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Effect of sledge hockey configuration on sledge hockey performance

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Abstract

The purpose of this study was to evaluate the position of a sledge hockey player in their sledge using measurements of knee angle, seat height, and stability. Prior to this study, sledge hockey coaches and athletes used trivial methods to position a player in their seat. Proper positioning can enhance performance and function of the athlete. Nine different positions were evaluated using two on-ice sledge hockey specific tests. Four experienced male sledge hockey players from the London Blizzard who compete in the Ontario Sledge Hockey Association participated in this study. The results suggest a knee angle of 140º with a medium knuckle height produced on average the fastest times ($p<0.05$). This study provides recommendations for current coaches and players, for achieving biomechanically efficient position of a player in the sledge, using on-ice sledge hockey specific tests.

Keywords: ice sledge hockey, adaptive sport, Paralympics, seat height, postural stability, Hockey Canada, time motion analysis

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Chapter 1

1 Introduction

The Paralympics is the highest level of competition for an athlete with a disability, and has expanded to include many different sports such as wheelchair athletics, wheelchair rugby, and wheelchair basketball. The Winter Paralympics began in 1976, with sledge hockey becoming an official Paralympic sport in 1994. Sledge hockey is an adaptive form of ice hockey used for athletes who have a disability which could be from limb loss, spinal cord injury, or a condition such as cerebral palsy.

Currently there has been very little research done on the sport of sledge hockey. Literature is scarce so learning about biomechanical, physiological, or the history of the sport, is acquired from coaches and players experience. Laurie Howlett, owner of Unique Inventions a leading manufacturer of hockey sledges, estimates there are about 10,000 sledge hockey players in the world (L. Howlett, personal communication, February 23, 2011). Todd Sargeant, the coach of the Canadian Junior National Sledge Hockey team, estimates there are 1,000 players in Canada, 400 of which live in Ontario (T. Sargeant, personal communication, September 16, 2010). In comparison, there are approximately 570,000 Canadians that are registered to play hockey each year, which does not include recreational athletes (IIHF, 2010).

From a hockey fans' perspective, able bodied and sledge hockey are almost identical as they are both high intensity sports with a lot of full body contact. The playing surface is the same size as the National Hockey League (NHL) including regular ice markings and goal nets. The obvious difference is the equipment used by sledge hockey players (*Figure 1*). The sledge consists of a seat, two skate blades, and rails that create a stable base from which the player can sit and manoeuvre (*Figure. 2*). Sledge hockey players use modified hockey sticks, with picks on the end of the stick, to propel them down the ice. The sticks are also used for puck handling.

Figure 1: A sledge hockey player in full equipment sitting in the sledge.

Figure. 2: A model of sledge created by Unique Inventions.

1.1 Scope of this study

This research project began with Todd Sargeant requesting a review of the equipment used by the players (T. Sargeant, personal communication, September 16, 2010). A review of the equipment was essential to better understand the needs of the sledge hockey players. At the beginning of this study, it was unknown what the players needed in terms of revising their equipment. To determine the research focus for this thesis, an introductory questionnaire was given by Mr. Sargeant to the players on the London Blizzard sledge hockey team. This team competes at the second highest level of sledge hockey competition in Ontario, Canada. The questionnaire was filled out by seven experienced players who had played sledge hockey for over five seasons (see Appendix A). The purpose of the questions was to find out which basic features of the sledge the players deemed most important. The results from **Error! Reference source not found.** suggested most of the players were unhappy with their sledge. Fixing the sledge and seat comfort were selected in greatest need of change. Responses to cost, aesthetics, and changing seat position indicated these factors were of less importance.

Prior to the questionnaire, I had no experience with sledge hockey or working with athletes with a disability. Understanding why players chose certain seating positions took further investigating. This required feedback from players and coaching personnel and also personal use in the equipment in practices. After discussing with the players about their preferred position it became apparent that each athlete adjusted their equipment based on “feel”. Most athletes on the Blizzard team had not changed the position of their sledge in years although the sledge was built for maximum customization. Further, there are no guidelines in place for a novice player to follow for optimal setup of their equipment. This could be a factor for the players being uncomfortable, as no one had taken the time to optimize their position in the sledge, like for example wheelchair racing.

Table 1: *Responses to the Questionnaire submitted to players of the London Sledge hockey team (n=7).*

	The cost for the sledge is fair	**I like the look of my sledge**	**I've been very happy with my sledge**	**I change the position of my sledge on a regular basis**	**My seat is comfortable**	**I have to fix my sledge at least once a month**
Yes	**7**	**4**	**2**		**2**	**4**
No			**4**	**5**	**2**	
Maybe		**3**	**1**	**2**	**3**	**3**

Another possible reason for the players being uncomfortable came from observing the materials they put in their seats (*Figure 3*). The manufactured seat provides some cushioning in the form of a thin layer of foam. Players add materials such as more foam or even blankets to increase support for the athlete's waist and thighs. After many discussions with the athletes, there does not seem to be a scientific basis for how the materials are placed in their seats. It would seem the players want to feel like a foot inside a ski boot: very tight with little movement. Different seat sizes are available but it would seem in general that the width of the design is too wide.

Making repairs or fixing the sledge seems to depend on the level of competition. Higher performing athletes subject the sledge to increased collision forces because they travel at higher velocities (L. Howlett, personal communication, February 23, 2011). The tubing surrounding the sledge has to be replaced more often as it shields the player's legs from impact. After talking with the London Blizzard trainer who fixes the sledges, most of the maintenance required is due to loose bolts or frame damage (T. Sinclair, personal communication, October 7, 2010). Mr. Howlett suggests that bolted parts are necessary for fast replacement during a game (L. Howlett, personal communication, February 23, 2011).

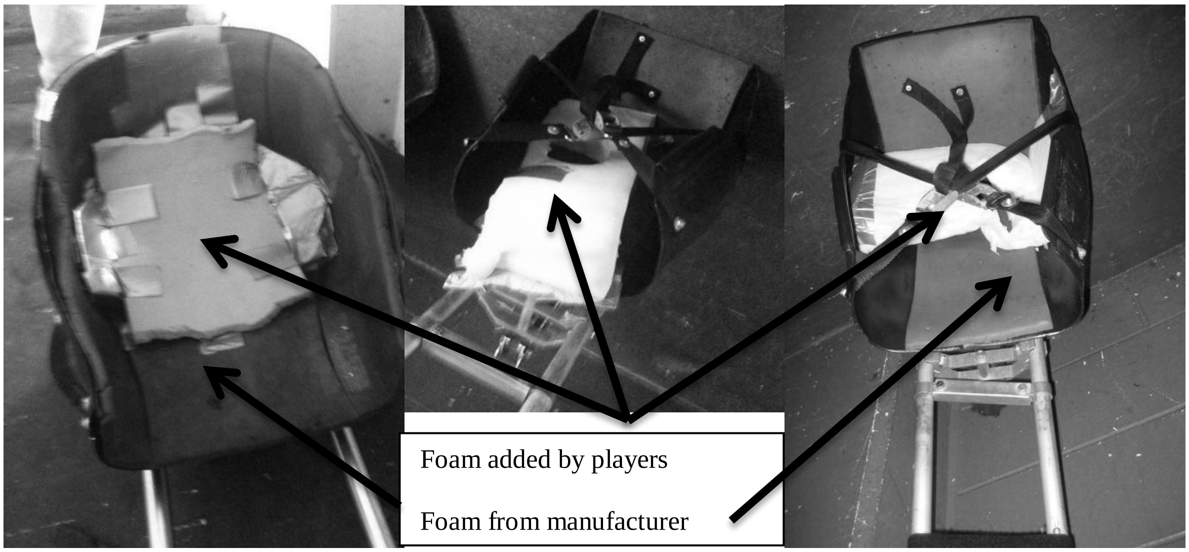


Figure 3: Materials added by sledge hockey players to their seats.

To help conceptualize the speed of these athletes, a very good able-bodied hockey player can do a lap of a hockey rink (*Figure 4*) in about 9m/s, taking about 15 seconds (Street, 2010), using a NHL hockey rink measuring 61m by 25.9m. From timing the Blizzard players in the same test, the best result was 22s and produced an average velocity of 6m/s. A car travels at roughly 12m/s throughout a city and collisions at these speeds can result in damaged bumpers. Car bumpers have crumple zones designed to prevent damage to the car. The rails around the sledge do not, thus the worst case scenario for breaking a sledge is when two heavy sledge hockey players collide at maximum speed. This does occur but according to Mr. Howlett, constant abuse is more prevalent than complete failure (L. Howlett, personal communication, February 23, 2011).

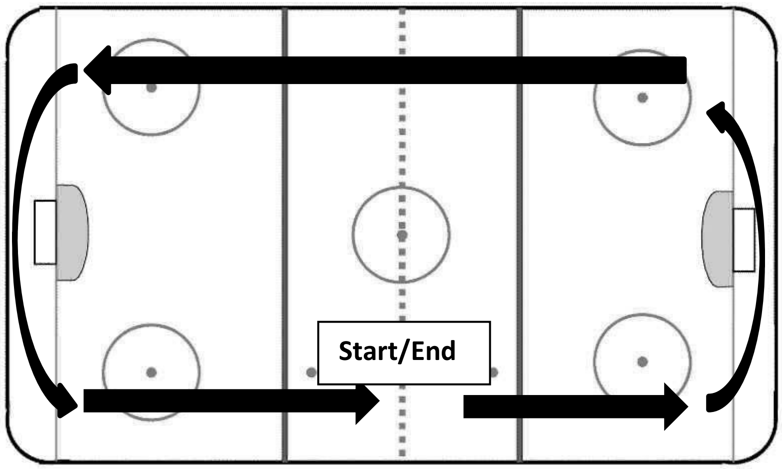


Figure 4: Simple lap test on a standard size ice hockey surface.

Protection of the players was not asked in the questionnaire because it was inferred that the athletes knew the consequences of playing the sport. All hockey players are susceptible to ligamentous and muscular injuries due to repeated high intensity movements and contact. A study following injury trends in the Salt Lake City Olympics (2002) found in total, eight sledge hockey players missed time due to injury in 36 games (Webborn, Willick, & Reeser, 2006). The authors from this study presented data showing that able hockey players also lost similar injury time during the same Olympic Games. This study provides evidence that, regardless of disability, players risk injury participating in hockey.

The results of the questionnaire completed by the experienced sledge hockey players, on the London Blizzard, provided valuable feedback about the sledge. Further communication with the athletes and coaches refined the scope of research to two key problems which are: improving the seat, and optimizing the position of the players in their sledge. Both these potential research areas are interrelated because changing the seat design will effect a player's position and finding the optimal player position may require the seat to be re-designed.

A successful ergonomic design accommodates the person otherwise the person must struggle to fit the system (Kroemer, 2006). Correct design relies on the understanding that every person is built differently and design work must reflect this. An ergonomic design criterion for the office chair was chosen to evaluate the sledge seat. This design criterion was chosen because office chairs are highly researched and the same principals apply to this study. The six design criteria for a typical work chair are described by Occhipinti, Colombini, Molteni, & Grieco, (1993):

1. Safety: A chair should never be the source of an injury or cause of an accident.
2. Adaptability: A chair is adaptable if it meets the anthropometric dimensions of 90% of the potential users.
3. Comfort: Comfort has been quantified as a sense of wellbeing of the user.
4. Practicality: Practicality is based on how easy the chair is to use.
5. Durability: Improving durability will translate into longevity of the device.
6. Suitability: Suitability of the job requires the seat to be designed appropriately for the condition for which it is going to be used.

Based on these criteria, safety of the sledge seat seems to be adequate according to the London Blizzard trainer, who alleged he has never seen a player forced to leave the ice because of an injury in the seat region (T. Sinclair, personal communication, November 17, 2010). The high density plastic that surrounds the athlete creates a resistant shield to prevent impacts from pucks, sticks and skates.

The sledge was manufactured to be adaptable to account for different disabilities within the sport. This gave the athletes the ability to fine-tune their position but does not guarantee they will do so as suggested by the questionnaire. A similar problem can be seen in bicycle racing where the manufacturer has given the user many different options to adjust for comfort and performance. The cyclist can change their seat position, handle bar height, their reach to the brakes, gear shifters, and crank arm length for better pedaling efficiency. Research has shown that the initial setup is important in preventing discomfort or personal injury due to prolonged improper setup (Mellion, 1991).

Comfort is an area that a sledge hockey seat could improve. Players are routinely adding materials such as foam or blankets to sit on (*Figure 3*). An ideal fit for sledge hockey athletes is when the pelvis and thighs cannot move in the seat. Thus it is assumed that comfort to a sledge hockey athlete is about feeling secure in the seat rather than a feeling of relief or enjoyment..

Practicality of the seat design, according to the design criteria, has been fulfilled as any sledge hockey player from novice to elite can sit in the seat. The actual seat is rigid but it can be tilted, adjusted vertically and horizontally along rails so the athlete can sit in a variety of positions. According to Howlett, the durability of a sledge hockey seat is roughly 3-5 years for a National team player and may last a lifetime for a less competitive player (L. Howlett, personal communication, February 23, 2011). National players are faster and collide with higher impact speeds that can break or deform the seat. Fortunately for the sledge athlete, manufactures sell individual parts so a frame could be purchased without a seat to reduce costs.

Lastly from the criteria, the sledge seat is suitable for the application of playing sledge hockey because it was built only with sledge hockey players in mind.

1.2 Problem Statement

It would appear that the seat is sufficient in all the areas except comfort. Whether a better position, new materials or new design are required to fix this area is uncertain. It is evident that players are adding materials to their seat to get a better fit (*Figure 3*). However, an appropriate selection of equipment and fitting would optimize function and performance (Goosey-Tolfrey, 2010). A comfortable seat also begins with a good fit (Helander & Zhang, 1997; Occhipinti et al., 1993). In wheelchair racing, the most popular adaptive sport, the chair is constructed based on the fitting assessment of the user (Cooper, 1990; Goosey-Tolfrey, 2010; Macleish, Cooper, Harralson, & Ster, 1993). Similarly if a procedure could be developed for sledge hockey, current and future athletes would benefit in finding their optimal position for playing. This would allow manufacturers to re-assess the seat and or materials in the seat to enhance player performance. Based on the information presented, this report will focus on developing a seating procedure for sledge hockey.

Chapter 2

2 Literature Review

There is minimal literature regarding the sport of sledge hockey. Many aspects of the sport must be considered prior to making recommendations regarding sledge positions.

This literature review is broken into four parts. The first part reviews the disability classification used by the International Paralympic Committee (IPC) for determining who is eligible to participate in the Paralympics. The second part examines the history of the sport of sledge hockey and provides details of the construction of the sledge and its various parts.

The third part of this review consists of three pilot studies. The first pilot study assessed the reliability and variability of the London Blizzard sledge hockey players using an on-ice conditioning test. The second pilot study evaluated three measurements used to quantify the position of a sledge hockey seat. The last study used time motion analysis to help create an on-ice sledge hockey specific test.

The last part of the literature review is the purpose, justification, and hypotheses for this report.

2.1 Disability Classification

Classifying all disabilities under one umbrella is very difficult due to the enormous amount of both physical and emotional disabilities; in this report only physical disabilities are described. Dr. Stuart, chief medical officer for Paralympics Great Britain, recommends to classify athletes with a disability in terms of functional ability rather than their disability (Stuart, 2010). Historically major disability groupings in the Paralympics are: wheelchair athletes, visually impaired athletes, athletes with cerebral palsy, amputee athletes, and deaf athletes (Stuart, 2010). Using these groupings means that an athlete with a T-5 spinal cord injury (paralysis of lower body and legs) will be competing against to a T-10 spinal cord injury (partial paralysis of lower body and legs). Testing for functionality is appropriate as athletes would be competing against other individuals who are similar in ability which is really the nature of sport.

Literature of population with special needs traditionally have sample sizes that are small, often less than ten subjects. Researchers interested in studying individuals with a disability have to 'take what they can get' and extract useful measures from the obtainable population. Statistical strength of these studies is typically low because of small participation. However, the results however can help clinicians, researchers, and manufacturers evaluate new products or customize existing ones for the individual's needs.

2.1.1 Classification of disabilities in Sledge Hockey

Sledge hockey allows anyone, man or women, who are able bodied or have a disability to participate. In order to be eligible to participate in sledge hockey at the Paralympic level of competition, an individual must have an impairment of permanent nature in the lower part of the body of such a degree that it is obvious and easily recognizable, and makes ordinary skating and consequently able-bodied standing ice hockey playing impossible (IPC, 2011).

2.2 Sledge: History

Sledge hockey, like other adaptive sports, has developed in participation and technology since its creation. The first prototype sledges had basic trays for seats that sat atop steel tubes that were entirely fixed to two normal hockey skate blades (*Figure 5*). As design iterations progressed, features such as tilt, seat height, and horizontal seat placement were incorporated into the design (*Figure 6*). In the early 1990s, a company called Unique Inventions, located in Peterborough (Ontario), began focusing on building hockey sledges fulltime. This company has developed into a leading manufacturer of sledges and has invested a lot of time working on different models to suit athletes' requirements (L. Howlett, personal communication, February 23, 2011).

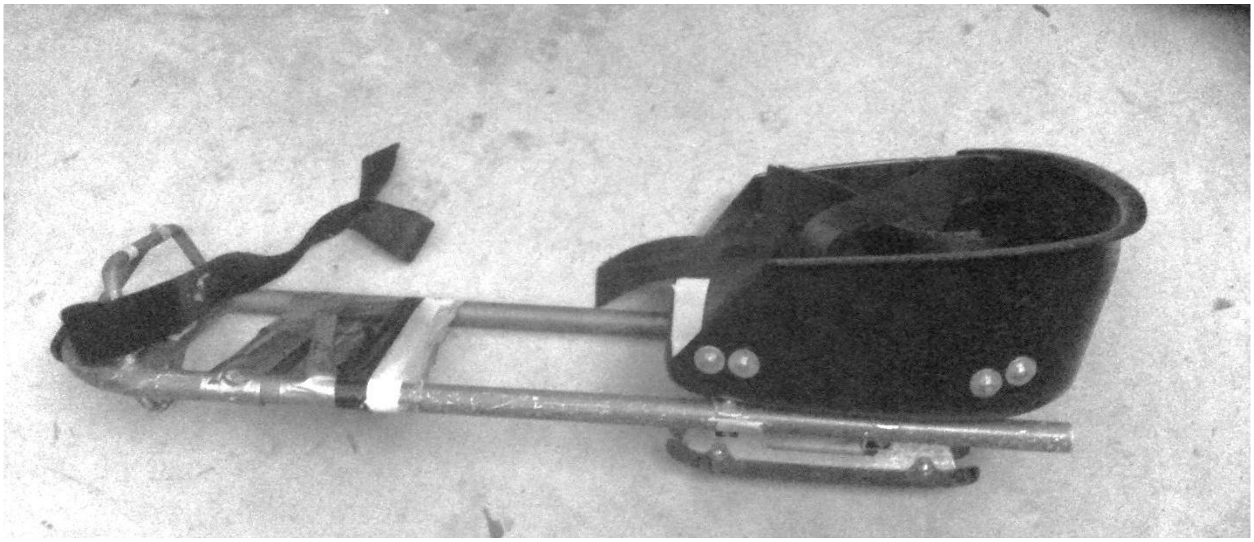


Figure 5: An earlier sledge design consisting of rails, seat, a nose, and skate blades.

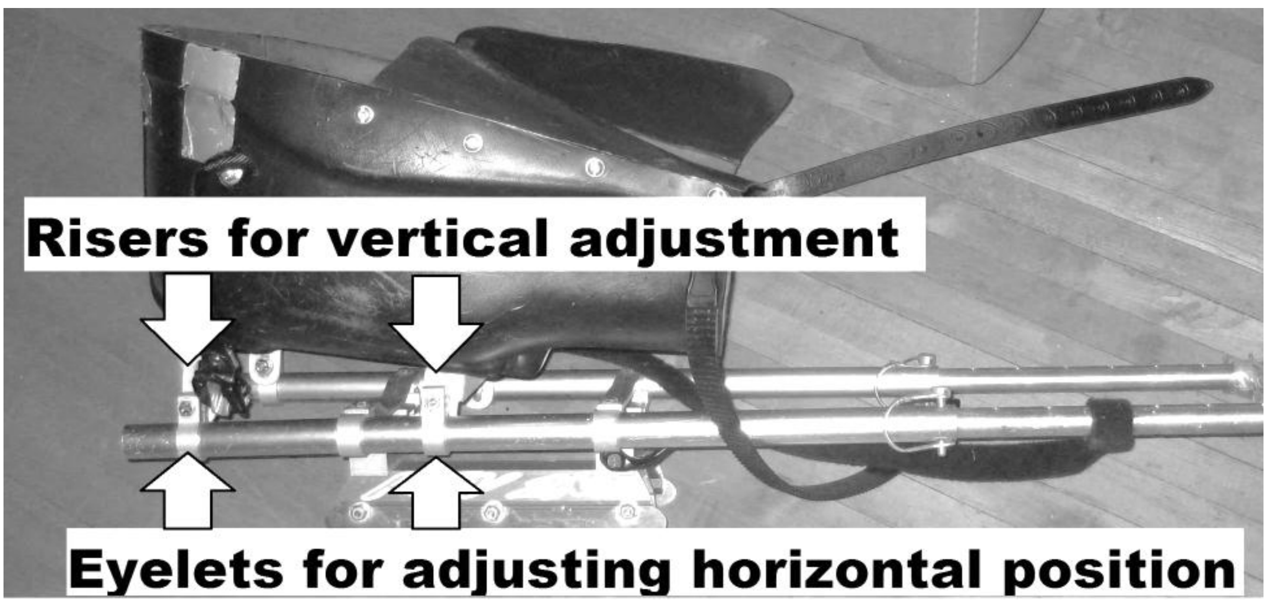


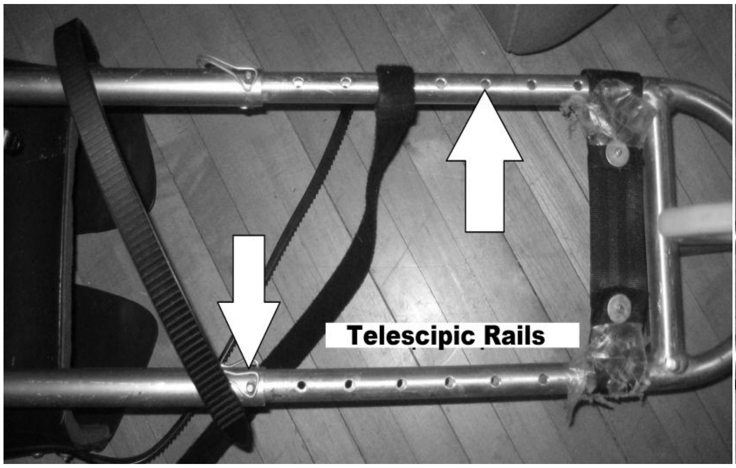
Figure 6*:* Horizontal and vertical adjustment locations for the seat.

There are other manufacturers of sledges outside of Canada but the global concepts of sledge design seem to be the same: plastic seat fixed to an adjustable frame and straps to restrain the athlete to their equipment. Customization is the key design feature of sledges as almost every part can be adjusted to fit the user's needs. The sledge is constructed of many different parts that attach to a U-shaped rail formulating the frame. The frame is telescopic and can be lengthened to fit a variety of players' leg lengths (*Figure 7*). Other parts connected to the rails are the nose, a foot cage, the skates, the skate holders a seat, eyelets, and the risers. The nose is either aluminum or plastic (*Figure 8*). The foot cage is welded to a set of rails that slide inside the rails that make up the frame. The foot cage is used to protect the feet of the player. The skate system consists of two blade holders and two blades 0.27m in length and 0.005m wide. The seat risers which are joined to the skate holders are attached to four eyelets that can be adjusted to move back and forth along the frames rails (*Figure 9*).

The nose and skate system act as contact points for the sledge on the ice. The width of the skate blade holders can be adjusted depending on the athlete's ability. The closer the blades are together, the more balance is required of the player to keep the sledge from tipping over. The seat height and tilt can be adjusted by the risers attached to four eyelets (*Figure 6*). The sledge length, skate holders, seat height and tilt can all be independently adjusted. Seat height must be a minimum of 0.085m and a maximum of 0.2m above the ice in accordance to section 3 of the IPC rule book (IPC, 2011). Seat height is measured from the ice to the lowest point of the main seating area.

The seat accounts for the majority of the total sledge mass as seen in Table 2**:** . The seat is made from high density polyethylene which provides a medium level of strength to weight ratio and is very durable. A thin layer of foam is added to the seat to cushion the player's bottom. Most players add foam to their setup (*Figure 3*) further increasing the weight of the sledge. Custom seating is an option that some manufacturers offer but is an added cost.

A set of straps used to restrain the player to the sledge are mounted on the outside of the seat. Players can choose either a low cost nylon strap or a more expensive ski boot ratchet strap. The benefit of the ski ratchet strapping is it is less likely to become loose however they are more costly and add weight.



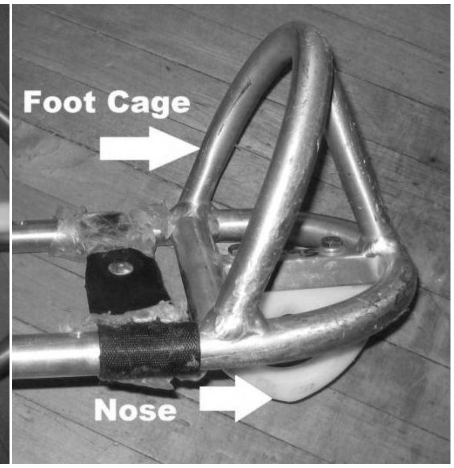


Figure 7: Telescopic rails of the sledge.

Figure 8: Nose and foot cage of the sledge.

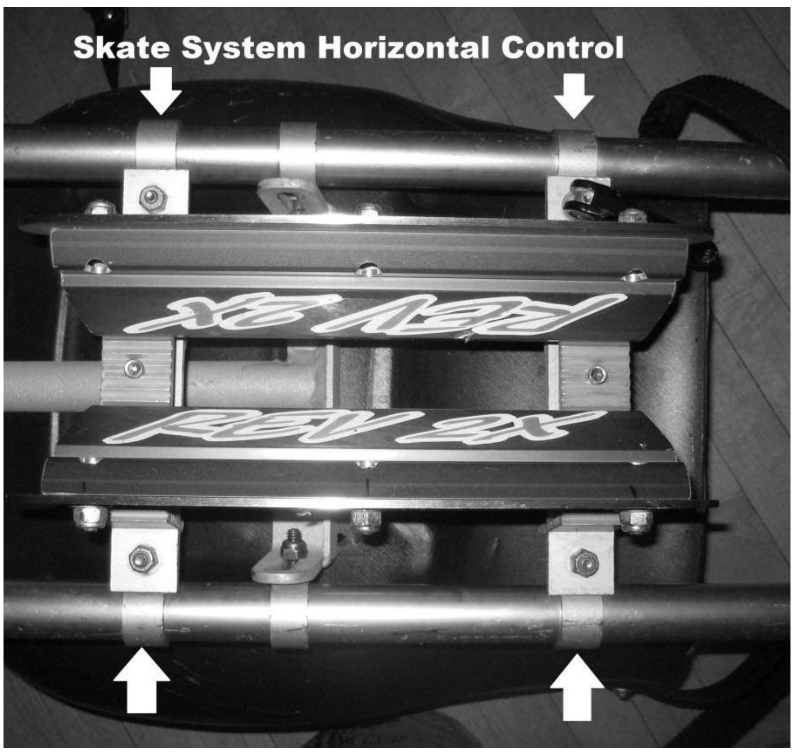


Figure 9: View from below: Skate system of the sledge consisting of two steel blades that are fixed individually to an aluminum blade holder (seen above with REV 2X printed upon its side). The the distance between the blade holder can be changed and the system can move horizontally along the rails.

Table 2: *Shown are the masses of the main components of the sledge. Data was collected using a 0.46m medium sized seat with snowboard binding straps.*

Part	Mass in kg (% of total mass)
Seat System (including straps)	2.3 (43%)
Frame (including rails and nose)	1.6 (30%)
Skate System	1.4 (27%)
Total	**5.3 (100%)**

Individual differences in body structure and physical ability are critical to keep in mind when designing sport equipment to gain maximal mechanical advantage. Currently if a player requests feedback on their position, they can request attention from the manufacturer or their coach (L. Howlett, personal communication, February 23, 2011). New players on the London Blizzard receive help from coaches for basic positioning. This involves trial and error by adjusting the skate holder and seat until the athlete can sit in the sledge without falling over. Since players are not altering their current position (**Error! Reference source not found.**), initial setup is critical for performance.

2.3 Adaptive Sport Research

The first manufactured wheelchair was created about 75 years ago by Jennings and Everest (Everest & Jennings, 1937) Everest, an engineer, built the chair for Jennings, a paraplegic, and together they formed a partnership to sell their prototype wheelchairs. In the following decades, there was need for mass produced wheelchairs because of the growing population of persons with disabilities and wounded war veterans. The first manufactured wheelchair consisted of a fabric hammock seat and metal armrests which can be easily folded and stored. This wheelchair design is still being used today in airports and shopping malls around the world. From this initial design, wheelchairs have developed in sophistication. Now, the wheelchair design is highly sophisticated with power and manual options, customization of seat, back and other components as well as adjustability of the wheelchair frame

The basic wheelchair (*Figure 10*) was used for most adaptive sports up until the mid-1970s (Cooper, 1990). The importance of wheelchair design specifically for sport (*Figure 11*) significantly improved athletic performances (Cooper, 1990; Macleish et al., 1993; Walsh, Marchiori, & Steadward, 1986). Cooper (1990) felt the 1988 Paralympic summer games saw the most significant changes because of the investment in researching technique and equipment which led to many new world records that were broken.

The first 'Paralympics' (Para a Greek term for alongside), took place in 1960 with 400 athletes participating (IPC, 2012). The first Paralympic winter games were held in 1976 in Sweden with 198 athletes participating. The most recent Winter Games were held in Vancouver in 2010 with 502 participants and the most recent summer Paralympics took place in Beijing (2008) with 4,000 athletes competing.

Sport wheelchair research has helped identify positional advantages for the athlete to become better suited to their equipment (Cooper, 1990; Macleish et al., 1993; Walsh et al., 1986). In turn, these improvements have influenced the construction of the daily use wheelchair (Macleish et al., 1993). Investing time in equipment design and research into proper training would appear to have helped the athletes achieve these new records in their athletic disciplines.

Figure 10: A 1980s model wheelchair used by Hansen to travel the world (Hansen, 1980).

Figure 11: A modern racing wheelchair (Athletics, 2010).

2.3.1 Adaptive Skiing

A review of adaptive sports literature suggests that skiing equipment would have similar seating requirements to sledge hockey. Adaptive skiing involves the same basic mechanics as sledge hockey with the individual's arms used to move the athlete and their equipment. In addition, athletes in both disciplines must balance on blades and use their core strength for manoeuvrability.

Adaptive skiing, like sledge hockey has received very little research. However, from a product prospective, more time seems to have been invested in seating for skiing. Two examples of the adaptive ski seat designs are from Spokesnmotion (*Figure 12*) and Tessier (*Figure 13*).

Figure 12: Spokesnmotion seat for adaptive cross country skiing (Spokes n Motion, 2010).

Figure 13: Seat designed by Tessier used in downhill skiing for athletes with a disability (Tessier, 2010).

The Spokesnmotion design utilizes a large dump (angle of the seat compared to the ground), which is characteristically used for athletes with paraplegia to help flatten their lumbar curve because they lack postural control (L. Howlett, personal communication, February 23, 2011). Without the use of their legs, an x-country skier would rely solely on their upper extremities for propulsion. The Spokesnmotion seat is designed to maximize propelling arm movement and enhance balance for cornering which are the two major design criteria for the adaptive x-country skiing athlete.

The Tessier seat embodies a very similar design to a sledge hockey seat. The "U" shape of the seat, and the strapping used to fix the leg, hip, and torso for safety, are features akin to the sledge hockey seat. Two advantages of the Tessier model are that there is more foam in the seat and a backrest that pivots. These features could be beneficial to a sledge hockey athlete since they would secure the pelvis and support the player's spine. The drawback of adding these to a sledge is that it could add more weight, increasing the mass that must be moved by the player on the ice.

2.3.2 Racing Wheelchair

Wheelchair racing has benefitted from being the focus of most research compared to other adaptive sports. Studies have suggested that proper positioning of the athlete in their equipment is very important (Cooper, 1990; Guo, Su, & An, 2006; Macleish et al., 1993; Walsh et al., 1986). Appropriate frame selection allows the user to achieve better aerodynamics, propulsion ergonomics, stability, maneuverability, efficient energy transfer, and torso support (Macleish et al., 1993).

The basic parts of a racing wheelchair are the frame, wheels, brakes, seat, and steering equipment. The frame length and size are determined by the user's body dimensions, type of racing (sprint versus endurance), and postural control (Macleish et al., 1993). Broader wheel base and longer chair length are more stable and are used for distance races such as the marathons while sprint races; in contrast where drafting and manoeuvring is important, require shorter wheelchairs with smaller wheelbases.

The fitting process for a sport wheelchair can be very time consuming because wheelchairs are custom made for the individual due to the disability of the individual (Cooper, 1990; Macleish et al., 1993). Do to the individuality of disabilities, attention to detail for perfecting the construction of each person in the racing chair is crucial. Studies linking anthropometric data of wheelchair athletes and chair dimensions need to be compiled l (Cooper, 1990). Having these data would provide current and future wheelchair racers with the ability to optimize their seating. Regardless, there is enough literature published, or found in online forums, for an inexperienced individual who wishes to begin wheelchair racing to obtain basic position in the chair. Some of the basic measurements for setting up the wheelchair are (Goosey-Tolfrey, 2010):

- Seat height which is measured from the floor to the bottom of the seat (*Figure 14*).
- The seat width which is measured by the hip width of the individual (*Figure 14*).
- Positioning the wheel camber for stability. Camber is the degree to which the wheel is tilted off the vertical, with the top of the wheel closer to the user's body and the lower part of the wheel furthest away (*Figure 14*).
- Distance of the center of gravity (COG) of the individual relative to the rear wheel axle position (*Figure 15*).

From these measurements, there are two measurements that relate to sledge hockey specifically which are:

- The seat height
- Positioning of the COG

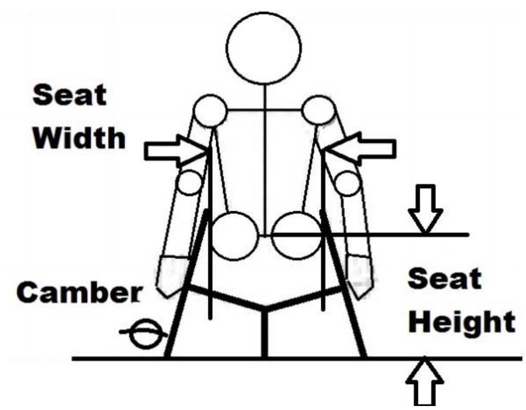


Figure 14: Measurements of seat width, camber, and shoulder height to push rim used for wheelchairs.

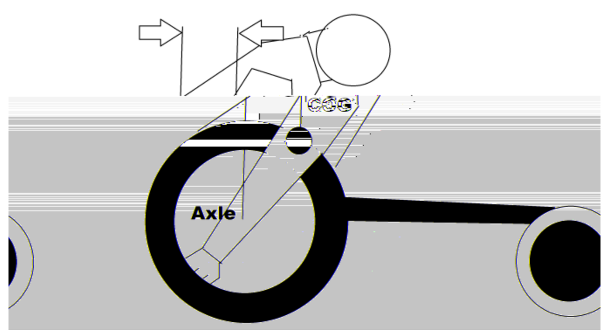


Figure 15: Shown is the measurement for the COG of a wheelchair athlete with respect to the rear axle.

Optimal Position of COG and Seat Height

Positioning the COG of the athlete is one the most important measurements for the racing wheelchair athlete (Cooper, 1990; Macleish et al., 1993; Top End Sports, 2010). This requires trial and error to find the optimal location (Cooper, 1990; Macleish et al., 1993). Optimal COG location is entirely based on the user's wheelchair skills because there is a trade-off between mobility and balance as the position of the COG changes. As the athlete leans forward, more of their weight is distributed between the front and rear wheels. This creates an effective support base for the athlete in their chair. Conversely if the COG is positioned too far forward, it can cause poor stroke kinematics, increased steering resistance, and a large downhill turning radius (Cooper, 1990). If the COG of the athlete is too far back then the chair will flip over backwards. A basic rule for an athlete's wheelchair setup is positioning the users COG over the rear axle of the chair (Macleish et al., 1993). Several racing wheelchair seat height studies support a shorter vertical distance between wheel axle and shoulder (Cooper, 1990; Masse, Lamontagne, & O'Riain, 1992).

Vanlandewijck, Theisen, & Daly, (2001) found that in other wheelchair sports such as basketball or rugby seat height was based on tactical position. A guard in wheelchair basketball who requires fast accelerations and versatility prefers a lower seat height. Conversely wheelchair basketball centers that are required to rebound have higher seat heights.

2.4 Pilot Studies

Further work was required for the main body of this study, for evaluating how a sledge hockey player should be positioned in their sledge, and how this process should be measured. In total, three unpublished studies were completed. The first study evaluated the London Blizzard sledge hockey team, for on-ice performance consistency, using the same on-ice test throughout their season. The second study evaluated measurements of seat height, tilt, and stability, of five player's sledges. The last study used time motion analysis to observe a sledge hockey player performance in a game. This analysis was done to better understand the physical demands of a sledge hockey player in a game situation.

2.4.1 Reliability and variability of the London Blizzard sledge hockey players using an on ice conditioning test.

The objective of this study was to assess the conditioning level of the London Blizzard team, using an on-ice fitness test, scheduled regularly throughout their season. The London Blizzard season begins in October and ends in March. The Blizzard players are typically on the ice three times a week with practices held mid-week and games on the weekend. Routine fitness measures are customary for athletes preparing for competition. The test conducted is within the confines of normal training requirements for the team, and was necessary to observe the consistency for similar tests for the main study.

Participants

Ten players including one female from the London Blizzard sledge hockey team participated in this analysis. The test was integrated into the practice and participation was voluntary. Players were familiar with testing as the coaches had done previous assessments in other seasons. The results shown are for London Blizzard players who participated in at least two tests.

Procedure

Sledge hockey currently does not have its own specific conditioning test, so one was chosen that could evaluate fundamental skills of acceleration, turning, and picking. Picking is a sledge hockey specific term, which describes the essential movement for a sledge hockey player, as they thrust their picks on the back of their sticks into the ice and push against them to create forward motion.

The test duration was also important and was based on time motion analysis of able-bodied hockey studies (Green et al., 1976; Peddie, 1995). The test was composed of doing a single lap of the ice (*Figure 4*) where the athlete started from rest behind the center ice line, then skated around the outside of the faceoff circles, staying behind the back of the net. The time was taken when the player crossed the center line again. The estimated time for a player to complete a lap was 20-45s which is about the length of a normal shift in a game of able-bodied hockey. These test procedures had to be done within five minutes including setup of player order, administering the test, and clearing the ice of the pylons. Ideally more tests could have been completed but the coordinating time outside their only practice was unachievable.

Players were randomly assigned by the coaches to groups of three (or less if uneven) and sent five seconds apart. Each group finished prior to the next group starting. Players who went off course were allowed to repeat but moved to the last group. Testing was always done at the exact same time during practice and on the same ice surface.

One repetition of the test was performed on each separate test day held on four separate occasions. Testing times were organized with the coaching staff prior to practice. Two test dates were cancelled because of holidays (December) and preparation for tournaments (March).

Equipment

Each test was timed using a standard Timex Ironman 30 lap counter stop watch. Times were rounded to the whole second and recorded by the same individual for each test.

Data Analysis

Lap data were entered into Microsoft Excel (Redmond, WA, United States) for data collation and analysis. Descriptive statistics of means and standard deviations were calculated for each player. A pooled variance (Equation 1) was calculated for the participants to see the overall estimate of variance. This equation was used to evaluate each player’s variation throughout the season.

Equation 1: Pooled variance use for calculating player test time variation throughout the season.

$$S^2_p = \frac{(n_1-1)\, s^2_1 + (n_2-1)\, s^2_2 + \ldots + (n_k-1)\, s^2_k}{(n_1-1) + (n_2-1) + \ldots\ldots + (nk - 1k)}$$

S^2_p = Pooled variance

n = is the sample size of the *i*th sample

s^2_k = is the variance of the *i*th sample

k = is the number of samples being combined

Results

Summary of the players' times can be reviewed in

. Player 1 produced consistently fast results finishing on average four seconds ahead of player 2. Players 2-6 were within a close margin suggesting similar level of conditioning. Players 6-9 were the most consistent producing the smallest standard deviations. The standard deviation was calculated from the pooled variance which for the entire group was 2.1s.

Table 3: *Lap test results completed by the London Blizzard players.*

Player	**October t(s)**	**November t(s)**	**January t(s)**	**February t(s)**	**Avg t(s)**	**Std Dev t(s)**
1	23	24		22	23	2.0
2	25	26		28	27	3.0
3	27	27	28	26	27	1.6
4	29	28		27	28	2.0
5*	32	29	29	30	29	2.8
6	31		30		30	1.4
7	31	32	32		32	1.2
8**	35	34			34	1.4
9	36			35	36	1.4
10	43	42	46		44	2.1
(*) Able-bodied				Average	31	1.89
(**) Female				Pooled Var.		4.4

Discussion

The focus of this study was to see if the players could produce consistent times performing an on-ice conditioing test during the season. Results from show that most players were within 10% of their average time throughout the season. The player's total standard deviation was respectable as the players had less than 7% variation ($p = 0.05$) over the course of the year. In high performance sport, these variations would be considered extreme, but for this study, the challenge is finding athletes who can provide reasonable consistency, and eliminating highly inconsistent individuals for future testing. Some deviation is expected as day to day performance variation is normal for athletes. Prior exercise to the testing could have contributed to the differences in test times as this was not constant throughout the season.

Precision of the measurements could have been improved using an electronic system or video. However, manual stopwatch timing has been proven to be very close to electronic timing systems for sprint testing (Hetzler, Stickley, Lundquist, & Kimura, 2008). In the report by Heltzer et al. (2008) 248 split times were collected and they found there was no difference ($p<0.01$) between manual and electronic timing.

Another limitation to this study is players only went counter clock-wise (testing only left turns). With most of the picking being in a straight line and the quality of players participating, this would be a low source of error.

Conclusion

The lap test used in this pilot study provided an easy way to verify if the players are improving throughout the season. Based on the results of this study, the London Blizzard sledge hockey players can be relied upon for future on-ice testing at any point during the season. The main body of this report will require on-ice tests to measure different seating arrangements.

2.4.2 Evaluating three seating measurements for sledge hockey.

The objective of this study was to assess three measurements for evaluating a sledge configuration. The selection of the measurements was based on the following measurement criteria: each measurement could be replicated by coach or player, gave useful feedback about the player position, and the measurement did not require the player to be in the sledge. This last criterion was for athletes who wanted to change their sledge position independently.

Methods

The measurements used to define the player's position in the sledge were formulated from studies on office chair ergonomics and wheelchair literature. Common office seat measurements are seat tilt, seat height, and stability placement of the individual (ACE Centre North, 2000; Helander, 2003; Occhipinti et al., 1993). Similarly, optimal seating for wheelchair users require proper placement of the COG based on the seat height, seat depth, and seat back angle (Boninger, Baldwin, Cooper, Koontz, & Chan, 2000; Guo et al., 2006; Masse et al., 1992; Top End Sports, 2010; Van der Woude, 1990).

Measurements

Tilt of an office chair is defined as the angle of the seat pan with respect to the floor (Ergocentric, 2012). The purpose of the pan of the seat is to support the thighs. In the present study, tilt was measured using the difference in height of the eyelets that held the sledge seat to the rails (*Figure 16*). The seat was not used because of its contoured outer shape which made placing an angle finder difficult.

Seat height for both the wheelchair and the office chair is commonly measured from a level surface to the middle of the bottom of the seat (refer to *Figure 16* for the sagittal view of this measurement). This measurement was chosen so comparisons could be made between the players vertical COG position in the sledge.

The horizontal component of the center of gravity was given a sledge hockey specific name called 'stability'. Stability is a measurement, in meters, that is measured from the center of the skate blade on the sledge to the center of the seat (refer to *Figure 16*). A positive stability value is where the center of the skate is measured ahead of the center of the seat. A higher positive value for stability would mean the player has their seat center further behind the center of the skate. In this rearward position, more balance is required from the player to keep the sledge from flipping over backwards. Similarly with wheelchairs, if the user is positioned further behind the center axle of the chair, there is a greater instability in this position.

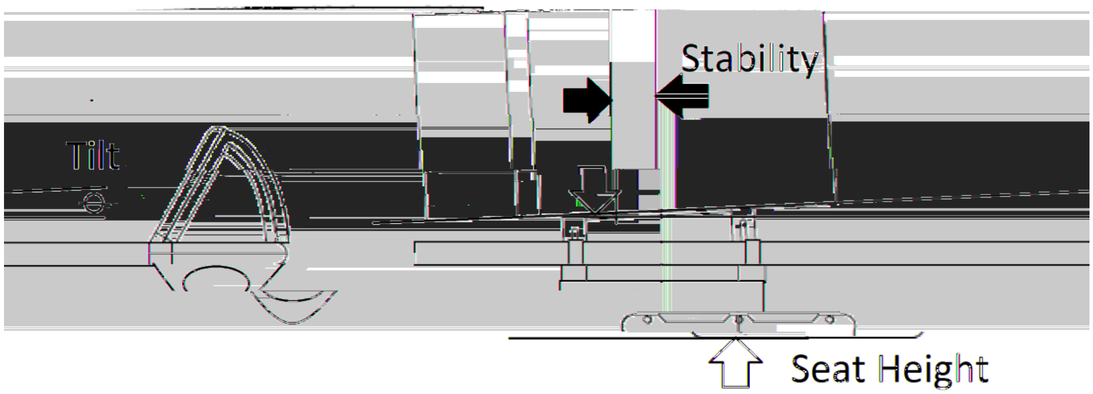


Figure 16: Shown are the three measurements of seat height, stability, and tilt. Seat height was measured from the ice surface to the bottom of the middle of the seat. Stability was measured from the center of the skate to the middle of the seat. Tilt was measured from the angle created from the difference in riser height

Finding stability began with marking the center of the skate blade and the center of the seat so these measurements could then be reproduced. The skate blade is metallic so a thin black mark was used. The seat required a white mark because of the dark colour of the seat. With the sledge on a level surface and the skate on the ground, two level rulers were placed beside the two marks and the distanced between them measured. This measurement was repeated three times and the average taken.

From pilot study one, the sledges used by the five fastest players were measured. Player six’s sledge was measured instead of player five because able-bodied individuals were not of interest in this study. Verbal consent was received prior to measuring each player’s sledge.

Equipment

A tape measure was used for finding measurements over 0.15m. All measurements less than 0.15m were measured with a set of Mitutoyo digital calipers. The tape measure was accurate to 0.05m and the calipers were accurate to ±0.005m. The calipers were used mostly for gathering the data for tilt, as the seat sometimes sat very close to the rails so reading from a tape measure would be imprecise.

Results

Measurement data of the five player's sledges can be found in *Figure 17* and

Table **4**. The average measurements of these five players were 0.16m ±0.03 for the seat height, 0.07m±0.04 for the stability, and tilt was found to be 0.4°±2.8.

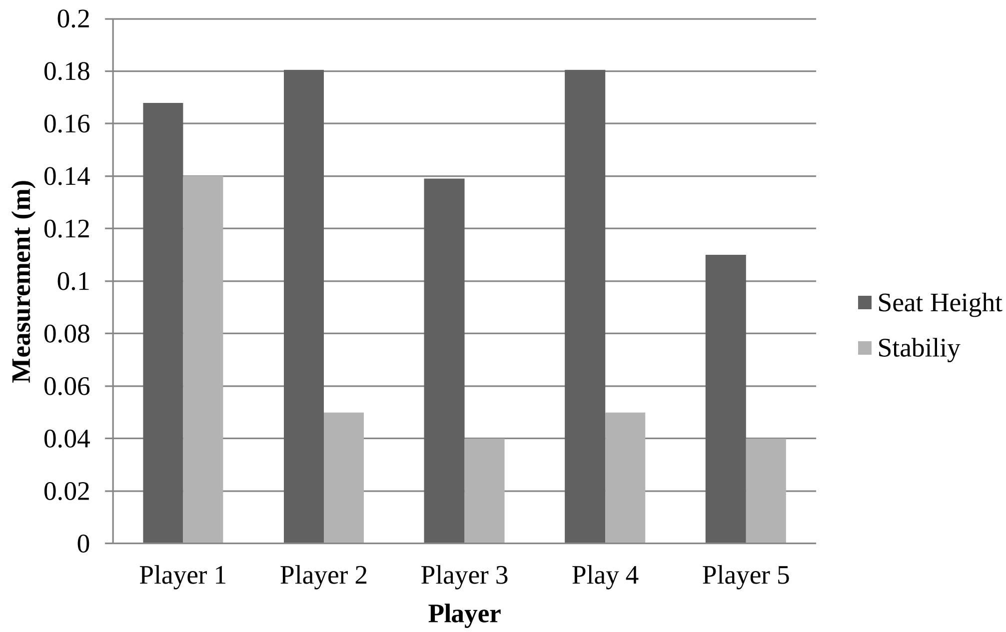


Figure 17: Seat height and stability measurements for the five player's sledges.

Table 4: *Measurement data of seat height, stability, and tilt of the five players sledges.*

	Measurements		
Player	Seat Height (m)	Stability (m)	Tilt (deg)
1	0.17	0.14	0
2	0.18	0.05	-3.9
3	0.14	0.04	1.8
4	0.18	0.05	3.9
5	0.11	0.04	0
Average	0.16	0.07	0.4
STD	0.03	0.04	2.9

Discussion

There were not many conclusive results from the trial data collected from the five player's sledges. Differences in the model of seat and the materials the players added to them affected all the measurements to some degree. The additional materials did not directly change the actual measurement or how it was conducted but drawing conclusions about how the players sat were definitely influenced (

Table **4**).

All the athletes' stability measurements were within a close margin except for player 1. Player 1's seat was almost three times further back compared to the sledges of the other athletes. Without seeing his sledge, his balance would seem to be superior to the others. However, player 1 adds a blanket to his seat for postural support, making his actual position more forward than the measurement represents. Additionally, the blanket conforms differently to his body each time he adds it to the sledge, making it difficult to replicate results. These materials also affected the seat height as the vertical COG could be higher or lower depending on the orientation of the materials, and how the player was sitting on them. A standard seat, with the same materials is required for future testing with the stability measurement and for accurate measurements of vertical COG.

The seat height measurement was also affected by the different models of sledges. Some sledges have flat bottoms while others are round. Finding the center of the seat can be done accurately, although, comparing the seat heights of each of the players would be misleading, if the same seat was assumed to be used by the reader. If a standard seat was used, then seat height and stability would both be useful measures.

Results from

Table **4** show that tilt was minimal; almost negligible. This has more to do with the position of the player than the measurement. The current seat does not support the lower legs well because of the flat pan, lack of cushioning, and there being lack of adjustment in that area. When a player is sitting in the sledge, a gap is formed the size of which is influenced by the players leg position (*Figure 18*). For example, a player with a knee angle close to 170º would have a small gap as the thighs would almost be touching the base of the seat. However, if the player adjusts their sledge to have a knee angle of 90º, this creates a larger gap. Ideally the seat would conform to the player's thighs at each position but this currently is not the case.

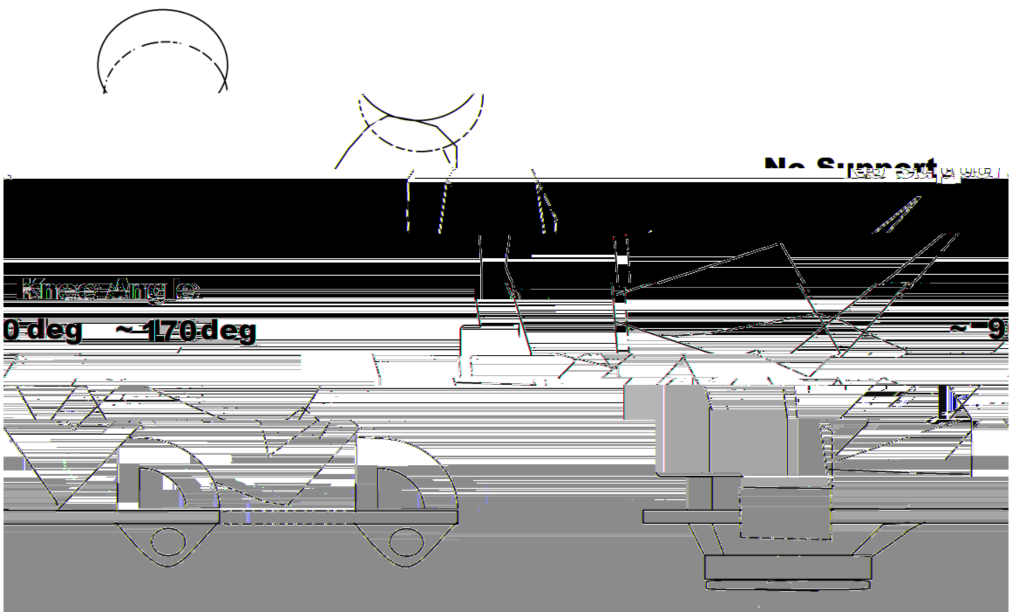


Figure 18**:** An example showing how the current seat does not support the thighs for two different knee angles.

Conclusion

This pilot study, evaluated the position of the seat on a sledge, using three measurements consisting of tilt, stability, and seat height. The seat height and stability measures were both affected by materials the players added to their sledge. Tilt, as defined by this pilot study, did not provide useful evidence about how the player was seated. It is recommended that a standard seat must be used so that comparison of each player's true position can be accurately measured. It is also recommended to reconsider how seat height and tilt should be measured.

Future Implications

After some consideration, the seat height and tilt measurements were revised and replaced by new and more useful measures as seen in *Figure 19*. Seat height was replaced by knuckle height. Body position reference, like the acromion used in wheelchairs, would make each position more relevant from player to player, and this would eliminate differences in seats built by different manufacturers. The acromion was not used because the players wore equipment covering their shoulders and access would be difficult on the ice with this protection in place. Knuckle height is measured from the center of players pinky finger knuckle, the fifth metatarsal, to the ground. The athlete must be sitting in their sledge with hands in a fist and down by their side. Tilt will be replaced by knee angle to account for the current pan of the seat not supporting the athlete's thighs. Knee angle is measured from the lateral malleolus (ankle), the lateral femoral condyle (knee), and the greater trochanter (hip).

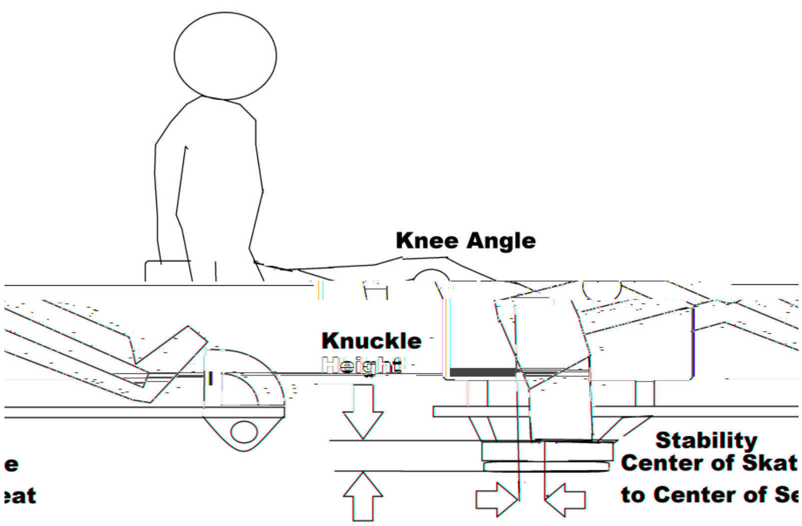


Figure 19: Measurements of the players' knee angle, knuckle height, and stability.

2.4.3 Using time motion analysis to create a sledge hockey specific test

Introduction

Hockey players require a variety of skills for playing their sport. Currently there is no specific hockey test that combines several skills in a method similar to competition. A common test used for able bodied hockey is a straight line sprint test of 20-50 meters (Behm, Wahl, Button, Power, & Anderson, 2005; Mascaro, Seaver, & Swanson, 1992). Sprinting is easy to visually monitor, measure, and give feedback, although it is only a small aspect of the game of hockey. Further, a typical shift for an able-body hockey player lasts for 40-58 seconds (Green et al., 1976; Peddie, 1995) requiring a player to skate over longer distances than just 20-50m. Thus more tests must be used to evaluate hockey player's skillset.

There are neither previous studies of the time motion analysis of a sledge hockey game, nor previous studies that compare a sledge hockey player's typical shift during a game to an able bodied player's shift during a game. Although sledge hockey and able-bodied hockey have similar rules, the actual game and how it is played may be very different. Relating data from previous able-bodied hockey literature may not truly represent the actual requirements of a sledge hockey player during competition. Thus, to ensure on-ice tests are applicable, an evaluation of a sledge hockey game was required.

Identifying the player's skills in the time motion analysis came from two studies (Table 5). The first done by Peddie (1995) who observed the physiological aspects of NHL hockey players, and the second by Beckman, Kudlacek, & Vanlandewijick (2007) whom developed a skills observation for sledge hockey teams at the Torino Olympics in 2006. The latter study used a point system based on wheelchair basketball that observed the instances each skill was performed (this data was not presented; only the final points for each team could be evaluated). In the present study, the skills chosen were a hybrid of both reports.

Methods

The evaluation took place during a game between the United States and Canada on April 19, 2011 at the World Sledge Hockey Championships. The time motion analysis was of a high profile Canadian National Team player who plays forward. There are other positions that could have been observed, but this specific player was selected for his consistent performances, puck handling, and picking intensity at international competition, and his experience playing for the Canadian National sledge hockey team. Time motion analysis is a common method for evaluating hockey skills and duration of time of a typical shift by a sledge hockey player (Green et al., 1976; Peddie, 1995). The analysis involves following a single player as opposed to following the puck for the duration the player is on the ice. This strategy allows the observer to authenticate the skills and movements of a single athlete, as opposed to viewing traditional video footage which focuses on the player who is controlling the puck. Video of this player was accomplished by a single individual, who was experienced with the game of sledge hockey, and had a perfect vantage point of the player on the ice during every shift.

Table 5: *Time motion analysis studies on hockey and sledge hockey*.

Author(s)	Skills Identified
Peddie (1995)	Bench time, low velocity skating, high velocity skating
Beckman, Kudlacek, & Vanlandewijick (2007)	Skating with the puck, skating without the puck, receiving checks, deking, passing, pass receiving, and shooting

Measurements

From the time motion analysis of the sledge hockey player, two sets of data were collected. These include duration of time each skill was performed and number of instances the subject performed the specified skill. The skills monitored for duration were high and low velocity picking, being stopped, and time between shifts. Number of instances was quantified for turning, checking, and puck possession was recorded.

Similar to able-bodied hockey where they watch foot speed to evaluate skating speed, frequency of picking is associated with player's velocity. Measuring duration of picking intensity is important, because the appropriate test length can be selected or created for the individual sledge hockey athlete. Picking can be broken down further into high velocity (rapid picking), low velocity picking (less frequent), and being stopped (no motion). Peddie (1995) defined high velocity skating on able-bodied hockey in his study by "the legs and arms of the player are in motion and moving fast... an all-out effort by the player." In the present study, high velocity picking was defined as the player rapidly contacting the ice with his sticks for forward propulsion. Distinguishing between high velocity versus low velocity picking, is similar to distinguishing between sprinting and jogging. There are similarities in the biomechanics but an individual observing the motion will clearly be able to observe the differences in effort. Picking was timed when the player's pick first contacted the ice until the last contact of the pick with the ice.

The ability to change direction is important for agility sports such as hockey. Experienced sledge hockey players are very agile, so it was important to measure quantity rather duration of the amount of turns the player made each shift. Turning was defined as a 90º or more deviation from the player's projected path. Also, if the player went in a continuous circle, this was counted as one turn. Small deviations from the players' trajectory were likely to be disputed, so a larger turning radius was necessary for analysis.

Hockey is a physical game and quantifying the number of instances a player is hit will give insight about the importance of secure seating. If the player checked someone or was checked, each of these counted as a single instance.

Puck possession is an important aspect of hockey but most of the player's time is spent without the puck which is why instances were used instead of duration (Lafontaine, Lamontagne, & Lockwood, 2004). Puck possession includes passing, pass receiving, shooting and stick handling with the puck. If the player was fighting for the puck or the puck contacted their sledge (for example shot block) this did not count as an instance.

The player had to have intended possession for an instance to be counted as puck possession.

Equipment

A Canon SD1000 video camera was used to follow the player on the ice. The video cameras frame rate was 30Hz. The video was started whenever the player was on the ice and the video was reviewed using Windows Live Movie Maker. This program allows the video to be analyzed frame by frame, and also has a time stamp for each frame. Duration and instances were tabulated in Microsoft Excel.

Results

The data presented are from 12 random shifts that a high profiled sledge hockey athlete performed during a World Championship game. The Canadian sledge athlete's longest shift was 115.9s and his shortest was 16.15s. His average shift length was found to be 36.7s and he averaged 171s of rest between each of those shifts. His total amount of rest between the 12 shifts was 1601s.

The data presented in

Table **6** suggests the player spent most of each shift (71.8%) performing low velocity picking, averaging about 26.4s of each shift. The player spent 6.9s on average of each shift (18.9%) performing high velocity picking and stopping accounted for 3.4s (9.4%). The number of instances the player performed each skill is presented in Table 7.

Turning yielded the largest number of instances a skill was performed per shift with an verage of 4.25. Puck possession and checking averaged less than one instance per shift.

Table 6: *Comparison of picking velocity from the time motion analysis.*

Skill	Total Time (s)	Average Time (s) Per Shift	Average Percentage (%)
High Velocity	83.1	6.9	18.9
Low Velocity	316.5	26.4	71.7
Stopped	43.2	3.4	9.4
Totals	442.8	36.8	100

Table 7: *Comparison of instances each skill was performed from the time motion analysis*.

Skill	Total Instances	Average Instances per Shift
Turning	51	4.25
Checking	11	0.92
Puck Possession	3	0.25

Discussion

The most important observation from the time motion analysis was that stick handling was minimal during a shift. This observation is consistent with other hockey studies that have also shown most of the play during a shift is done without the puck (Beckman et al., 2007; Green et al., 1976; Peddie, 1995). The one time that this athlete did touch the puck, he scored. Reviewing the video does show the athlete was open and available to receive the puck but opposing team closely defended him.

Similar to the results from the study done by Peddie (1995) on able-bodied hockey, the sledge hockey player observed in this study relied on short repeated sprints, and had long recoveries between them. The average shift length was shorter in the present study, 36.9s versus 58.5s for able bodied forward players. The amount of rest was also considerably different with the sledge hockey athlete, as he had an average of 171s of rest in comparison to 282.2s for the able bodied forward players. A possible explanation for the sledge hockey player having less rest than an able-bodied hockey player is, the Canadian sledge hockey team uses only three lines of forwards, so nine forward players, whereas the NHL uses four lines (12 players). Since the sledge hockey player had a lower average shift length, he was probably on the ice more and thus, had shorter rest periods.

Turning is an important aspect of sledge hockey; demonstrated by the large number of instances per shift. Sledge hockey players cannot easily look backwards or pick in reverse. They must constantly turn towards the puck and face their opponent when defending.

The tests used in this present study were defined by a consistent high performance athlete that may or may not be indicative of a lower performing, or lower functioning, sledge hockey athlete. However, coaches and athletes in all sports try to emulate top level athletes in their biomechanics and positioning in competition. Therefore, the most suitable player to analyze would be the highest performing athlete.

A limitation to this study was that only one athlete was followed. Additionally, players who play in other positions may have different durations as shown by other hockey studies (Green et al., 1976; Lafontaine et al., 2004; Peddie, 1995). Another limitation is quantifying the duration of each skill and counting each instance was only done by one person. The video was reviewed frame by frame and the videos taken were from an ideal vantage point of observing the player. Additionally, even with 10% human error associated with miscounting and misidentifying the skills and duration would have only minimal effect on the overall interpretation of the results.

Conclusions

The time motion analysis data collected from a single high level sledge hockey player provided awareness of the skills used during a sledge hockey game and the duration of time the athlete spent at different intensities. From these limited data, sledge hockey resembles able bodied hockey in terms of repeated sprints with long recoveries between efforts. Turning was observed to be an important aspect of sledge hockey while puck handling was not. Puck handling is a necessary skill of hockey but like other time motion analysis studies; this skill is minimally observed during each shift.

Selecting a sledge hockey specific test based on the results should include a segment of high velocity picking of 6-7 seconds. Test duration should be no longer than 33.5 seconds. The test should also incorporate several turns and the players should have long bouts of rest between efforts.

2.5 Purpose, Justification, and Hypothesis.

Purpose

The objective of this study was to see if there was an effect on the seating configuration on a sledge hockey player. Positional setup is crucial in sport and understanding the seating requirements of a sledge hockey player, will help current and future athletes in their competitions.

Justification

Currently there are no guidelines for optimal seating for players who participate in sledge hockey. Adjustments are currently based on how a player 'feels' (L. Howlett, personal communication, February 23, 2011). Studies in other sports, such as cycling, have shown that the user will not adjust the equipment after the product has been purchased, which can lead to injury or poor biomechanics (Mellion, 1991). The present study will discover if different seated positions affect the sledge hockey players' performance using on-ice tests.

Hypotheses

The first hypothesis is that new measurements will be useful for quantifying and comparing different positions of the players in their sledges.

The second hypothesis is that a low knuckle height and knee angle of 140º will be the preferred position amongst the players tested.

The third hypothesis is that within the measured positions there will be individualized preferences amongst the players.

The fourth hypothesis is that the tests chosen based on the results of pilot study three data will be useful for measuring outcomes of the different seated positions.

Chapter 3

3 Methods

There were three test days, the first consisted of off-ice measurements of athlete and sledge, and the other two days consisted of the on-ice testing. Three days were necessary because of the time required for measuring and the amount of tests the athlete must complete.

3.1 Subjects

Five male sledge hockey players' ages, 21-48 from the London Blizzard team took part in this study. These players were selected because they were physically capable to participate, and they could make all the required testing times. Consent forms for participation in this study were given to the players prior to testing (this form can be seen in **Appendix C**).

Anthropometric measurements of each player's height, weight, arm length, and leg length were taken. If the athlete could not stand or if measuring height by standing was too difficult, he was asked to lie on his side on the floor. Similarly, a chair was provided for weighing the athlete. The scale will be zeroed prior to the athlete sitting on the chair. The arm length was measured from acromion to the center of the pinky finger knuckle. Leg length was measured from the greater trochanter, through lateral femoral condyle, to the bottom of the foot. These last two measurements were taken three times on both sides of the body and then averaged. The player's age, years playing sledge hockey and the athlete's disability were also recorded. The degree of disability was not furthered questioned.

3.2 Test Sledge

Pilot study two indicated that it was necessary to have a standard seat for comparing the seated positions of the athletes. An adjustable test sledge (*Figure 20*) was created to standardize seating measurements and make seating changes faster and easier for the required tests.

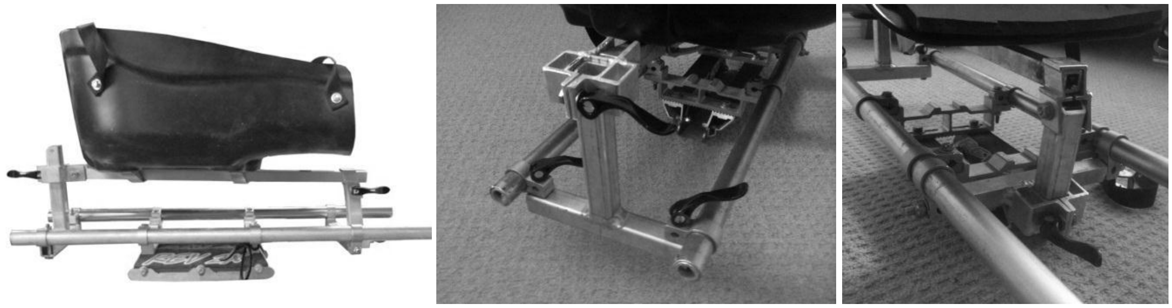


Figure 20**:** Pictures of the side, back, and front of the adjustable test sledge used in this study. The quick release collars (black levers) allow the seat to be vertically and horizontally adjusted with ease as compared to using bolts.

The test sledge has similar parts to the regular sledge such as rails, seat, and skate blades. The design of the test sledge differs from a standard sledge by the seat height, tilt, and fore-aft position of the seat is all controlled by quick release collars instead of bolts. The seat slides vertically on two seat posts connected at the front and rear of the seat. Marked on the posts was a ruler (in centimeters) for replicating measurements. The rails of the sledge are also marked every centimeter which was used for locating the stability measurement based on the seat and skate holder position.

The test sledge seat was 0.44m in length and the skate blades and holder are the standard size for sledge hockey. The skate blades were kept the same distance apart, 0.04m measured from outside of both blades, for all tests. This distance was recommended by the coach of the London Blizzard.

Attached to the seat are two sets of basic nylon straps to secure the player into the seat. Inside the seat is a thin layer of foam that is provided by the manufacturer. The players were not allowed to add any materials inside the seat during any of the testing days.

The minimum the seat height could be adjusted to was 0.14m. This was measured from the bottom of the center of the seat to the ice. Ideally the seat would be able to go lower but due to the design if the seat is further dropped, the front seat post would hit the ice.

3.3 Off-Ice Measurements

Knee angle and knuckle height measurements were evaluated at a Canadian National Sledge Hockey Invitational Camp on September 10, 2011 in Barrie, Ontario (seen in *Figure 19*). I was invited to the camp to take these measurements but was given only a short duration to measure the 27 players attending the camp. From the limited findings, a knee angle of 140º was found to be the average of the players measured using a goniometer (Lafayette Instrument Co.). Knuckle height could only be observed as the players sat in their own sledges but the majority of players' fists could easily touch the ice. A stand is necessary to do future knuckle height measurements.

Prior to each off-ice measurement in the present study, the test sledge skate and seat location were adjusted similar to the player's sledge being measured, and placed on a level surface 0.1m above the ground. Athletes were required to wear tight fitting clothes and their regular footwear used during competition. Each player sat in the test sledge in two positions: relaxed and acceleration (*Figure 21*). The relaxed position was characterized by having the players' arms by their side, at 90º with respect to the ground, and with a neutral spine. The accelerating position resembles that of a cross-country skier with the athlete's arms outstretched in front reaching as far forward as possible, increasing the amount of pick contact time with the ice. From these two positions, the three measurements of seat height, knee angle and stability were assessed as follows (refer to *Figure 19*):

1. Three seat heights of 0.14m, 0.165m, and 0.19m were used to evaluate the players. These were used because of the construction of the test sledge. Knuckle heights were recorded at these positions in relation to the ground. Players were seated in their sledge in the relaxed position and arms down by their sides. Measurements were taken from the center of their ungloved pinky finger knuckle to the ground. A small fine tip mark was placed on the center location of the knuckle, and was re-measured and averaged six times for accuracy.

2. The telescopic rails were moved to different lengths to achieve the three knee angles of 170º, 140º, and 110º used in this study. The 140º knee angle was chosen because it was the average of the Canadian National Sledge hockey team. The 170º and 110º knee angles were used because most players would be very unlikely to go beyond this knee angle, thus, they were chosen as the limits of the measurement. The knee angle was measured using a goniometer (Lafayette Instrument Co.). Markers were placed at the lateral femoral condyle, greater trochanter and lateral malleus, so the measurement could be repeated. The averages of six measurements were taken for each knee angle.
3. Prior to measuring stability, the athlete must be stable in both the relaxed and acceleration position without the nose of the sledge touching the ground. When the nose touched the ground, the skate system was moved forward 0.02m. This procedure was repeated until the nose remained off the ground in both positions. Once this position was determined, stability was recorded. Stability was measured from the center of the seat to the center of the skate blade of the sledge. A positive measurement indicates that the middle of the skate blade is ahead of the middle of the seat. These measurements were repeated for each knee angle but not knuckle height. Knuckle height changes did not affect the balance of the individual so one measurement of stability was sufficient for all seat heights.

Measurements of knuckle height, knee angle, and stability, were also taken for each player in their own sledge.

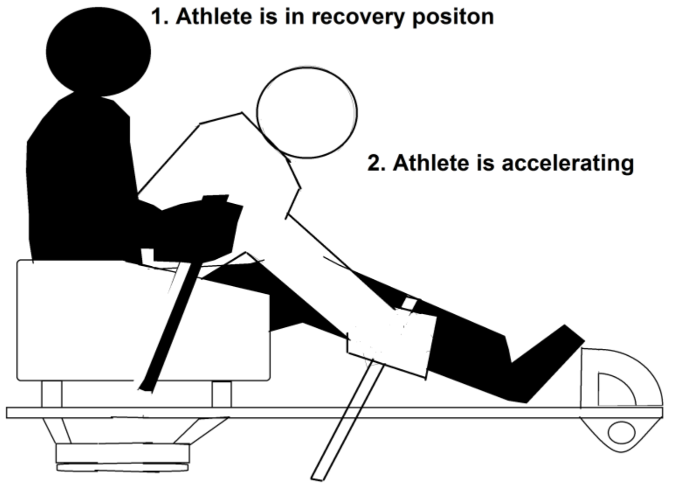


Figure 21: The two most common positions for sledge hockey player: recovery and accelerating position.

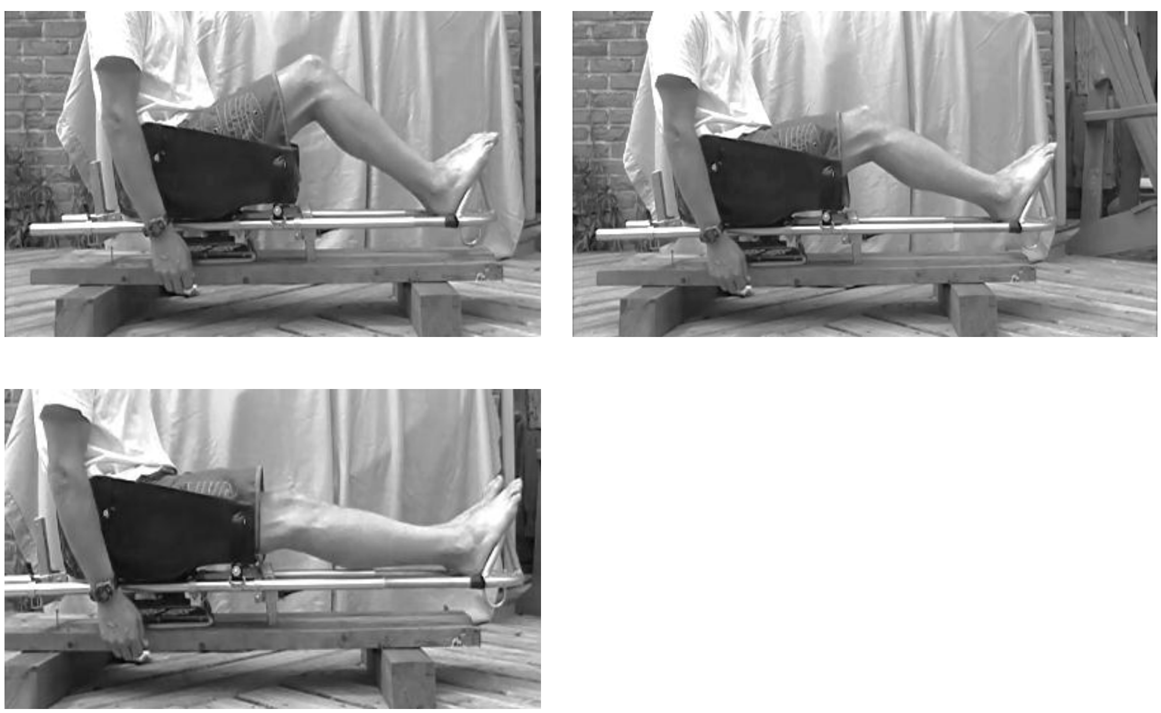


Figure 22: The individual in the sledge is modeling the knee angle positions in the sledge. Clockwise from top: 110º, 140º, and 170º.

3.4 On Ice-Testing

On-ice testing consisted of two tests (*Figure 23*): a sprint test and an agility test. These tests were chosen based on the findings from video analysis and are explained below:

1. Sprint test: The athlete covered 27.12m in a straight line at maximum speed. This distance was chosen to match the 6-7 seconds of high intensity picking quantified in the video analysis.
2. Agility test: The T-test or agility shuttle run as it is also commonly called, was used to assess the athlete's ability to turn while maintaining speed. This test was chosen because it has a high number of turns comparable to pilot study three. The test course consisted of a "T" with pylons spaced 5.42m apart totaling 27.12m. When instructed, the athlete began from rest at the stem of the "T" and pick to the center pylon. At the center they chose which direction to turn around the pylon, either left or right. After the initial turn, they picked towards the outside pylon of their chosen direction. Once reaching the pylon they did a 180º turn to get around it and then picked towards the other end to do another 180º turn. After completing the last turn they returned to the center and their time was taken as they passed the center pylon.

These two tests were performed on separate days. Each athlete did a minimum of nine repetitions of each test, on each test day, to assess the nine different combinations of seat positions. Recovery between repetitions was at least two minutes in duration. These tests were evaluated during regular London Blizzard practices, and the recovery time was sufficient for the athlete to perform consistently. Each athlete practiced in the test sledge prior to testing.

All tests were completed at the beginning of practice and the test order was randomized. The players were also timed using their own sledges in both tests. All on-ice tests occurred at Western Fair arena (the London Blizzard practice facility) located in London, Ontario. The players used their own sticks for all repetitions in both tests.

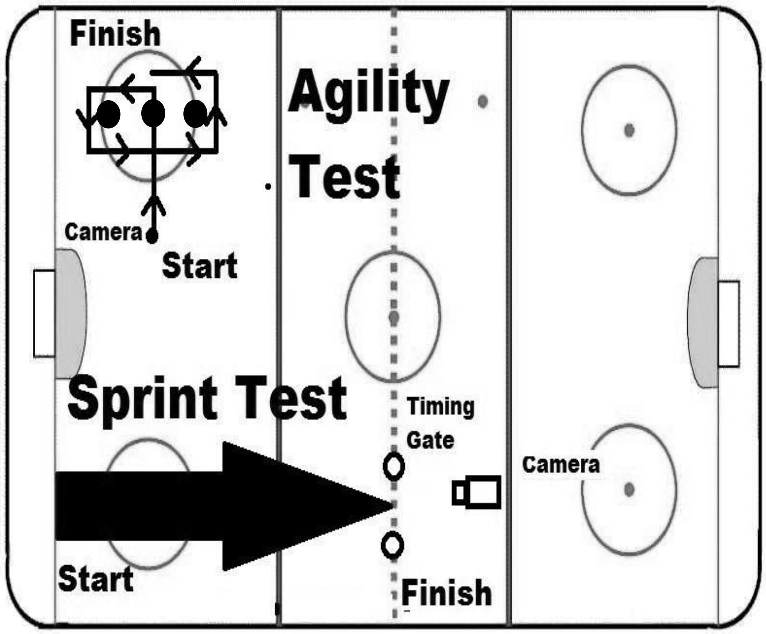


***Figure 23*:** The two tests used in this study: sprint test and agility test.

3.5 Equipment

A set of Mitutoyo digital calipers was used to obtain the measurement of the knuckle heights from the ice surface. The caliper arm was placed on the level floor and then moved vertically until the mark on the knuckle was found. A goniometer (Lafayette Instrument Co.) was used to measure the knee angles of each individual. Timing of each individual test was done exclusively using a Samsung SD Camcorder and reviewed using Windows Live Movie Maker. Windows Live Movie Maker provides a time stamp and the ability to watch frame by frame. Video was taken at the referred locations in *Figure 23*. The camera was positioned so it could see the start, the player, the timing gate (in the sprint test only), and the ending of each test.

Due to the position of the camera in the sprint, a laser timing gate (*Figure 24*) was used to determine the end of each repetition of the test. The timing gate circuit consisted of a light, a resistor and photo resistor connected in series. The laser timer was positioned on a tripod 0.25m above the ice. An external laser was used to illuminate a light on the timing gate. When the player's body shielded the laser, the light shut off because the photo resistor created a large resistance when there is no light.

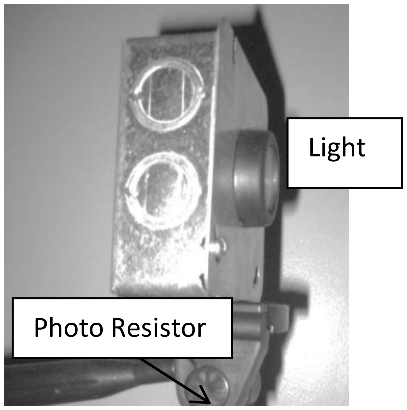


Figure 24**:** Light gate used in sprint test.

3.6 Statistics

Due to the small sample size and different disabilities of the participants, basic statistics such as averages and standard deviations ($p = 0.05$) were chosen for this study. Where applicable, group averages are provided to highlight common preferences in seating amongst the players.

Chapter 4

4 Results

This study began with five players but one was removed because all tests were not completed. This individual was physically able to do all the tests but could not attend his scheduled testing time due to unforeseen circumstances.

4.1 Off-Ice Measurements

The anthropometric data of the four players who participated in this study are presented in Table 8. The seating measurements of stability, knuckle height, and knee angle, were taken of the player in their own sledge, and can be reviewed in Table 9. A picture of each of their positions is shown in *Figure 25*.

Table 8: *Anthropometric data measured from the five sledge hockey players in this study.*

Player	Height (m)	Weight (kg)	Arm Length (m)	Leg Length (m), R/L	Disability
1	1.36	50.5	0.64	0.70/0.58	Spina Bifida
2	1.77	60.6	0.68	0.83/0.84	Cerebral Palsy
3	1.82	75.2	0.69	0.85/0.83	Cerebral Palsy
4	1.625	54.5	0.55	0.71/0.69	Paraplegic

Table 9: *The measurements of stability, knuckle height, and knee angle of each player in their own sledge.*

Player	Stability (m)	Knuckle Height (m)	Knee Angle (deg)
1	0.02	-0.05	110
2	0.05	-0.03	142
3	0.15	0.01	140
4	0.06	0.05	135

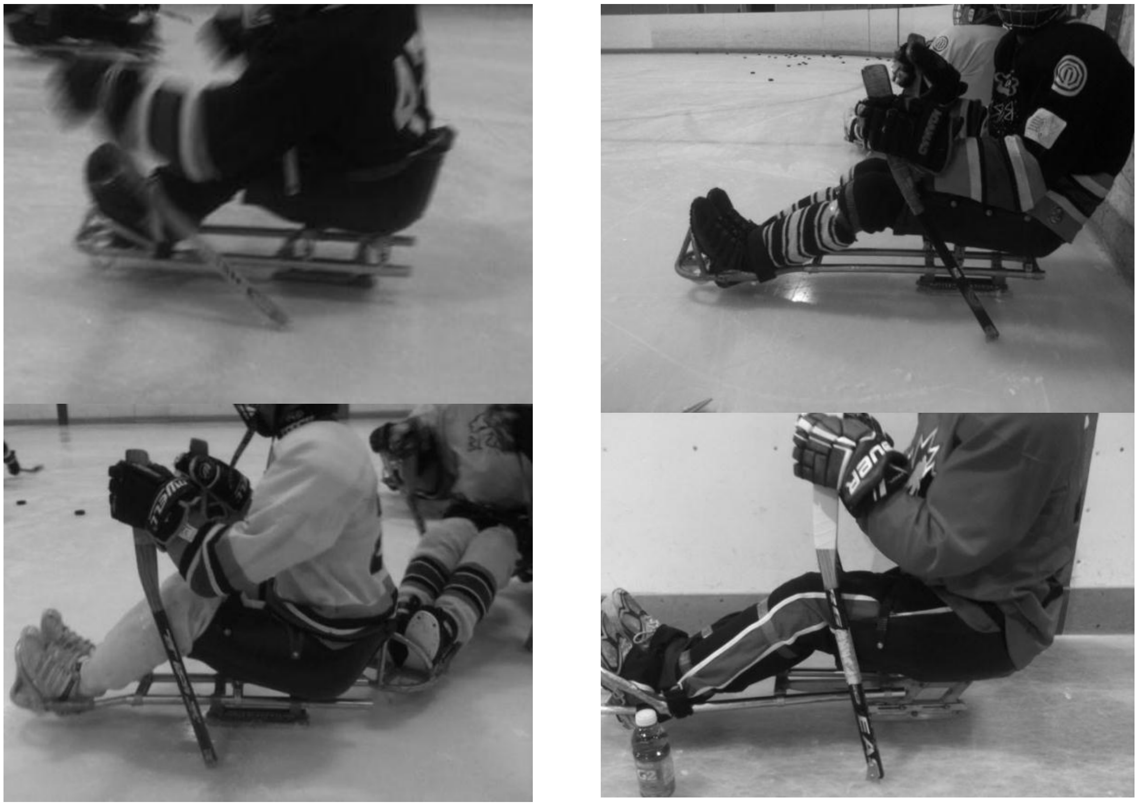


Figure 25**:** Clockwise starting from the top left: player 1-4 position in their own sledge.

For simplification of identifying seating positions, a classification system seen in **Error! Reference source not found.** was assigned to the different measurements taken in the test sledge seen in Table 11.

Table 10: *Number system assigned to the knee angle and seat heights.*

Knee Angle	Assigned #	Knuckle Heights	Assigned #
170	1	Low	L
140	2	Med	M
110	3	High	H

Table 11: *The seating measurements of each player in the test sledge.*

	Stability values for each Knee Angle (m)			Knuckle Height (m)		
Player	1	2	3	L	M	H
1	0.06	0.03	0.03	-0.100	-0.075	-0.050
2	0.04	0.04	0.04	-0.060	-0.035	-0.010
3	0.10	0.08	0.08	-0.025	0.000	0.025
4	0.04	0.04	0.00	0.090	0.115	0.140

4.2 On Ice-Testing

In the sprint test, the average rest time between repetitions was 179$\pm$31 seconds. The average rest between the agility repetitions was 149$\pm$31 seconds. The same criteria for repeating trials were used for both tests. A successful repetition is where the player navigated the course in what they felt was their best effort. All repetitions during the sprint test were completed. Three repetitions of the agility tests had to be repeated because players fell or went off course.

4.2.1 Sprint Test

Among the measurements taken from the players sitting in the test sledge, the fastest average position, in the on-ice sprint test was 2L (i.e., 140° knee angle and low knuckle height), in a time of 7.19s, and the slowest average position, was 3H with a time of 7.83s (Table 12). Individually, each of the players had at least one position that was faster completing the sprint test in the test sledge, than in their own personal sledge (Table 12 and *Figure 26*). Player 1 had six positions in the test sledge where he performed faster than in his own personal sledge: 1M, 1H, 2M, 2H, 3L, and 3M. Player 2 and 3 each had one faster time in the test sledge, than that of their own sledge, and they were both in position 2L. Player 4 had four faster times in the test sledge in positions 1L, 2L, 2M, and 3M, than his own sledge. Individually, player 1's fastest time was in position 3L, player 2's was 2L, player 3's was 2L, and player 4 was 2M.

Table 12: *Sprint data of N =4 players and their respective positions and times in the test sledge and their own sledge (PS).*

	Position and Time(s)									
Player	1L	1M	1H	2L	2M	2H	3L	3M	3H	PS
1	8.20	8.04	8.16	8.32	8.11	8.02	7.68	8.00	8.52	8.2
2	7.77	7.83	7.73	7.36	7.71	7.51	8.47	8.24	8.07	7.42
3	6.33	6.64	6.76	6.26	6.67	6.52	6.80	6.69	6.83	6.32
4	7.31	7.61	7.47	6.83	6.76	7.47	7.46	7.08	7.90	7.44
Avg	7.40	7.53	7.53	7.19	7.31	7.38	7.60	7.50	7.83	7.35
SD	1.60	1.24	1.17	1.75	1.42	1.25	1.38	1.47	1.43	1.55

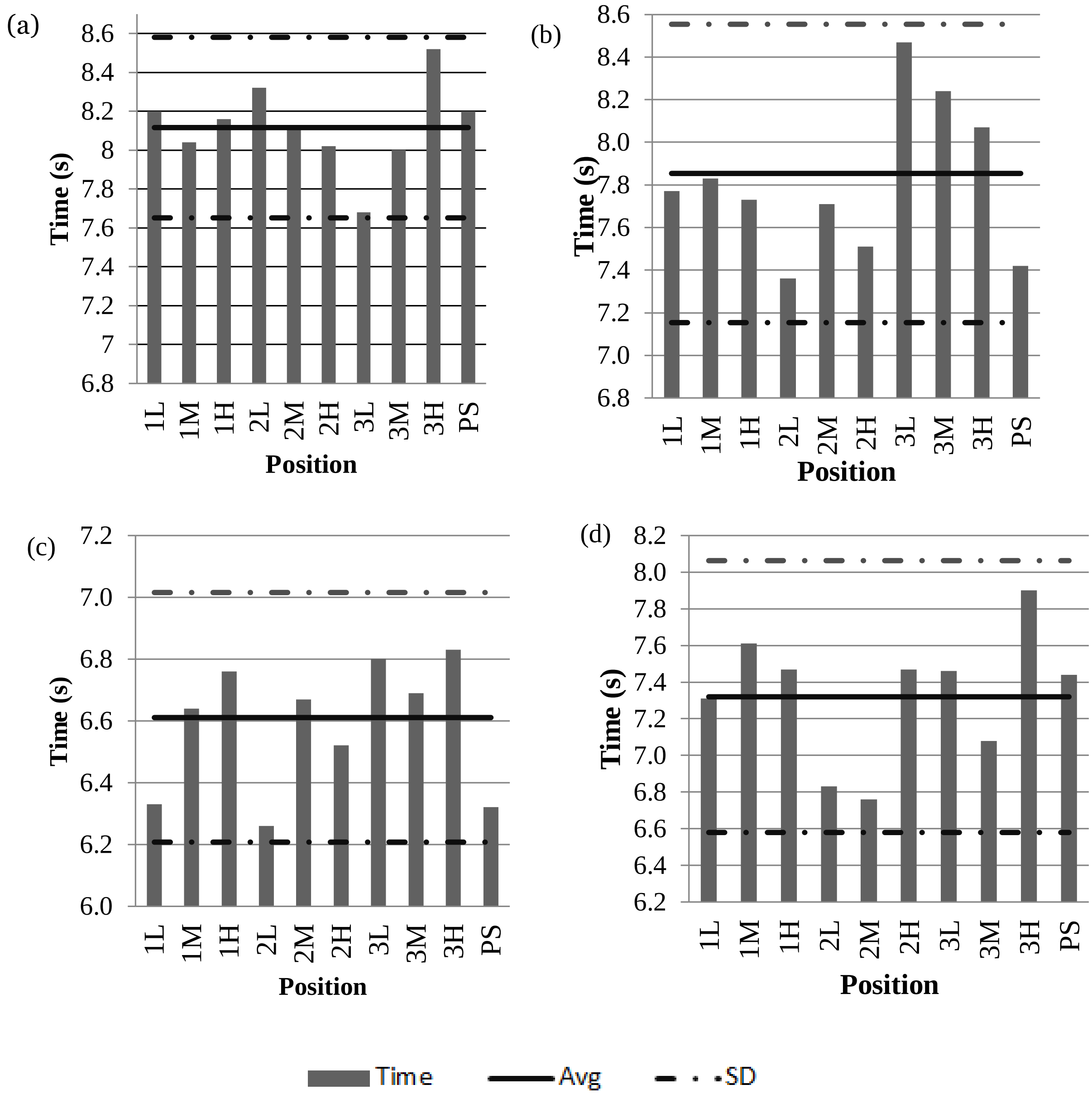


Figure 26: Individual player sprint times, (a) player 1, (b) player 2, (c) player 3, and (d) player 4 in the nine different positions in the test sledge. Refer to Table 9 for position references.

4.2.2 Agility Test

In the on-ice agility test, the fastest average position among the positions of the players measured in the test sledge was 2M, in a time of 12.08s. The slowest average position was 3H, with an average time of 13.23s (Table 13). Individually, each of the players had at least one position that was faster completing the agility test in the test sledge, than in their own personal sledge (*Figure 27*). Individually, player 1 had five positions that were faster in the test sledge, than his own personal sledge. These positions were 2L, 2M, 2H, 3L, and 3H. Player 2 had four positions that produced faster times in the test sledge, than when he repeated the test in his own sledge. These positions were 1M, 2L, 2M, 2H and 3M. Player 3 had three positions that were faster in the test sledge, than his own sledge. His positions were 1H, 2M, and 2H. Player 4 had two positions where he was faster in the test sledge, which were 2H and 3M, than his own sledge. The fastest time for the agility test in the test sledge for player 1 was in position 2L, player 2 was in 1M, player 3 was in 1H, and player 4 was in 3M.

Table 13: *Agility data for N = 4 players in the test sledge and their own sledge (PS).*

Player	1L	1M	1H	2L	2M	2H	3L	3M	3H	PS
1	15.03	14.52	15.61	12.96	13.83	14.03	14.18	15.29	13.96	14.39
2	12.29	11.3	12.58	11.89	11.55	13.3	14.82	11.55	14.45	12.20
3	11.49	11.01	10.23	10.99	10.25	10.42	11.28	11.05	11.63	10.68
4	13.79	12.43	12.89	13.3	12.69	11.97	12.55	11.9	12.88	12.23
Avg	13.15	12.32	12.83	12.29	12.08	12.43	13.21	12.45	13.23	12.38
SD	3.15	3.19	4.41	2.10	3.07	3.18	3.20	3.85	2.50	3.05

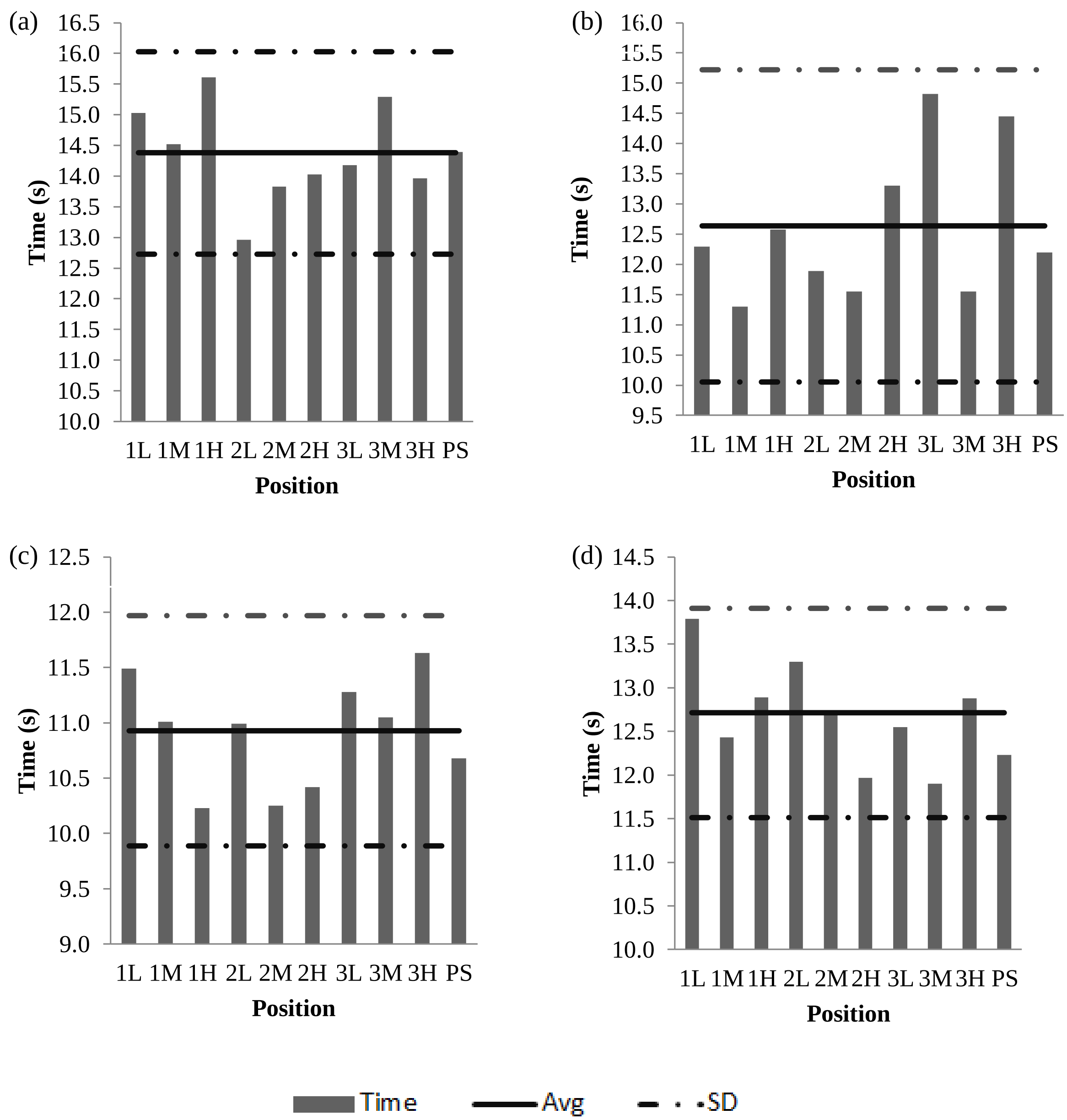


Figure 27: Individual player agility times, (a) player 1, (b) player 2, (c) player 3, and (d) player 4 in the nine different positions in the test sledge. Refer to Table 9 for position references.

4.2.3 Combined Test Results

Times were combined for both tests to see if there was a preferred position amongst each player, for each of the positions in the test sledge. Also for comparison, the times of both tests the player achieved in their own sledge were added (refer to Table 14 for this data).

Individually, player 3 presented the most consistent results for all seating positioning regarding the overall difference of the added times for the two tests, 1.54s difference from his fastest to slowest position. Player 2 had the largest difference of the combined test results with a time of 4.16s. Both player 1 and 4 had differences of combined test times of 2.49s and 2.12s respectively.

Comparing the nine test sledge positions to their own sledge, players 1, 2, and 4 were at least 0.49s faster in the combined tests. Player 3 had a similar time between the test sledge and his own sledge.

Table 14: *Individual player test times combined for the different positions. POS = Position, Diff = Difference between first and present position, PSC= Player sledge combined time.*

Player 1			Player 2			Player 3			Player 4		
POS	T (s)	Diff	POS	T (s)	Diff	POS	T (s)	Diff	POS	T (s)	Diff
2L	21.28		1M	19.13		2M	16.92		3M	18.98	
3L	21.86	-0.58	2L	19.25	-0.12	2H	16.94	-0.02	2H	19.44	-0.46
2M	21.94	-0.66	2M	19.26	-0.13	1H	16.99	-0.07	2M	19.45	-0.47
2H	22.05	-0.77	3M	19.79	-0.66	2L	17.25	-0.33	3L	20.01	-1.03
3H	22.48	-1.2	1L	20.06	-0.93	1M	17.65	-0.73	1M	20.04	-1.06
1M	22.56	-1.28	1H	20.31	-1.18	3M	17.74	-0.82	2L	20.13	-1.15
1L	23.23	-1.95	2H	20.81	-1.68	1L	17.82	-0.9	1H	20.36	-1.38
3M	23.29	-2.01	3H	22.52	-3.39	3L	18.08	-1.16	3H	20.78	-1.8
1H	23.77	-2.49	3L	23.29	-4.16	3H	18.46	-1.54	1L	21.1	-2.12
Avg	22.50			20.49			17.54			20.03	
STD	1.61			2.97			1.10			1.34	
PSC	22.59			19.62			17.00			19.67	

Chapter 5

5 Discussion

Each player achieved at least one faster time in both tests when positioned in the test sledge, as compared to their own sledge. These findings suggest that the sledge hockey players involved in this study, can improve their current position in their sledge, and that their performance can be improved with a change in position. Significance of these findings is low based on the small sample size. However, this study had a small, consistent group of sledge hockey players selected after almost two years of evaluation. A larger subject group was not feasible for this current study, considering the small population of sledge athletes from the surrounding area.

5.1 Off-Ice Measurements

The measurements used for evaluating the position of each player was an improvement from pilot study two. Measuring knee angle and stability were easier to evaluate because of the graduated measurements on the rails, and seat posts, of the test sledge. In the future, improvements could be made to the test sledge, such as the vertical seat height adjustment. Controlling the height variation was restricted by the front seat post which at its lowest point put the center of the seat at 0.14m above the ice, thus this point is well above the lowest seat height of 0.085m that is allowed by the rules of the game. To accommodate a lower seat height with the same construction, the test sledge would have needed different seat posts. Ideally, the rear and front posts would have been of the same design, but this was an afterthought and is a recommendation for creating a future test sledge.

The stability measurement, as a replacement for the traditional trial and error positioning, provided information pertaining to their seating at different knee angles. Comparing the stability data of the players in their own sledge, against the nine positions of the test sledge in Table 9, these measurements had minimal differences, except for player 3. Referring to pilot study two, these differences in stability are perhaps from materials added to the player’s sledge, which were prohibited in the test sledge. Actually measuring stability is not required for future coaches and athletes, as trial and error is an acceptable method for placing the skates relative to the seat. The stability procedure is useful if a player is searching for optimal positioning in their sledge.

The seat height measurement based on knuckle height, was useful if comparisons between players seated in different models of sledges needed to be made. With several versions of sledges available to purchase, and players using their own materials in the seat, having a graduated system installed on the risers of the sledge would allow athlete and coach to more accurately try different seated positions. As shown in this study, differences in seat height of 0.05m produced varying performances, suggesting that small adjustments can change the performance dramatically. Thus, sledge hockey players should be aware that replication of their seating is very important when testing different positions.

Using knee angle instead of measuring tilt, as suggested in pilot study two, was a more effective approach of evaluating different positions of the players. A recommendation for determining optimal knee angle should begin with the athlete's legs at a 140º knee angle, as this was on average the fastest position from the player's on-ice test results. This study evaluated a large range of knee angles which, for a coach or athlete trying to fine tune their position, is not necessary. Smaller changes of 10-15º should be used to determine optimal position for the player in the sledge.

Of the four participants of this study, only player 2 and 3 had similar disabilities. There are several grades of cerebral palsy, their shared disability, but this information was not obtained. The results for both on-ice tests show measurable differences in player skill level. This could be due to a number of factors, although player disability was a likely cause. A recent study done by Molik et al. (2012) analyzed elite sledge hockey players and concluded that there were no measureable differences in skill (n=114) based on their own skills observation assessment. The authors stated that lower functioning athletes are not represented at higher levels (National and Olympics) and that sledge hockey would have to change their classification if this population is to be represented. This statement supports Stuart's (2010) argument that testing for functionality is critical for disability competition. Future work is needed to develop an on-ice evaluation test that assesses sledge hockey player functionality. Then comparisons can be made between athletes of same ability instead of disability.

5.2 On Ice Testing

The tests used in this study were suitable to analyze the different player positions. The sprint test would be ideal for coaches who have a new player and want to try different positions in the sledge. The agility test would be most beneficial for athletes who want to optimize their positions in their sledge, as turning is quite prevalent in sledge hockey games (refer to pilot study three).

Multiple trials would have been useful to validate each position. However, there were constraints to the amount of time for testing, as the participants were only available during their one on-ice practice each week. More test sledges or test days would be required for gathering additional data.

There were variations of the rest times due to changing the seating positions in the sledge. For the majority of the tests, the rest time was similar for all the players. When a player had to repeat a repetition, they took the standard two minute rest before attempting the test again.

5.2.1 Sprint Test

Performances from the sprint test revealed the players performed best at similar positioning to that of their own sledge. This would suggest that current players who self-select their own position are able to optimally configure their sledge for sprinting in a straight line.

Players shared similar preference in seat height as the fastest times were set in the low or medium height position. This observation is similar to findings of wheelchair sports studies, where athletes favour a lower COG (Boninger et al., 2000; Masse et al., 1992). Increased propulsion from a lower seat height could be from increased picking, as the athlete would be able to contact the ice sooner as compared to picking in a higher seated position. An additional benefit of the lower COG, could be increasing power transfer from the player to the ice. This could mean longer contact time, or higher average force generated by sitting in a lower position, or a combination of both. These postulations should be confirmed in future studies.

For the knee angle, three of the players had their fastest times with a 140º, similar to the Canadian National Sledge Hockey team. Future testing should focus on smaller increments, starting with a knee angle 140 º to determine if there may be a knee angle that produces better performances.

Results from the player's sprint data show that here are no obvious trends (*Figure 26*). More trials and subjects are necessary to determine if there may be trends in the data regarding seat height and knee angle with respect to performance in the sprint test.

5.2.2 Agility Test

The players' fastest individual times in the agility test were achieved in different positions from both their own sledge and the sprint test (Table 13). This demonstrates the necessity of the agility test for evaluating the players' positions. However, these results were puzzling, as there were no obvious trends from the individual player data shown in *Figure 27*. The fastest times seem to be reached at seating positions, although, the average illustrates that players who sat with a 140 º knee angle had the fastest times, similar to the sprint test.

Individually, player 3 completed the agility test in the least amount of time, similar to the sprint test. Interpretation of his data found in *Figure 27* is difficult, as he appears to perform superiorly in positions 1H-2M, albeit, position 2L was well above the average of the three other values. Similarly, player 2 would seem to have a trend of fast positions from 1M-2M, except 1H was a high value. Player 2 also completed the agility test in less time in the 3M position. This seems uncharacteristic as 3L and 3H were both well above the standard deviation. Player 1 had a fast time in position 2L; however, the rest of the data is unclear. Player 4's results are ambiguous and difficult to interpret.

Some suggested reasons for the inconsistencies in the data could be explained by the test sledge being heavier than the player's personal sledge, the test sledge seat provided more security to the pelvic region of the player than their personal sledge, and the skate blade width was different on the test sledge than the player's sledge. The test sledge mass was heavier due to the added features, and typically in sport, lighter is faster, especially for human propulsion (for example cycling). This would suggest that if the player positioned in the test sledge, is faster than the position in their own sledge, than the player's position in their own sledge is not optimal, and supports the reasoning for this study. When the player produced a faster time in the test sledge compared to their own sledge in the same position, the Hawthorne effect, or other factors expressed could have contributed to the improved performance. Possibly the seat of the test sledge provided increased postural support by securing the pelvic region in the seat, which helped the player turn faster. Also, the skate blade width of the test sledge may have provided an advantage to some of the players by increasing balance. An elite athlete would likely produce consistent performances on varying skate blade widths. Lesser athletes may or may not have improved with the recommended skate blade width setting on the test sledge. More repetitions of the different measurements in both on-ice tests are required for developing more distinct conclusions.

5.3.3 Combined Tests

The combined test data shown in Table 14 reveals a lot about the relationship between the players chosen sledge position. Player 3 had his lowest time in position 2M and his own sledge position is similar. Position 2M was also an ideal position for the other three players. The combined test results suggest that position 2M is a biomechanically efficient position. Masse et al. (1992) similarly found in their study that more biomechanically efficient wheelchair users shared similar positions.

Individually, each player's overall fastest combined test position differed. Positional preference could be from the athlete's disability. Similar to wheelchair construction, customization of the sledge would have to occur for optimizing the position for each player to account for their disability (Cooper, 1990; Macleish et al., 1993).

The data presented in Table 14 shows that all players can optimize performance by changing their current positions. Player 1 for example had several positions faster than his own sledge, which translates into 1.22s or a 5.8% performance improvement compared with his current position. Player 2 and 4 could both optimize their position and gain 2.5% and 3.5% in performance. Even player 3 could gain 0.5% in combined performance times by changing his current position, with one of the test positions. The combined data suggests that elite sledge athletes have optimally positioned themselves, while less skilled players require more assistance in finding their optimal position.

Chapter 6

6 Conclusions

Measuring important seating factors such as knee angle, stability, and seat height on a collective group of experienced sledge hockey players provided insight into establishing a baseline position for coaches and athletes. Currently, players who self-adjust their sledges were likely to have positions favorable for sprinting but not for agility. This study also indicates elite level athletes may have more efficient positions but can still improve their arrangement in the sledge.

The results suggest that similar to Canadian National sledge hockey team player's, a biomechanically efficient position for a sledge hockey player in their sledge is with a knee angle of 140º, and with a low seat height where the knuckles of the players can easily touch the ice. Future recommendations are for athletes to begin in this position, and then try small changes in knee angles and seat heights to find their optimal position.

Similar to other adaptive sports, seating preferences for sledge athletes require individual attention because of the athlete's disability. Additionally, athletes with lower functionality and motor control require more consideration for positional setup in a sledge. A recommendation is to have a device like the test sledge to assist athletes to find their preference in seating.

The on-ice tests used in this study were helpful for evaluating the player's position in the sledge. The sprint test gives immediate feedback regarding the player's position, and setup time is minimal. The agility test provides more realistic simulation of a game situation, but takes more setup time. Coaches and athletes can narrow their position selection using sprint test and then use the agility test to find an optimal position of the player in the sledge.

Recommended future work for clinicians, manufacturers, sledge hockey players, and coaches include improving the materials inside the seat for providing security of the hips and pelvis. A proper setup is crucial for athletic performance. However, if the athlete cannot remain in their desired position because of the equipment limitations, performance will always be suboptimal.

References

ACE Centre North. (2000). The Importance of Good Seating The Importance of Good Seating. *North*. Retrieved January 25, 2010, from www.ace-north.org.uk

Athletics, E. (2010). Picture on left of female wheelchair athlete. Retrieved August 10, 2011, from http://www.englandathletics.org/library-media/images/wheelchair_racer.jpg

Beckman, E., Kudlacek, M., & Vanlandewijick, Y. (2007). Development of a skills observation protocol for sledge ice hockey-pilot study. *Gymn.*, *37*(1), 45.

Behm, D., Wahl, M., Button, D., Power, K., & Anderson, K. (2005). Relationship between hockey skating speed and selected performance measures. *J Strength Cond Res*, *19*(2), 326-31.

Boninger, M., Baldwin, M., Cooper, R., Koontz, A., & Chan, L. (2000). Manual wheelchair pushrim biomechanics and axle position. *Arch Phys Med Rehabil*, *81*(5), 608-13.

Cooper, R. (1990). Wheelchair racing sports science: A review. *J Rehabil Res Dev*, *27*(3), 295.

Ergocentric. (2012). The Anatomy and Biochemisty of the Human Body. Retrieved March 14, 2012, from http://www.ergocentric.com/segments.asp?code=M2Eseg4

Everest, H., & Jennings, H. (1937). Folding wheelchair, Patent No. 2095411. Washington, DC: U.S. Patent Trademark Office.

Goosey-Tolfrey, V. (2010). *Wheelchair Sport* (1st ed., pp. 30-44). Champaign, IL: Human Kinetics.

Green, H., Bishop, P., Houston, M., McKillop, R., Norman, R., & Stothart, P. (1976). Time motion and physiological assessments of ice hockey performance. *J Appl Physiol.*, *40*(2), 159-63.

Guo, L.-yuen, Su, F.-C., & An, K.-N. (2006). Effect of handrim diameter on manual wheelchair propulsion : Mechanical energy and power flow analysis. *Clin Biomech*, *21*, 107-115.

Hansen, R. (1980). Older racing wheelchair circa 1970s. Retrieved February 27, 2012, from http://www.google.ca/imgres?q=rick+hansen&um=1&hl=en&sa=N&biw=1366&bih=566&tbm=isch&tbnid=LU90LEvabXV-zM:&imgrefurl=http://www.abbott.ca/dotca/url/content/en_CA/40.10.80:80/general_content/General_Content_00279.htm&docid=JFqZNMVLwyy6CM&imgurl=http:/

/www.abbott.ca/static/cms_workspace/en_CA/content/image/photo-rickhansen.jpg&w=378&h=221&ei=a8ZLT7PMHqHK0AHNoPD1DQ&zoom=1&iact=rc&dur=279&sig=102581199732788340763&page=1&tbnh=126&tbnw=215&start=0&ndsp=13&ved=1t:429,r:6,s:0&tx=105&ty=57

Helander, M. (2003). Forget about ergonomics in chair design? Focus on aesthetics and comfort! *Ergonomics*, *46*(13-14), 1306-19.

Helander, M., & Zhang, L. (1997). Field studies of comfort and discomfort in sitting. *Ergonomics*, *40*(9), 895-915.

Hetzler, R., Stickley, D., Lundquist, K., & Kimura, I. (2008). Reliability and Accuracy of Handheld Stopwatches Compared With Electronic Timing in Measuring Sprint Performance. *J Strength Cond Res*, *22*(6), 1969-1976.

IIHF. (2010). Survey of Ice Hockey Players. Retrieved May 10, 2011, from http://www.iihf.com/iihf-home/the-iihf/survey-of-players.html

IPC. (2011). Rules from the International Paralympic Committee, Section 2.6: Classification. Retrieved January 11, 2011, from http://www.ipc-icesledgehockey.org/export/sites/ipc_sports_ice_sledge_hockey/Rules/2009-2010-IPC_Sledge_Hockey_Regulations_v1.4.pdf

IPC. (2012). International Paralympic Committee Historical Results Database. *Athletes*. Retrieved March 21, 2012, from http://www.paralympic.org/Athletes/Results

Kroemer, K. (2006). *"Extra Ordinary" Ergonomics - How to accomodate big and small persons, the disabled and elderly, expectand mothers, and children.* (1st ed., pp. 40-45). Boca Raton: CRC Press.

Lafontaine, D., Lamontagne, M., & Lockwood, K. (2004). Time motion analysis of ice-hockey skills during games. *Unpublished Research*.

Macleish, M., Cooper, R., Harralson, J., & Ster, J. (1993). Design of a composite monocoque frame racing wheelchair. *J Rehabil Res Dev Res.*, *30*(2), 233-249.

Mascaro, T., Seaver, B., & Swanson, L. (1992). Prediction of skating speed with off-ice testing in professional hockey players. *J Orthop Sports Phys Ther*, *15*(2), 92-8.

Masse, L., Lamontagne, M., & O'Riain, M. (1992). Biomechanical analysis of wheelchair propulsion for various seating positions. *J Rehabil Res Dev*, *29*(3), 12-18.

Mellion, M. (1991). Common cycling injuries. Management and prevention. *Sports Med*, *11*(1), 52-70.

Molik, B., Morgulec-adamowicz, N., Kosmol, A., Yilla, A. B., Filipkowska, A., Lewandowski, M., Pijanowska, J., et al. (2012). Game Performance in Ice Sledge Hockey : An Exploratory Examination Into Type of Disability and Anthropometric Parameters. *Clin J Sport Med*, *22*(1), 65-69.

Occhipinti, E., Colombini, D., Molteni, G., & Grieco, A. (1993). Criteria for the ergonomic evaluation of work chairs. *Med Lav*, *84*(4), 274-85.

Peddie, D. (1995). Time-motion analysis and heart rate telemetry of ice hockey play. *Unpublished Manuscript*.

Spokes n Motion. (2010). Cross Country Skiing. Retrieved December 10, 2010, from http://www.spokesnmotion.com/

Street, R. (2010). Fastest Skater NHL All-Star Competition. *Fastest Skater*. Retrieved May 10, 2010, from http://www.rauzulusstreet.com/hockey/nhlallstar/allsuperskills.htm

Stuart, M. (2010). Medical Aspects of Paralympic Sport. *SIRC Newsletter March*. Retrieved May 10, 2010, from http://www.sirc.ca/newsletters/march10/documents/45526228.pdf

Tessier. (2010). Tessier Down Hill Ski Picture. Retrieved December 10, 2010, from http://www.dualski.com/en/sieges/

Top End Sports. (2010). Positional Setup of the Racing Wheelchair. Retrieved May 10, 2010, from http://www.topendwheelchair.com/faq/details.asp?ID=4

Vanlandewijck, Y., Theisen, D., & Daly, D. (2001). Wheelchair Propulsion Biomechanics: Implications for Wheelchair Sports. *Sports Medicine*, *31*(5), 339-367.

Walsh, C., Marchiori, G., & Steadward, R. (1986). Effect of seat position on maximal linear velocity in wheelchair sprinting. *Can J Appl Sport Sci.*, *11*(4), 186-90.

Webborn, N., Willick, S., & Reeser, J. (2006). Injuries among disabled athletes during the 2002 Winter Paralympic Games. *Med Sci Sports Exerc*, *38*(5), 811-5.

Van der Woude, L. (1990). Seat height in hand rim wheelchair propulsion. A follow-up study. *Rehab Sci.*, *3*(3), 79-83.

Appendices

Appendix A: Sledge hockey questionnaire

Information About You

Position:

☐	**Forward**	☐	**Assistant Coach**
☐	**Defenseman**	☐	**Trainer**
☐	**Goalie**	☐	**Volunteer**
☐	**Coach**	☐	**Casual Player**

Years Played:

☐	**Less than one year**	☐	**Five to nine years**
☐	**One to two years**	☐	**Ten to nineteen years**
☐	**Three to four years**	☐	**Twenty years or more**

Feedback About The Sledge

Please Note Which Brand/Model You Own/Play with:	No	Maybe	Yes
1. I enjoy playing sledge hockey	☐	☐	☐
2. The cost for the sledge is fair	☐	☐	☐
3. I like the look of my sledge	☐	☐	☐
4. I've been very happy with my sledge	☐	☐	☐
5. I change the position of my sledge on a regular basis	☐	☐	☐
6. My seat is comfortable	☐	☐	☐
7. I play contact hockey (checking)	☐	☐	☐
8. I have to fix my sledge at least once a month	☐	☐	☐

If there is one that I would change about my sledge it would be:

Appendix B: Example of sledge hockey time motion analysis data

Table 15: *Example of time motional analysis data collected from pilot study three.*

Movie	Accelerating		Poling		Gliding		Stopping		Open Ice		Against Boards		Stick Handling		Turning	
Shift	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
	10.07	12	19	24	11.53	14.43	16	19					14.43	16		
	24.79	26.27			26.27	28									24	24.79
5965																
	34.86	*38.27*	*19*	*24*	*37.8*	*42.43*	*16*	*19*	*0*	*0*	*0*	*0*	*14.43*	*16*	*24*	*24.79*
	3.41		5		4.63		3		0		0		1.57		0.79	
	1.65	4.4	0	1.65			5	11.62			4.4	5			14.81	16.04
5964			11.62	14.81	16.04	18.4										
	1.65	*4.4*	*11.62*	*16.46*	*16.04*	*18.4*	*5*	*11.62*	*0*	*0*	*4.4*	*5*	*0*	*0*	*14.81*	*16.04*
	2.75		4.84		2.36		6.62		0		0.6		0		1.23	
	26.63	32.12	6.76	7.97	11.19	15.2	33	39.12	7.97	8.23	32.12	33			8.23	11.19
	50.16	57.84	19.23	20.71	22.74	26.63			90.58	92.36	39.12	41.46			15.2	19.23
	72.79	80.11	43.72	48.66	48.66	50.16					60.43	63.86			20.71	22.74
	85.85	87.92	58.2	59.47	65.36	70.13									41.46	43.72
	100.53	103.51	109.11	113.72	70.67	72.79									57.84	58.2
	118.68	122.7			80.11	84									59.47	60.43
					92.36	96.58									63.86	65.36
5966					98.33	100.53									70.13	70.67
					103.51	107.61									84	85.85
					116.07	118.68									87.92	90.58
															96.58	98.33
															107.61	109.11
															113.72	116.07
	454.6	*484.2*	*237*	*250.5*	*709*	*742.3*	*33*	*39.12*	*98.55*	*100.6*	*131.7*	*138.3*	*0*	*0*	*826.7*	*851.5*
	29.56		13.51		33.31		6.12		2.04		6.65		0		24.75	

Some notes about the table:

Movie/Shift – Each movie equals one shift. The movie number was used for referencing the video recorded name.

Start and End – Represents the time where the player began or ended the specified skill

Low Intensity Picking – Was quantified from the sum of poling, gliding, stick handling, and turning for each shift.

High Intensity Picking – Was quantified from accelerating.

Stopping – Was quantified from stopping, open ice, and against boards.

Totals for each shift- The last line in each movie/shift is the total time spent doing the specified skill.

Number of instances – These were counted from the table of data. For example, the player would have had one instance of puck possession from the three shifts shown in Table 15.

Appendix C: Ethics letter of information

Seating Procedure for Sledge Hockey

Letter of Information
Version December 1, 2011

Principal Investigator:
Dr. Volker Nolte

Co-investigator:
Cliff Worden-Rogers

Experiment
"Seating Procedure for Sledge Hockey" is a research project designed to analyze different positions of the seat in sledge hockey. This study will hopefully lead to a procedure in setting up players by improving their biomechanics.

Physical Demands
As an athlete who currently participates in sledge hockey, you are being invited to take part in this project. Should you agree to participate, you will be asked to perform a series of on ice tests in different seated positions. The tests will be comprised of a straight line sprint test and an agility test (skating around pylons). You will be required to do a minimum of 18 runs (9 for each test). You will be given an allotted rest time of 2 minutes between each run. You will be given a week of rest between each set of tests. Each test day will take about 30 minutes to complete. The following measurements will also be taken: body height, body weight, arm length, and leg length.

Time Commitment
Participation in this study will take roughly 30 minutes of your time on three separate occasions. The three different sessions will be five to seven days apart. The first session you participate in will involve measurements of you, your sledge, and you in the adjustable test sledge. The second and third session will involve you and the test sledge doing the on-ice efforts.

Risks
The risks in taking part in this study should be no greater than that you face in the regular training you do for your sport. In the unlikely event that an injury does occur, the first aid and emergency procedures at the Western Fair Grounds will be followed. All emergency procedures are in place and the team trainers are always present to deal with any possible injuries that may occur.

Benefits
Information garnered in this study may be useful for your own training and will be shared with you if you desire. Sprint training and agility training can be beneficial to a sledge hockey player. The testing that will be conducted will help identify which seating procedure will be most beneficial for you.

Confidentiality
The information collected in this study will be kept indefinitely. No permanent information will be kept linking your name to your performance in testing. This information may be published in a future study but neither your name nor identity will ever be publicly released.

Participation
Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time without impact on your current or future participation in sledge hockey.

Questions
If you have any questions about your rights as a research participant or the conduct of the study you may contact the director of the Office of Research Ethics.

Seating Procedure for Sledge Hockey

Consent Form

Principal Investigator:
Dr. Volker Nolte

Co-investigator:
Cliff Worden-Rogers

‘

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Participant
Name (please print)__________________________ Signature_______________________

Date____Location_______________________

Investigator
Name (please print)__________________________ Signature_______________________

Date____Location_______________________

Curriculum Vitae

Name:	Cliff Worden-Rogers
Post-secondary Education and Degrees:	University of New Brunswick Fredericton, New Brunswick, Canada 2002-2007 B.Sc.
	The University of Western Ontario London, Ontario, Canada 2010-2012 M. Sc.
Honours and Awards:	Summer Company Government of Ontario 2011
Related Work Experience	Teaching Assistant The University of Western Ontario 2011-2012