

- I/we have consulted my/our family physician as to my/our fitness to participate in the described testing.

- I/we have read and understand the letter dated ______________ signed by Professor Dale Taylor and agree that the University of Calgary and/or researcher will be wholly absolved from any legal liability in the event of any accident or injury during or as a result of the test sessions or procedures described.

- I/we the undersigned agree to be be/or to have my child or ward photographed and video-taped during the test sessions.

___________________________ Date __________________
(participant's signature)

___________________________ Date __________________
(parent/guardian's signature)

## A.3 Photographic Release Form

- I/we the undersigned hereby consent to the publication of the selected photograph(s), slide(s) and videotaped sequences of ______________________ in
  (participant's name)
  the master's degree document.

- I/we the undersigned hereby consent to the use of the selected photograph(s), slide(s) and videotaped sequences in presentations to groups of individuals interested in the health and rehabilitation of the disabled, or manufacturers interested in producing the new seating device.

______________________ Date ____________
(participant's signature)

______________________ Date ____________
(parent/guardian's signature)

## A.4 Subject Information

If you are interested in participating in the study on seating and positioning for ice sledging, please provide the researcher with the following information by filling out this form and returning it with your Participation Consent Form.

Age ____________ o male o female

Disability ________________________________________

What ice-sledging activities do you participate in?

o sledge hockey

o ice picking

o recreational sledging

o racing

o tandem sledging

Which term best describes your physical capacity for ice sledging?

o able bodied

o good upper body mobility

o limited upper body mobility

o poor upper body mobility

o non mobile

## A.5 Human Factors Data Sheet

(A) SUBJECT DATA

Subject's Name: ______________________________

Age: ____________ Sex: o Male o Female

Disability: ______________________________

Player Activities:
- o Sledge Hockey
- o Racing
- o Ice Picking
- o Tandem Sledging
- o Recreational sledging
- o Passenger
- o Outdoor sledging
- o Picker

Physical Capacity:
- o Able-bodied
- o Poor Upper Body Mobility
- o Good Upper Body Mobility
- o Non Mobile
- o Limited Upper Body Mobility

SPECIAL CONDITIONS:

o Spastic Movement ______________________________

o Lack of Coordination ______________________________

o Limited Sensation ______________________________

o Body Proportions ______________________________

o Limited Flexation
- Hip ______________________________
- Knee ______________________________
- Foot ______________________________
- Trunk ______________________________
- Arm ______________________________
- Hand ______________________________
- Ankle ______________________________

o Other ______________________________

(B) ANTHROPOMETRICS

| | | | |
|---|---|---|---|
| Sitting Height | ____________ | Shoulder Width | ____________ |
| Eye Level | ____________ | Torso Width | ____________ |
| Shoulder Level | ____________ | Upper Arm Length | __________ |
| Armpit Level | ____________ | Lower Arm Length | _________ |
| Thigh Length | ____________ | Arm Length | ____________ |
| Lower Leg Length | __________ | Torso Restraint Length | _______ |
| Thigh Height | ____________ | Hip Restraint Length | _______ |
| Sitting Length | ____________ | Thigh Restraint Length | _______ |
| Sitting Width | ____________ | Ankle Restraint Length | _______ |
| Knee Width | ____________ | Foot Length | ______________ |
| | | Foot Width | ______________ |

(C) TEST SLEDGE MEASUREMENTS:

Method of Transfer ________________________________________

Level of Back Support Required

- o Sacrum
- o Lumbar
- o Thoracic
- o Shoulder
- o Head
- o Independent/None

| | | | |
|---|---|---|---|
| Back Angle | ____________ | Foot Support Angle | ____________ |
| Seat Height | ____________ | Hip Support Width | ____________ |
| Seat Angle | ____________ | Head Support Height | ____________ |
| Thoracic Support Height | ____________ | | |
| Torso Restraint | _______ | Cushioning | o Seat |
| Hip Restraint | _________ | | o Hips |
| Leg Restraint | _________ | | o Back |
| Foot Restraint | _________ | | o Head |

Additional Modification ________________________________________

(D) PICK REQUIREMENTS:

Pick Type: o Standard o Quad

Pick Control Right Hand ______________________

Left Hand ______________________

General Comments:

______________________________________________

(E) SAFETY:

HAVE YOU EVER BEEN HURT WHILE ICE SLEDGING?

o Yes o No

How were you hurt?

o By another's sled

o Contacting the board

o By the ice picks

o Other; Explain: ______________________

______________________________________________

Where were you hurt?

______________________________________________

______________________________________________

## Appendix B: Subject Data

Table B.1 Age, Sex, Upper Body Mobility and Player Activities

| Subject | Sex | Age | Mobility: Ex | G | L | P | N | Player Activities: J | S | I | RS | R | T1 | T2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | F | 40 | | | X | | | | | X | X | X | X | |
| 2 | M | 31 | | | X | | | | X | | X | | | |
| 3 | M | 10 | | | | | X | | | | | | | X |
| 4 | F | 43 | | X | | | | | | X | | | | |
| 5 | M | 22 | | | | X | | | | | X | | | |
| 6 | M | 11 | | X | | | | X | | X | X | X | X | |
| 7 | M | 15 | | | | X | | | | | X | | | X |
| 8 | M | 19 | X | | | | | | X | | | X | | |
| 9 | M | 11 | X | | | | | X | | | X | | | |
| 10 | M | 30 | | | X | | | | X | | | | | |
| 11 | F | 38 | | X | | | | | | X | X | | X | |
| 12 | M | 23 | | | | X | | | | | X | | | |
| 13 | M | 45 | | X | | | | | X | | X | X | | |
| 14 | M | 11 | | | X | | | | | X | X | | | |
| 15 | M | 10 | | | | | X | | | | | | | X |
| 16 | M | 13 | | X | | | | X | | X | X | X | | |
| 17 | M | 23 | | | | X | | | | X | | | | |
| 18 | F | 13 | | | X | | | | | X | | | | |
| 19 | M | 46 | | X | | | | | X | | | X | | |
| 20 | M | 21 | | X | | | | | X | | | X | | |
| TOTAL: | 4F<br>16M | min10<br>max46<br>range36 | 2 | 7 | 5 | 4 | 2 | 3 | 6 | 8 | 11 | 7 | 3 | 3 |

Mobility:

Ex= excellent upper body mobility
G = good upper body mobility
L = limited upper body mobility
P = poor upper body mobility
N = non mobile

Player Activities:

J = junior sledge hockey
S = senior sledge hockey
I = ice picking
RS= recreational sledging
R = racing
T1= tandem sledging-picker
T2= tandem sledging-passenger

Table B.2 Special Conditions

| Subject | Special Conditions |
|---|---|
| 1 | Visually impaired/back brace interferes with backrest |
| 2 | Spastic movement affects upper body control/limited flexibility (R&L) ankles |
| 3 | Scoliosis: (L) shoulder & hip higher/limited flexibility (L) arm & leg/spastic movement/ no functional movement/large head |
| 4 | Limited hip flexibility/(R&L) hip dislocation/arthritis (R) arm & shoulder |
| 5 | Limited upper body control/limited flexibility wrists & ankles/limited flexibility (L&R) knees |
| 6 | (L) leg is longer & brace blow knee/(R) leg brace to hip |
| 7 | Scoliosis leans to left/very limited use of (R) arm/ (R) leg shorter by 5 cm. |
| 8 | Very slight lack of coordination. |
| 9 | None. |
| 10 | Spine fused/limited arm movement/very large head. |
| 11 | Limited flexibility (R) hip, knee, (L) arm & hand. |
| 12 | Only able to use left arm. |
| 13 | No flexibility (R) foot & ankle. |
| 14 | No sensation below arm pits/limited flexibility in spine, hip, knee/legs splay outward when sitting. |
| 15 | No functional movement/very limited flexibility in legs. |
| 16 | Slight incoordination. |
| 17 | Only able to use left arm/right leg & arm paralyzed. |
| 18 | Disproportionately short arms, left arm stronger/limited flexibility fingers, wrists, elbows, shoulders, ankles. |
| 19 | Left leg amputated at hip. |
| 20 | Limited hip, knee & ankle flexibility, pressure sore on ischia, lump due to spinal cord injury mid-back. |

Table B.3 Anthropometric Measurements

| Subject | Sitting Height | Eye Level | Shoulder Level * | Armpit Level | Thigh Length * | Lower Leg Length * | Thigh Height * |
|---|---|---|---|---|---|---|---|
| 1 | 88.5 | 77.5 | 62 | 51 | 40 | 42 | 19 |
| 2 | 74 | 69 | 51 | 41 | 37 | 39 | 14.5 |
| 3 | 70 | 55 | 42 | 35 | 35 | 36 | 13 |
| 4 | 86 | 76.5 | 60 | 47.5 | 41 | 42 | 15.5 |
| 5 | 76.5 | 68.5 | 48 | 34 | 37.5 | 41 | 19 |
| 6 | 71 | 61.5 | 48.5 | 40 | 35.5 | 30 | 11.5 |
| 7 | 67 | 57 | 44 | 29 | 38 | 37 | 12 |
| 8 | 91 | 81 | 60.5 | 53 | 48 | 43.5 | 18 |
| 9 | 69 | 60 | 45 | 37 | 34 | 35.5 | 12.5 |
| 10 | 82 | 70.5 | 56 | 42 | 39 | 39 | 18 |
| 11 | 83 | 70 | 55.5 | 40 | 35.5 | 39/38 | 14 |
| 12 | 85 | 75.5 | 57 | 39.5 | 43 | 48 | 16 |
| 13 | 91 | 80 | 61 | 45 | 46.5/44 | 47/41 | 16/14 |
| 14 | 66 | 50.5 | 39.5 | 30 | 29.5 | 30 | 14.5 |
| 15 | 60 | 51 | 40 | 33 | 27 | 24.5 | 8 |
| 16 | 64 | 54 | 41 | 39 | 34 | 34 | 12 |
| 17 | 85.5 | 75.5 | 56.5/54.5 | 45 | 40/37 | 42/37.5 | 18 |
| 18 | 83 | 71 | 54 | 47.5 | 36/37.5 | 40 | 15 |
| 19 | 82.5 | 71.5 | 57 | 44 | 39.5 | 45 | 19 |
| 20 | 89.5 | 79.5 | 62 | 51.5 | 40 | 44 | 12 |
| Min: | 60 | 51 | 39.5 | 29 | 27 | 24.5 | 8 |
| Max: | 91 | 81 | 62 | 53 | 48 | 48 | 19 |
| Range: | 31 | 30 | 22 | 24 | 21 | 23.5 | 11 |

* two measurements were taken when the subject indicated that one side differed from the other. The first measurement given is the left and second for the right side.

Table B.3 Anthropometric Measurements, (cont'd)

| Subject | Sitting Length | Sitting Width | Knee Width | Shoulder Width | Torso Width | Upper Arm Length * | Lower Arm Length * | Arm Length * |
|---|---|---|---|---|---|---|---|---|
| 1 | 109 | 46 | 34 | 37 | 40 | 29 | 25.5 | 51.5 |
| 2 | 92 | 33 | 28 | 33.5 | 29 | 29 | 25 | 53 |
| 3 | - | 29.5 | 24 | 28 | 25.5 | - | - | - |
| 4 | 111 | 44.5 | 30.5 | 37.5 | 35 | 32 | 27 | 57 |
| 5 | 116 | 32 | 21 | 35 | 26 | 30 | 25 | 50 |
| 6 | 89 | 31 | 28 | 33.7 | 27.5 | 24 | 22.5 | 44 |
| 7 | 90 | 27 | 20 | 30.5 | 23.5 | 24 | 23.5 | 43 |
| 8 | 117 | 37 | 25.5 | 37 | 33 | 27.5 | 22.5 | 49 |
| 9 | 90 | 26 | 19 | 28.5 | 22.5 | 23.5 | 21.5 | 44 |
| 10 | 103 | 35 | 23 | 32 | 29 | 29 | 26 | 57 |
| 11 | 100 | 38 | 25 | 33 | 30 | 24.5 | 23 | 46 |
| 12 | 126 | 41.5 | 26 | 40 | 33 | 27.5 | 29 | 54 |
| 13 | 118/115 | 37 | 23.5 | 39.5 | 32 | 28 | 28.5 | 53 |
| 14 | 87 | 42 | 53 | 31 | 31.5 | 25 | 21.5 | 43 |
| 15 | 60 | 23 | 23 | 27 | 25 | 20 | 16.5 | 37 |
| 16 | 94 | 28 | 41 | 33.5 | 27 | 22 | 22 | 43 |
| 17 | 116 | 39 | 40.5 | 36 | 32 | 26.5/24 | 20/23 | 53.5/47 |
| 18 | 103.5 | 36.5 | 25 | 30.5 | 27.5 | 23/19 | 24.5/21 | 40.5/35.5 |
| 19 | 113 | 42 | 15 | 41 | 41 | 30 | 27 | 55.5 |
| 20 | 115 | 36.5 | 26.5 | 41.5 | 33.5 | 31 | 26 | 57.6 |
| Min: | 60 | 23 | 15 | 27 | 22.5 | 20 | 16.5 | 37 |
| Max: | 126 | 46 | 53 | 41 | 41 | 30 | 28.5 | 57.6 |
| Range: | 66 | 23 | 30 | 14 | 16 | 10 | 12 | 20.6 |

* two measurements were taken when the subject indicated that one side differed from the other. The first measurement given is the left and second for the right side.

Table B.3 Anthropometric Measurements, (cont'd)

| Subject | Torso Rest. Length | Hip Rest. Length | Thigh Rest. Length | Ankle Rest. Length | Foot Length | Foot Width |
|---|---|---|---|---|---|---|
| 1 | 92 | 95 | 77 | 41 | 27 | 11 |
| 2 | 85 | 62 | 54 | 49 | 27 | 10 |
| 3 | 72 | 79 | 69 | 50 | 20 | 8 |
| 4 | 74 | 84 | 67.5 | 49 | 27 | 10 |
| 5 | 70 | 63 | 64 | 43 | 28.5 | 9.5 |
| 6 | 61 | 63 | 50 | 42 | 21.5 | 8.5 |
| 7 | 56 | 58 | 46 | 39 | 22 | 8.5 |
| 8 | 68 | 67 | 64 | 54 | 29.5 | 10.5 |
| 9 | 48 | 45 | 46 | 46 | 24 | 8.5 |
| 10 | 70 | 71 | 60 | 49 | 27.5 | 9.5 |
| 11 | 64 | 73 | 61 | 47 | 25.5 | 9.5 |
| 12 | 78 | 79 | 67 | 49 | 30 | 10.5 |
| 13 | 69 | 78 | 64 | 51 | 31 | 10.5 |
| 14 | 70 | 79 | 64 | 42 | 22.5 | 8 |
| 15 | 48 | 55.5 | 42 | 33 | 20 | 7 |
| 16 | 60 | 53 | 59 | 37 | 25 | 10 |
| 17 | 68 | 79 | 68 | 44 | 28 | 10 |
| 18 | 62.5 | 73 | 61 | 52 | 25.5 | 10 |
| 19 | 90.5 | 90 | 50 | 38 | 31 | 11 |
| 20 | 61 | 60 | 49 | 50 | 31 | 11 |
| Min: | 48 | 53 | 42 | 33 | 20 | 7 |
| Max: | 92 | 95 | 77 | 54 | 31 | 11 |
| Range: | 44 | 42 | 35 | 21 | 11 | 4 |

Table B.4 Test Sledge Measurements

| Subject | Level of Back Support: S* | L | T | H | Back Support Height | Back Angle | Seat Height | Seat Angle | Back to Seat Angle |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | X | | | 38 | 65 | 11.5 | 10 | 105 |
| 2 | | X | | | 38 | 76 | 11.5 | 0 | 104 |
| 3 | | | | X | 60 | 45 | 11.5 | 20 | 115 |
| 4 | | X | | | 38 | 75 | 11.5 | 5 | 100 |
| 5 | | X | | | 38 | 68 | 13.5 | 15 | 97 |
| 6 | X | | | | 20 | 74 | 13.5 | 5 | 101 |
| 7 | | | X | | 38 | 75 | 11.5 | 0 | 105 |
| 8 | X | | | | 20 | 75 | 13.5 | 0 | 105 |
| 9 | X | | | | 20 | 76 | 11.5 | 15 | 89 |
| 10 | X | | | | 29 | 80 | 13.5 | 12.5 | 87.5 |
| 11 | | X | | | 38 | 78 | 11.5 | 0 | 102 |
| 12 | | | X | | 60 | 65 | 11.5 | 15 | 100 |
| 13 | X | | | | 27.5 | 70 | 13.5 | 0 | 110 |
| 14 | | X | | | 38 | 85 | 11.5 | 0 | 95 |
| 15 | | | | X | 60 | 65 | 11.5 | 20 | 95 |
| 16 | | X | | | 38 | 69 | 11.5 | 15 | 96 |
| 17 | | X | | | 38 | 57 | 11.5 | 15 | 108 |
| 18 | | X | | | 38 | 70 | 11.5 | 15 | 95 |
| 19 | X | | | | 29.5 | 75 | 13.5 | 0 | 105 |
| 20 | | X | | | 38 | 70 | 13.5 | 0 | 110 |
| Total: | 6 | 10 | 2 | 2 | | | | | |
| Min: | | | | | 20 | 45 | 11.5 | 0 | 87.5 |
| Max: | | | | | 60 | 85 | 13.5 | 20 | 115 |
| Range: | | | | | 45 | 40 | 2.5 | 20 | 27.5 |

* S= Sacrum; L= Lumbar; T= Thoracic; H= Head.

Table B.4 Test Sledge Measurements, cont'd

| Subject | Hip Support Width * | Foot Support Angle | Sitting Length | Thoracic Support Height | Thoracic Support Width | Head Support Height |
|---|---|---|---|---|---|---|
| 1 | 45 | 10 | 100.5 | - | - | - |
| 2 | 33 | 23 | 89.5 | - | - | - |
| 3 | 29.5 | 35 | 79.7 | 32.5 | 26 | 60 |
| 4 | 42 | 7 | 106.5 | - | - | - |
| 5 | 32 | 31 | 93.5 | - | - | - |
| 6 | 31 | 5 | 96 | - | - | - |
| 7 | 29 | 20 | 91.5 | 29 | 24 | - |
| 8 | 37 | 20 | 105 | - | - | - |
| 9 | 26 | 22 | 81.5 | - | - | - |
| 10 | 36 | 24 | 93.5 | - | - | - |
| 11 | 37 | 15 | 91.5 | - | - | - |
| 12 | 39 | 18 | 104 | 41 | 33 | - |
| 13 | 37 | 12 | 107.5 | - | - | - |
| 14 | 34 r | 3 | 91.5 | - | - | - |
| 15 | 25 | 36 | 52.5 | 30 | 25 | 53 |
| 16 | 27 r | 23 | 84 | - | - | - |
| 17 | 39 | 15 | 99 | - | - | - |
| 18 | 35 | 27 | 95 | - | - | - |
| 19 | 39.5 | 19 | 99.3 | - | - | - |
| 20 | 36.5 | 25 | 103.8 | - | - | - |
| Min: | 25 | 3 | 52.5 | 29 | 24 | 53 |
| Max: | 45 | 36 | 107.5 | 41 | 33 | 60 |
| Range: | 20 | 33 | 55 | 12 | 9 | 7 |

Note: r= measurements taken at rear edge of hip support

Table B.4 Test Sledge Measurements,
(cont'd)

| Subject | Restraint Requirement Torso | Hip | Leg/ Knee | Foot | Cushioning Requirement Seat | Hip | Back | Head |
|---|---|---|---|---|---|---|---|---|
| 1 | | X | | X | X | | X | |
| 2 | | X | | X | X | | X | |
| 3 | X | X | X | X | X | X | X | X |
| 4 | | X | | X | X | X | X | |
| 5 | | X | | X | X | | X | |
| 6 | | X | | X | X | X | X | |
| 7 | X | X | | X | X | X | X | |
| 8 | | X | | X | X | X | X | |
| 9 | | X | | X | X | | X | |
| 10 | | X | | X | X | X | X | |
| 11 | | X | | X | X | | X | |
| 12 | X | X | X | X | X | | X | |
| 13 | | X | | X | X | X | X | |
| 14 | | X | | X | X | X | | |
| 15 | X | X | X | X | X | X | X | X |
| 16 | | X | | X | X | | X | |
| 17 | | X | | X | X | | X | |
| 18 | | X | | X | X | | X | |
| 19 | | X | | X | X | X | X | |
| 20 | | X | X | X | X | X | X | |
| Total: | 4 | 20 | 4 | 20 | 20 | 11 | 19 | 2 |

Table B.5 Test Sledge Modification

| Subject | Individual Sledge Modifications |
|---|---|
| 1 | Foam wedge/2 extra layers of foam added to backrest/ 1 extra layer foam added to seat. |
| 2 | Footrest angle 112. |
| 3 | Footrest angle 110/deeper sides on footrest to contain feet/(L) wrist restraint/support to contain movement/deeply contoured head rest to allow spastic movement/could have used greater seat angle (30). |
| 4 | 3 cm block under (R) foot and 1 cm block under (L) to compensate for leg length variation. |
| 5 | 1 extra layer of foam for seat. |
| 6 | Must sit with legs almost straight due to braces. |
| 7 | None |
| 8 | None |
| 9 | None |
| 10 | Would prefer a backrest level between 20 and 38 cm for higher sacrum support. |
| 11 | None |
| 12 | Stronger thoracic support/wider back/knee restraint/longer seat (35-40 cm) in length/1 extra layer foam on seat. |
| 13 | Slightly higher sacrum support (275 cm)/would prefer backrest between 20 and 38 cm. |
| 14 | Required hip support which was wider at front than rear (34 rear) (40 front)/required a flat cushioned kneeboard to support and protect splayed knees. |
| 15 | 2 extra layers 5 cm foam on seat/deeply contoured headrest (width 15 cm, depth 11 cm, height 15 cm) to contain head while allowing movement/additional foam beside legs/ could have used greater seat angle. |
| 16 | None |
| 17 | None |
| 18 | None |
| 19 | Would prefer a backrest height (29.5 cm)/longer seat (40 cm) in length/cushioning important for left hip. |
| 20 | Required additional foam on seat/required additional foam on backrest to protect lump on spine. |

Notes: In some cases a seat angle was essential to prevent subjects from sliding/slumping in seat.

Table B.6 Pick Requirements

| Subject | Pick Requirements |
|---|---|
| 1 | Standard |
| 2 | Improved pick-ice contact (standard) |
| 3 | N/a - no functional arm movement |
| 4 | Standard |
| 5 | Improved pick-ice contact/improved grip (standard) |
| 6 | Improved puck control (standard) |
| 7 | Improved pick-ice contact/ improved grip (quad) |
| 8 | Improved puck control (standard) |
| 9 | Standard |
| 10 | Improved puck control (standard) |
| 11 | Standard |
| 12 | Improved pick-ice contact/improved grip (quad) |
| 13 | Standard |
| 14 | Improved pick-ice contact/improved grip (quad) |
| 15 | N/a - no functional arm movement |
| 16 | Standard |
| 17 | Improved pick-ice contact/improved grip (quad) |
| 18 | Improved pick-ice contact/improved grip (quad) |
| 19 | Standard |
| 20 | Standard/improved puck control |

Types of pick improvement needed: Ice contact: 7
Grip: 6
Puck control: 4

Table B.7 Equipment Needs

| Subject | Equipment Needs |
|---|---|
| 1 | Requires an auditory puck for ice hockey. |
| 2 | Improved hand protection for hockey. |
| 3 | Tandem sledge which is easier for picker to propel, and larger helmet. |
| 4 | Protection for outside of knees, shoulders, hands. |
| 5 | A means of guiding/controlling pick movement. |
| 6 | Improved hand protection. |
| 7 | A means of propelling sledge using only (L) arm/a means of guiding/controlling pick movement. |
| 8 | Body protection for areas which contact boards. |
| 9 | None |
| 10 | Larger helmet/protection from ice pick scratches/body protection for areas which contact boards. |
| 11 | None |
| 12 | A means of propelling sledge using only (L) arm. |
| 13 | Ability to modify/change backrest and blades for hockey or racing. |
| 14 | Larger helmet. |
| 15 | Tandem sledge which is easier for picker to propel. |
| 16 | None |
| 17 | None |
| 18 | None |
| 19 | None |
| 20 | None |

Types of equipment improvements needed:

| | |
|---|---|
| Hand protection: | 3 |
| Body protection: | 3 |
| Helmet: | 3 |
| One arm propulsion: | 2 |
| Pick control: | 2 |
| Tandem: | 2 |
| Modify for racing: | 1 |
| Auditory puck: | 1 |

## Appendix D: Parts List

| Components and Sub-Assemblies / Parts | | Quantities | Materials |
|---|---|---|---|
| 1. Running Base | | | |
| 1.1 rear frame | | 1 | 1.9 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| 1.1.1 | rear bumper | 1 | 1.27 cm thick medium density rubber 1.9 cm I.D. x 5.7 cm O.D. disks |
| 1.1.2 | frame length adjustment guides | 2 | 2.2 cm O.D. x 0.09 cm wall thickness 4130 tubing 0.041 cm thick teflon liner |
| 1.1.3 | cross brace | 1 | 1.27 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| 1.1.4 | adjustment clamp * | 2 | mild steel bar |
| 1.1.5 | seat mount tabs * | 2 | 0.28 cm mild steel plate |
| 1.1.6 | 0.64 cm x 2.54 cm hex cap screws | 2 | steel |
| 1.1.7 | 0.64 cm I.D. x 1.9 cm O.D. washers | 2 | steel |
| 1.1.8 | runner guides | 2 | 1.27 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| 1.2 front frame | | 1 | 1.9 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| 1.2.1 | front skid | 1 | 1.27 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| 1.2.3 | front bumper | 1 | 1.27 cm thick medium density rubber 1.9 cm I.D. x 5.7 cm O.D. disks |
| 1.2.4 | foot rest mount tabs * | 2 | 0.28 cm mild steel plate |
| 1.2.5 | cross brace | 1 | 1.27 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| 1.2.6 | tubing plugs | 2 | mild steel |
| 1.3 removable rear runners * | | 2 | 1.27 cm O.D. x 0.09 cm wall thickness 4130 tubing 1.6 cm x 0.35 cm hardened steel bar + 1.27 cm angle iron |
| 1.3.1 | rear runner * mount | 2 | 1.27 cm angle iron, 1.27 cm sq steel tubing, 0.64 cm x 3.2 cm hex cap screw |
| 1.3.2 | 0.64 cm dia nuts | 2 | steel |
| 1.3.3 | 0.64 cm I.D. x 1.9 cm O.D. washers | 2 | steel |
| 2. Support System | | | |
| 2.1 seat frame | | 1 | |
| 2.1.1 | seat support base | 1 | 1.27 cm O.D. x 0.09 cm wall thickness 4130 tubing 1.9 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| | 2.1.1.1 threaded tubing plugs * | 2 | 0.64 cm N.C. thread x 1.717 cm O.D. mild steel |
| | 2.1.1.2 seat mounting tabs * | 2 | 0.28 cm mild steel plate |
| | 2.1.1.3 tubing plugs | 2 | 1.7 cm O.D. mild steel |
| 2.1.2 | seat angle adjustment mechanism | 1 | 3.2 cm O.D. x .124 wall thickness mild steel tubing, 0.64 cm x 6.35 cm hex cap screw |
| | 2.1.2.1 adjustment sliders * | 2 | 2.2 cm O.D. x 0.09 cm wall thickness 4130 tubing 0.28 cm mild steel plate, 0.09 cm thick teflon liner |
| | 2.1.2.2 threaded tubing plugs * | 2 | 0.64 cm I.D. x 2.849 cm O.D. mild steel |
| | 2.1.2.3 0.64 cm x 1.9 cm hex cap shoulder screws * | 2 | steel |
| | 2.1.2.4 0.64 cm I.D. x 1.9 cm O.D. washers | 2 | steel |
| | 2.1.2.5 0.64 cm I.D. 3.2 cm O.D. washers | 2 | steel |
| | 2.1.2.6 channel bolt * | 1 | 0.28 cm mild steel, 0.64 cm x 2.54 cm hex cap screw |
| | 2.1.2.7 threaded knob | 1 | 0.64 cm thread |
| | 2.1.2.8 0.64 cm I.D. x 1.9 cm O.D. washer | 1 | steel |

| Components and Sub-Assemblies Parts | | Quantities | Materials |
|---|---|---|---|
| 2.1.3 | pivoting back support | 1 | 1.9 cm O.D. x 0.09 cm wall thickness 4130 tubing, 2.2 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| | 2.1.3.1 backrest mounting tabs * | 2 | 0.28 cm mild steel |
| | 2.1.3.2 backrest mounting clip | 1 | 0.64 cm O.D. x 0.09 cm wall thickness mild steel tubing, 0.158 cm mild steel plate |
| 2.1.4 | backrest adjustment mechanism | 1 | 3.2 cm O.D. x 0.124 cm wall thickness mild steel tubing |
| | 2.1.4.1 adjustment sliders * | 2 | 1.9 cm O.D. x 0.09 cm wall thickness 4130 tubing, 0.28 cm mild steel plate, 0.041 cm thick teflon liner |
| | 2.1.4.2 threaded tubing plugs * | 2 | mild steel 0.64 cm N.C. thread x 2.849 cm O.D. |

| Components and Sub-Assemblies Parts | | Quantities | Materials |
|---|---|---|---|
| | 2.1.4.3 0.64 cm x 1.9 cm hex cap shoulder screws * | 2 | steel |
| | 2.1.4.4 0.64 cm I.D. x 1.9 cm O.D. washers | 2 | steel |
| | 2.1.4.5 0.64 cm I.D. x 3.2 cm O.D. washers | 2 | steel |
| 2.2 seat | | | |
| 2.2.1 | curve ply base | 1 | 0.64 cm thick curve ply with fir reinforced edges |
| 2.2.2 | 0.64 cm dia t-nuts | 2 | steel |
| 2.2.3 | laminate wedge cushion | 1 | high density rebond base, 3.0 cm thick low density polyurethane foam top layer |
| 2.2.4 | cordura seat cover | 1 | cordura, 5.08 cm velcro hook + loop, 2.54 cm velcro hook + loop |
| 2.2.5 | 0.64 cm x 2.54 cm hex cap screws | 2 | steel |
| 2.3 hip support | | | |
| 2.3.1 | foam padding | 2 | 1.27 cm thick high density ensolite foam |
| 2.3.2 | adjustment strap | 1 | 5.08 cm webbing, 5.08 cm velcro hook + loop |
| 2.3.3 | 6 cm slider | 1 | steel |
| 2.3.4 | cordura + lycra hip support cover | 1 | cordura outside panel, lycra inside panel, 5.08 cm velcro hook + loop |
| 2.4 hip restraint | | | |
| 2.4.1 | buckle | 1 | quick release automative type buckle for 5.08 cm webbing |
| 2.4.2 | seat belt | 1 | 5.08 cm webbing |
| 2.4.3 | seat belt anchors | 2 | 0.28 cm mild steel |
| 2.5 regular backrest: 26 cm wide x 35 cm high | | | |
| 2.5.1 | curve ply base | 1 | 0.64 cm thick curve ply with maple dowel edge reinforcement |
| 2.5.2 | 0.64 cm dia t-nuts | 2 | steel |
| 2.5.3 | laminate cushion | 1 | 1.27 cm thick high density rebond base, 3.0 cm thick low density polyurethane foam top layer |
| 2.5.4 | cordura regular backrest cover | 1 | cordura, 2.54 cm velcro hook + loops |
| 2.6 hockey backrest: 26 cm wide x 23 cm high | | | |
| 2.6.1 | curve ply base | 1 | 0.64 cm thick curve ply with maple edge reinforcement |
| 2.6.2 | 0.64 cm dia t-nuts | 2 | steel |
| 2.6.3 | laminate wedge cushion | 1 | high density rebond base, 3.0 cm thick low density polyurethane foam top layer |

| Components and Sub-Assemblies Parts | Quantities | Materials |
|---|---|---|
| 2.6.4 cordura hockey backrest cover | 1 | cordura, 2.54 cm velcro hook + loop |
| 2.7 full backrest: 30 cm wide x 57 cm high | | |
| 2.7.1 curve ply base | 1 | 0.64 cm thick curve ply with maple edge reinforcement |
| 2.7.2 0.64 cm dia t-nuts | 4 | steel |
| 2.7.3 laminate cushion | 1 | 1.27 cm thick high density rebond base, 3.0 cm thick low density polyurethane foam top layer |
| 2.7.4 cordura full backrest cover | 1 | cordura, 2.54 cm velcro hook + loop |
| 2.8 footrest | | |
| 2.8.1 footrest plate | 1 | 0.158 cm steel mesh, 0.64 cm O.D. x 0.09 cm wall thickness tubing |
| 2.8.2 calf rest supports | 2 | 0.9 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| 2.8.3 pivot bar | 1 | 1.9 cm O.D. x 0.09 cm wall thickness 4130 tubing |
| 2.8.4 threaded tubing plugs * | 2 | 0.64 cm N.C. thread x 1.717 cm O.D. mild steel |
| 2.8.5 foot restraint | 1 | |
| 2.8.5.1 adjustment strap | | 5.08 cm webbing |
| 2.8.5.2 6 cm slider | | mild steel |
| 2.8.5.3 snap fasteners | | |
| 2.9 calf support | | |
| 2.9.1 cordura cover | | cordura |
| 2.9.2 adjustment strap | | 5.08 cm webbing, velcro hook + loop |
| 2.9.3 padding | | 1.27 cm thick low density polyurethane foam |
| 2.10 calf guards | | |
| 2.10.1 cordura cover | | cordura |
| 2.10.2 padding | | 1.27 cm thick ensolite |
| 2.11 thoracic support | | |
| 2.11.1 foam padding | 2 | 1.27 cm thick high density ensolite foam |
| 2.11.2 cordura + lycra cover | 1 | cordura outside panel, lycra inside panel |
| 2.11.3 adjustable torso strap | 1 | 5.08 cm webbing, 5.08 cm velcro hook + loop |
| 2.11.4 5.7 cm slider | 1 | steel |
| 2.11.5 adjustable shoulder straps | 2 | 5.08 cm webbing |
| 2.11.6 buckles | 2 | Fastex buckles for 5.08 cm webbing |
| 2.12 headrest | | |
| 2.12.1 curve ply base | 1 | 0.64 cm thick curve ply |
| 2.12.2 laminate wedge cushion | 1 | high density rebond wedge, 1.27 cm thick low density polyurethane foam |
| 2.12.3 cordura headrest cover | 1 | cordura, 2.54 cm velcro hook + loop, 5.08 cm velcro hook + loop |
| 2.12.4 0.64 cm dia t-nuts | 2 | steel |
| 2.12.5 0.64 cm x 1.27 cm flat head machine screws | 2 | steel |
| 2.12.6 height adjustment bar | 1 | 1.27 cm O.D. x 0.09 cm wall thickness 4130 tubing, 0.158 cm mild steel plate |
| 2.12.7 0.64 cm I.D. x 3.0 cm O.D. washers | 4 | steel |
| 2.12.8 0.64 cm x 2.54 cm hex cap screws | 2 | steel |
| 2.13 neck support | | |
| 2.13.1 cordura cover | 1 | cordura, 2.54 cm velcro hook + loop, 5.08 cm velcro hook + loop |
| 2.13.2 laminate contoured cushion | 1 | high density rebond, 1.27 cm thick low density polyurethane foam |

Finish: metal frame, runners, seat frame and footrest are spray painted with Endura, American motors 1985, MFR Code 4C, Dupont Code B8452.

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