

## CHAPTER 1

### INTRODUCTION & AIM

#### 1.1. Introduction

Cardiorespiratory endurance or aerobic capacity is generally recognized as a major component in the evaluation of physical fitness and maximal oxygen consumption ( $\dot{V}O_2$  max) is considered the most valid measure (criterion measure) of cardiorespiratory fitness (Gabbard, 1992; Fox, Bowers & Foss 1993; ACSM, 2006). These are essential aspects of performance in team sports such as ice-hockey (the focus of this study), not only in endurance events. Although direct measurement (laboratory-based testing) is the single best measure of cardiorespiratory fitness or aerobic capacity, these laboratory-based tests have many disadvantages, more particularly in that they require extensive and sophisticated equipment, they are time consuming, and costly, and they are restricted to testing one subject at a time. Furthermore, laboratory-based tests are restricted to exercise on a treadmill, cycle or simulation ergometre, with the subject required to wear a mask, attached to a gas analyser, and they require the subject to remain close to the equipment (restricting factors). Other disadvantages include unfamiliarity and discomfort in the artificial conditions when compared to the actual sporting event, and this often affects the results obtained. Laboratory tests, also, often do not take into account the specificity of the muscular requirement for a given sport (Léger & Boucher, 1980; Ahmaidi *et al.*, 1992; Grant *et al.*, 1995).

Although direct measurement of  $\dot{V}O_2$  max (aerobic capacity) is widely utilised, most laboratory based tests specific to ice-hockey measure variables related to anaerobic metabolism. Montgomery (1988) states that results from aerobic and anaerobic laboratory tests should be used with caution if the objective is

to evaluate the fitness of elite ice-hockey players. Indirect measurements (field-based tests) where  $\dot{V}O_2$  max is estimated from performance tend to be more sports-specific, have better utility for coaches and athletes, and have many advantages, namely: they do not require extensive and sophisticated laboratory equipment, allow for groups of athletes to be tested simultaneously, and are less expensive and time consuming.

Field-based tests have been designed for endurance runners (Léger & Boucher, 1980) and intermittent shuttle running sports such as soccer and basketball (Léger *et al.*, 1988). There has recently been a movement towards testing athletes in a sport specific environment in a variety of different sports, such as cross-country skiing (Doyon *et al.*, 2001; Vergès *et al.*, 2006), badminton (Chin *et al.*, 1995), cycling (Ricci & Léger, 1983; Marion & Léger, 1988), swimming (Monpetit *et al.*, 1981), water polo (Rechichi, Dawson & Lawrence, 2000), and soccer (Nicholas, Nuttall & Williams, 2000; Labsy *et al.*, 2004).

Sport specific tests are highly valued in sport science. The physiological assessment of athletes in their natural training and competition environment, such as a functional skating capacity test (performance test), provides information on the acute adaptation to specific activities (which may be different to the adaptations found in the laboratory during treadmill running and cycling), and ability to perform aerobic skating in ice-hockey (Léger, Seliger & Bassard, 1979; Léger *et al.*, 1988; Montgomery, 1988). Such tools also appear more informative than a  $\dot{V}O_2$  max score to establish the ability of a skater to perform aerobic skating (Léger, Seliger & Bassard, 1979), and also more accurately reflect "true" values (Ferguson, Marcotte & Monpetit, 1969). Furthermore, Léger, Seliger & Bassard (1979) demonstrated that ice-hockey players as compared to runners had a greater mechanical efficiency while skating on the ice (difference of 15%) and a lower mechanical efficiency on the treadmill (difference of 7.9%).

Aerobic capacity is a key parameter for endurance performance even for a highly anaerobic and high-speed intermittent sport such as ice hockey (Montgomery, 2006). It is also well known that  $\dot{V}O_2$  max values are specific to the muscles used and the type of activity used by subjects in their training regimen (Léger, Seliger & Bassard, 1980, Mc Ardle *et al.*, 1978).

In day-to-day practice, many coaches use the 20 m shuttle running test to assess aerobic fitness of their ice hockey players. However, some specialists question this approach since it is not specific enough, running is not skating. For these reasons a test that is skating specific without any respiratory equipment and specialized expertise is perceived as a real advantage (Léger *et al.*, 1988; Boreham, Paliczka & Nichols, 1990).

In the seventies, researchers at Université de Montréal measured the  $\dot{V}O_2$  max of subjects while ice-skating on oval or shuttle courses, using a maximal multistage intermittent protocol with 3 to 5 minute stages and 5 to 10 minute recovery to empty the meteorological balloons at the end of each stage (Ferguson, Marcotte & Monpetit, 1969; Larivière, Lavallée & Shepard, 1976; Léger, Seliger & Bassard, 1979; Léger, 1981; Simard, 1976). Except for the study by Larivière, Lavallée & Shepard (1976), the purpose of these studies was to compare ice skating  $\dot{V}O_2$  to treadmill  $\dot{V}O_2$  in different conditions and to establish energy cost of skating at different velocities. Due to the small number of subjects in these studies, regressions to predict  $\dot{V}O_2$  max from the ice-skating performance could, however, not be established. Another limitation in these results was that subjects were wearing gas collection systems during these studies, which affected the performance and the regression between maximal skating speed and  $\dot{V}O_2$  max. Even so, the correlations were above 0.8. Two exceptions to these studies were Larivière, Lavallée & Shepard (1976) and Kuisis (2003). In Larivière, Lavallée & Shepard (1976) the hockey players skated back and forth over a course that measured 100 ft (~30 m), but the validity criteria used was the PWC<sub>170</sub> which is itself a more or less valid test. The correlation obtained was only 0.53 with 68 young

hockey players (8-17 years). More recently Kuisis (2003) used a 20 m skating course, using the maximal multistage 20 m shuttle running test (Léger *et al.*, 1988) as the criterion variable, with a correlation of 0.73.

Montgomery's group from McGill University in Montreal (Nobles *et al.* 2003) developed a skating treadmill protocol. It reported lower  $\dot{V}O_2$  values at sub maximal speed on the ice vs. skating treadmill but similar maximal values. No correlation was reported between maximal ice skating speed (or treadmill skating speed) and  $\dot{V}O_2$  max measures.

A skating treadmill protocol is certainly more specific than a running treadmill protocol to assess aerobic fitness of skaters but is in no way comparable to ice skating and is much less accessible, and more expensive, than ice skating or ground running field tests. However, few studies have been done specifically to develop an ice skating field test to assess aerobic fitness of hockey players and figure skaters.

In 2001, Kuisis and van Heerden experimented using the maximal multistage 20 m shuttle run protocol on the ice with subjects wearing their respective competition equipment plus the Aerosport  $\dot{V}O_2$  system, in five young male ice hockey players ( $17.8 \pm 1.8$  years old) and nine adolescent female figure skaters ( $15.3 \pm 4.1$  year old). They demonstrated that the equation developed for running overestimated  $\dot{V}O_2$  max as directly measured on ice with an Aerosport portable system. However, the number of subjects in each group of subjects was too small to develop regressions to predict  $\dot{V}O_2$  max from the maximal speed achieved during the maximal continuous multistage stop and go 20-m shuttle skating test.

## 1.2. Recent Developments in the Field of Ice-Skating

Recently three new skating tests to assess aerobic fitness have emerged. Kuisis (2003) used velocity of motion (n=45), energy expenditure (n=10), and mechanical efficiency (n=10) to modify the original running 20 MST (Léger *et al.*, 1988) for ice, using the same procedures, but with reduced time allowed to complete each stage of the test. The test proved reliable ( $r=0.87$ ; n=15) and showed good concurrent validity ( $r=0.73$ ; n=10), but did not conclusively prove the validity of the new skating test. This test is continuous, maximal, and progressive in nature, with frequent stop-and-go over distance of 20 m, wearing full kit.

Leone *et al.* (2007) recently submitted a manuscript where the performance during a maximal intermittent (1 minute/0.5 minute work/rest ratio) multistage 45 m ice-skating shuttle test with stop and go, wearing full ice hockey equipment (Skating Maximal Aerobic Test or SMAT), was compared to the  $\dot{V}O_2$  max measured during that test with the retro-extrapolation method (Léger *et al.*, 1982). The oxygen uptake was assessed at submaximal and maximal velocities during an on-ice intermittent maximal multistage shuttle skate test (n=30 age-group elite hockey players,  $14.7 \pm 1.5$  years). The comparison between the running 20 MST and SMAT (112 males and 31 females) revealed that boys reached significant higher values of  $\dot{V}O_2$  max in the SMAT ( $\sim 5$  ml  $\text{kg}^{-1}$   $\text{min}^{-1}$ ,  $p \leq 0.01$ ) which was not the case for girls ( $p > 0.05$ ). The correlation coefficient between the skate test and the run test was modest, with  $r=0.69$  for boys and  $r=0.47$  for girls, which indicated that the running 20 MST shared respectively only 48.2% and 21.9% of the variance with the SMAT. That would tend to support the higher specificity of the SMAT over the 20-m shuttle run test. Unpublished results on 37 professional hockey players (age  $24.8 \pm 4.3$  years) from one National League team yielded  $r=0.969$ ,  $\text{SEE}=2.06$  ml  $\text{kg}^{-1}$   $\text{min}^{-1}$  between  $\dot{V}O_2$  max and maximal speed.

Similarly, Petrella *et al.* (2005a) also examined the reliability of the Faught Aerobic Skating Test (FAST) using a test-retest design. They reported an intra class correlation coefficient of 0.82 in 15 male and one female bantam hockey players aged  $12.94 \pm .25$  years. Finally, Petrella *et al.* (2007) introduced a maximal continuous multistage 160 ft (48.8m) ice skating shuttle test with wide turns wearing only gloves, hockey stick and helmet. The FAST was compared to direct  $\dot{V}O_2$  max from the treadmill Bruce test on 532 hockey players, (males=384, females=148; 9-25 years). Depending on age-gender cohorts, moderate  $R^2$  values ranging from 0.174 to 0.396 were reported. Intra class correlation determined the FAST to be reliable ( $r=0.76$ ,  $p<0.001$ ) in 47 male and 12 female varsity hockey players over the age of 19 years (Faught, Nystrom & Montelpare, 2003).

### 1.3. Statement of the Problem

The validity of these three ice-skating field tests is not always obvious since the reported statistical indices ( $r$  and SEE) are quite different, probably because they were obtained for different age and gender groups, sometimes with small groups of subjects, wearing different equipment, and using different types of protocols. The nature of the task (skating) must be specific to the sport, but must not be done at the expense of the obtained score (final velocity or  $\dot{V}O_2$  max). Among the newly introduced tests the skating ability and skills required are different. Some rely more on stop-and-go, while others require a wide turn with continuous cross-over skating. It is important to validate and use these tests with subjects that have good degree of skill control.

The comparison of these newly developed ice skating aerobic field tests is a logical next step in gaining a better understanding of field tests for hockey players and figure skaters, as is the comparison of these tests to a running field test and  $\dot{V}O_2$  max as measured on a treadmill in the laboratory and

eventually during the test itself with a lightweight portable system. Thus far only the modified (skating) 20 MST (Kuisis, 2003) has been compared (using a limited amount of subjects) to the maximal multistage 20 m shuttle running test in an attempt to demonstrate its superiority, although establishing the validity of the test is incomplete since it used the running 20 MST in assessing its concurrent validity (indirect validation). A similar validation procedure was used by Larivière, Lavallée & Shepard (1976), who validated a skating test by using the PWC<sub>170</sub> as the criterion variable. Table 1.1 illustrates the principal characteristics of these ice skating field tests along with the 20-m running field test.

**Table 1.1: Characteristics of the Maximal Multistage Running & Ice-Skating Field Tests to be used in this Study**

	20-m Shuttle Run Test (20 MST)	20-m Shuttle Skate (MS20 MST)	45-m Shuttle Skate (SMAT)	48.8 m Shuttle Skate (FAST)
<b>Source</b>	Léger <i>et al.</i> (1988)	Kuisis (2003)	(Leone, Léger, & Comtois, 2002, unpublished)	Petrella <i>et al.</i> (2007)
<b>Displacement Technique</b>	Shuttle Stop & Go Gym Running	Shuttle Stop & Go Ice Skating 1 hand on stick	Shuttle Stop & Go Ice Skating 1 hand on stick	Shuttle Wide turn Ice Skating 1 hand on stick
<b>Protocol Type</b>	Max Multistage Continuous Linear	Max Multistage Continuous Linear	Max Multistage Intermittent Linear	Max Multistage Continuous Curvilinear
<b>Speed vs. Stage</b>				
<b>Stage duration</b>	1 min	1 min	1 min	45 s → 19.5 s*
<b>Rest interval</b>	0 s	0 s	30 s	0 s
<b>Initial speed</b>	8.5 km h <sup>-1</sup>	10.0 km h <sup>-1</sup>	12.6 km h <sup>-1</sup>	15 s(11.7 km h <sup>-1</sup> )
<b>Speed increase</b>	0.5 km h <sup>-1</sup>	~0.5 km h <sup>-1</sup>	0.72 km h <sup>-1</sup>	-5 s (0.4→2.0 km h <sup>-1</sup> )
<b>Equipment</b>	Running shoes	Full hockey kit (+ portable $\dot{V}O_2$ system**)	Full hockey kit	Skates, stick, helmet, gloves

\* For the best results so far

\*\* In experimental phase of original study only.

The validation of the three preceding ice-skating field-tests needs to be expanded as follows:

1. with medium to large groups of subjects with heterogeneous levels of fitness, i.e. wide range in maximal speed and/or  $\dot{V}O_2$  max values in order to demonstrate a hypothesized link between these two variables,
2. with homogeneous skating ability to keep maximal correlation between maximal speed and  $\dot{V}O_2$  max, unless technical skating ability could be measured accurately (which is not easy) and inserted in the prediction model along with maximal skating speed,
3. with subjects of same gender, age and specialty category (e.g. hockey, speed skating or figure skating) knowing that these variables directly affect the relationship between maximal speed and  $\dot{V}O_2$  max in  $\text{ml kg}^{-1} \text{min}^{-1}$  units (Léger *et al.* 1988 and Petrella *et al.*, 2007), and
4. with equipment specific to the specialty, particularly the type of skate.

#### **1.4. Aim of the Study**

As mentioned in the introduction there are three newly designed field tests for assessing aerobic capacity in ice-hockey and figure skating. The aim of this study is as follows:

1. to compare the MS20MST (Modified skating 20 MST; Kuisis, 2003), SMAT (Skating Multistage Aerobic Test; Leone, Léger, & Comtois, 2002, unpublished), and FAST (Faught Aerobic Skating Test; Petrella *et al.*, 2007) ice-skating tests to determine how they relate to each other or to determine their common variance,
2. to assess the external and relative validity of the three new practical ice-skating tests to predict maximal aerobic power ( $\dot{V}O_2$  max) in adult male hockey players that have mastered their skating skills, using direct treadmill  $\dot{V}O_2$  max ("gold standard") as the criterion variable, to determine

which one is better suited for the evaluation of the maximal aerobic power of ice hockey players and to develop a regression to predict  $\dot{V}O_2$  max from the MS20MST. The external validity will be assessed by comparing observed  $\dot{V}O_2$  max to  $\dot{V}O_2$  max predicted from original equations of the SMAT and FAST,

3. to determine which test is rated by the players as being the best suited and most functional test,
4. to determine if these on ice skating tests are in effect better than the over-ground 20 MST (20 Metre Shuttle Run Test; Léger *et al.*, 1988) (by including a conventional 20 MST in the comparison with the hypothesis that such a simple test would be as valid as more specific ice skating tests that require costly ice time).

Once the best skating test has been identified, it will be a useful tool for coaches, selectors and the sports medicine team, in a number of ways, namely:

- to contribute a field test that is sport specific, inexpensive, easy to administer and time efficient,
- to serve as a tool in the monitoring of fitness by test-retest improvements at different stages of the season, or as a training tool;
- to serve as a criteria for return to sport after injury or illness; and
- be used as one of the physical components in the process of player selection.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Locomotion on Ice, Development of Skates, Skating Sport History, and Surface

##### 2.1.1 Locomotion on Ice

The words: "to skate" were derived from the Dutch word "schaats", which can be further traced to old German and French words meaning "shank bone" or "leg bone". The exact time and process by which humans first learned to ice skate is not known, but archaeologists believe that the activity was widespread (primitive animal bone ice skates have been found in places such as Russia, Scandinavia, Great Britain, the Netherlands, Germany, and Switzerland), and originated in Northern Europe two or three thousand years ago. Skating did not start as a sport or any kind of entertainment, but the skate, like the ski, was born as a primitive and vital, convenient and efficient form of transport. Postmen and tax collectors in some densely populated areas, such as Holland, skated to their destinations. In the Netherlands, ice skating was considered proper for all classes of people to participate in, however, in other places, participation in ice skating was limited to only members of the upper classes (Bass, 1980a; Niinimaa, 1982; Montgomery, 1988; Muller, Renstrom & Pyn, 1994; Snyder & Foster, 1994; Wikipedia, 2007). See Figure 2.1.

Skating as a sport began to develop during the 14<sup>th</sup> century, at first with simple races on frozen canals and rivers. In 1742 the first skating club was founded in Edinburgh, Scotland, but it was not until 100 years later that the Skating Club of London was founded, its members using the Serpentine lake in Hyde Park when weather permitted (Bass, 1980a, Bass, 1980b).

**Figure 2.1: Medieval Scene of Ice-Skating by Esaias van de Velde**



### **2.1.2 Development of Skates**

The first skates were made from the shank or rib bones of elk, oxen and reindeer. These bones were ground down until they formed a flat gliding surface, and were then secured to shoes by means of leather thongs. These primitive bone-made ice skates did not have sharp gliding edges like modern ice skates. It is unclear when the first iron runners were used on skates, but the addition of edges to ice skates was invented by the Dutch in the 13th or 14th century. These ice skates were made of steel, with sharpened edges on the bottom to aid movement (Wikipedia, 2007).

Modern ice-hockey skates are designed for protection as well as performance. Ice-hockey skates differ from those of the figure and speed skates in blade length (the ice-hockey skate has a shorter blade than a speed skate); blade rocker, boot structure, and skate weight to match performance needs of the skater. The hockey skate also has a stiffer, taller boot than a speed skate. Since speed and agility are fundamental skills of a hockey player, recent innovations such as plastic brackets, lightweight blades and moulded skates have improved performance (Montgomery, 1988; Muller, Renstrom & Pyn, 1994; Snyder & Foster, 1994). See Figures 2.2 and 2.3.

Figure skating boots provide good support and a snug fit. The boot is in slight plantar flexion with a raised heel. The skate blade is approximately 4 mm wide and has a slight crown of rock (convex shape) along its entire length. The inner and outer edges are sharp with a slight hollow between them. The front of the blade is modelled with a toe pick used for jumping (Muller, Renstrom & Pyn, 1994).

**Figure 2.2: Figure, Hockey and Speed skates**



**Figure 2.3: Figure, Hockey, and Speed Blades**



### 2.1.3 Skating Sport History

#### a) Ice-Hockey

Ice hockey is a team sport played on ice. It has been stated that ice-hockey is the fastest and most high intensity game played on two feet. Ice-hockey is a complex skill involving the contributions of many diverse components. In addition, the game is rough, requiring at times intense physical contact, aggressive play and intermittent exercise intervals at maximal capabilities (Mascaro, Seaver & Swanson, 1992; Gilder & Grogan, 1993; Cox *et al.*, 1995; Behm *et al.*, 2005). *"There's no other sport that requires so much. It requires the ability and agility of a figure skater, and the quickness of a speedskater. Physically, it demands the power of a football player to dig in the corners for the puck and absorb the full-speed collisions while checking the opponent. Then comes the ability to handle and control the puck, a skill more difficult than finessing a golf ball across the green into the cup"* (Broccoletti, 1986 In: Twist & Rhodes, 1993a).

16th-century Dutch paintings show townsfolk playing a hockey-like game on a frozen canal. The first game to use a puck rather than a ball took place in 1860 on Kingston Harbour, involving mostly Crimean War veterans (Wikipedia, 2007). The first documented women's hockey competition was in the late 1800's (Bracko & George, 2001). Ice-hockey has been an Olympic sport since 1920.

The development of the modern game of ice-hockey was centred on Montreal. On March 3, 1875 the first organized indoor game was played at Montreal's Victoria Rink. In 1877, several McGill University students codified seven ice hockey rules. The first ice hockey club, McGill University Hockey Club, was founded in 1880. The game became so popular that it was featured in Montreal's annual Winter Carnival in 1883. In 1885, the game was

introduced in Ottawa. During the same year, the Oxford University Ice Hockey Club was formed (Wikipedia, 2007). See Figure 2.4.

**Figure 2.4: Ice-Hockey Played at McGill University, Montreal, 1901**



In 1888, the new Governor General of Canada, Lord Stanley of Preston, whose sons and daughter became hockey enthusiasts, attended the Carnival and were impressed with the hockey spectacle. In 1892, recognizing that there was no recognition for the best team; he purchased a decorative bowl for use as a trophy. The Dominion Hockey Challenge Cup, which later became more famously known as the Stanley Cup, was first awarded in 1893 to the champion amateur team in Canada, Montreal AAA. It continues to be awarded today to the National Hockey League's championship team (Wikipedia, 2007).

By 1893, there were almost a hundred teams in Montreal alone, and leagues throughout Canada. The Montreal Canadiens hockey club was founded in 1909. In North America, two openly professional leagues emerged: the National Hockey Association (NHA) in 1910 and the Pacific Coast Hockey Association (PCHA) in 1911. Beginning in 1915, these two leagues competed for the Stanley Cup. The National Hockey League (NHL) was formed in November of 1917, following a dispute between NHA team owners (Montgomery, 2006; Wikipedia, 2007).

With the growth of professionalism in Canada, a new challenge cup, the Allan Cup, was introduced for amateur players to replace the Stanley Cup. This led to the foundation of an amateur governing body, the Canadian Hockey Association. Hockey has been played at the Winter Olympics since 1924 (and at the summer games in 1920), where Canada won six of the first seven gold medals (Wikipedia, 2007).

Ice Hockey is Canada's official winter sport (lacrosse is the official summer sport). Ice hockey is one of the fastest growing women's sports in the world, with the number of participants increasing 400 percent in the last 10 years. While there are not as many organized leagues for women as there are for men, leagues of all levels exist, including the National Women's Hockey League, Western Women's Hockey League, and various European leagues; as well as university teams, national and Olympic teams, and recreational teams. There have been nine IIHF World Women Championships. The annual men's Ice Hockey World Championships are highly regarded by Europeans, but they are less important to North Americans because they coincide with the Stanley Cup playoffs. Consequently, Canada and the United States, and other countries with NHL players have never been able to field their best possible teams because many of their players are playing for the Stanley Cup, and thus, the world championships no longer represent all of the world's top players (Wikipedia, 2007).

Women's hockey players have been competing internationally since 1990 when the first world championships were held in Canada, but it was not until the 1998 Olympic Winter Games in Nagano, Japan, that women's hockey was included (with full medal status) for the first time, with the USA winning the gold medal. There have been four world championships of women's ice-hockey, with Canada winning the gold, and the USA winning the silver medal at every tournament (Montgomery, 1988; Montgomery *et al.*, 1990; Snyder & Foster, 1994; Bracko, 1998; Bracko & George, 2001; Wikipedia, 2007).

Canadian and American youth hockey systems have different age group categories as follows: 10 and 11 years ("Atom"), 12 and 13 years ("Pee Wee"), and 14 and 15 years ("Bantam") (Bracko & Fellingham, 2001). University hockey is much less intense than Major Junior A competition. The hockey season is much shorter, less than half as many games are played, and practice sessions are far less frequent. Major Junior A teams are private profit-making enterprises. Players on Major Junior A teams devote a substantial amount of their time to playing hockey (approximately eight months of the year, 90 or more games with practice sessions conducted on virtually all non-game days). Although, the maximum age for players in this league is 20 years, this league represents a major source of hockey players for the professional leagues in North America. Ice-hockey at the highest level is represented by the NHL. Professional hockey teams generally begin training camps in mid September, after which an 80 game season extends into April. Playoffs may extend the season up to an additional six weeks (Houston & Green, 1976; Minkhoff, 1982).

Currently Canada and the United States dominate the world ice-hockey scene. The number of registered hockey players in Canada is 574 125 (1.76% of the population), and 485 018 (0.16% of the population) in the USA (Montgomery, 1988; Montgomery *et al.*, 1990; Snyder & Foster, 1994; Bracko & George, 2001; Wikipedia, 2007).

## **b) Figure Skating**

Figure skating ("artistic skating") is a popular official Winter Olympic sport in which individuals, couples, or groups perform spins, jumps, and other moves on ice, to music. Johnny Heater, a Master of Ceremonies for the U. S. National Figure Skating Championships, commented that to be a good figure skater one must have the balance of a tightrope walker, the endurance of a marathon runner, the aggressiveness of a football player, the agility of a wrestler, the nerves of a golfer, the flexibility of a gymnast, and the grace of

a ballet dancer (Albright, 1979; Brown & Mc Keag, 1987). In addition, figure skaters require high degrees of personal discipline and diligence (Micheli & Mc Carthy, 1996). Training, both on and off the ice, is extensive and the physical, emotional, and financial costs are often large. Because figure skating is both athletic and artistic, it attracts many spectators; its popularity was evident in the 1992 Albertville Winter Olympics, where the ladies final was the most watched amateur sporting event of 1992, surpassing all professional events other than the NFL football (Poe, O'Bryant & Laws, 1994; Micheli & Mc Carthy, 1996; Muller, Renstrom & Pyn, 1994; Wikipedia, 2007).

The first figure skating club in the USA was formed in Philadelphia in 1849. Jackson Haines, recognized as the pioneer of the present-day international style of skating, was a professional dancer and sought ways to wed his ballet knowledge to the ice. Germany's first club was formed in Frankfurt in 1881 (Bass, 1980b). The International Skating Union (ISU) which regulates figure skating judging and competitions was founded in 1892. The first European Championship was held in 1891, and the first World Championship was held in 1896. Only men competed in these events. In 1902, a woman, Madge Syers, entered the World competition for the first time, finishing second. The ISU quickly banned women from competing against men, but established a separate competition for ladies in 1906. Pair skating was introduced at the 1908 World Championships. The first Olympic figure skating competitions also took place in 1908. The first World Championships in ice dancing were not held until 1952 (Wikipedia, 2007).

Traditionally figure skating was popular in countries with naturally occurring ice. Today many nationalities participate in elite skating competitions (Smith & Ludington, 1989; Muller, Renstrom & Pyn, 1994). Many of the best skaters currently come from Russia and the USA which are traditional powers in the sport. The number of participants in the USA alone increased from about 40000 skaters registered in 450 member clubs of the United States Figure Skating Association (USFSA) in 1987 (Brown & Mc Keag, 1987) to an

estimated 95000 USA Figure Skating registered skaters in 1994 (Poe, O'Bryant & Laws, 1994).

### c) Speed Skating

Speed skating is a competitive form of skating in which the competitors race each other in travelling a certain distance on skates. Types of speed skating include: long track speed skating, short track speed skating, inline speed skating, marathon speed skating and quad speed skating. The ISU, governing body of both ice sports, refers to long track as "speed skating" and short track as "short track speed skating" (Wikipedia, 2007).

Speed skating can be tracked back to the 1200s in areas where snowfall was frequent and ice was plentiful. The first speed skating race took place in 1763, over a distance of 24 km on the Fens River in England. Since 1909, the 11 cities speed skating race/tour (De Elfstedentocht) has been conducted in the northern part of the Netherlands and has been held at irregular intervals whenever the ice over the 200 km course is deemed good enough, and has been held 15 times in the nearly 100 years since 1909. The "Nederlandse Schaatsrijderbond" was founded in 1882 and organised the world championships of 1890 and 1891. See Figure 2.5. Long track speed skating has been an Olympic sport since 1924 for men and since 1960 for women. Long track skating is performed on a 400 m oval ice rink, and the events include: 500-, 1000-, 1500-, 5000-, and 10000 m for men; and 500, 1000-, 1500-, 3000-, and 5000 m for women. Short track speed skating is performed on a 111 m oval ice-rink. Short track speed skating was demonstrated as an Olympic sport in 1988 and became an Olympic medal sport in 1992. The short track events include: 500- and 1000 m for men and women, as well as a 3000 m relay for women and a 5000 m relay for men. Marathon skating generally involves a course of 40 km or longer, either on artificial ice, or on real ice (Snyder & Foster, 1994; Wikipedia, 2007).

In the 1930s, women began to be accepted in ISU speed skating competitions. Although women's races had been held in North America for some time, and women competed at the 1932 Winter Olympics in a demonstration event, the ISU did not organise official competitions until 1936. The women's long track speed skating has since been dominated by Germany. In 1992, short track speed skating was accepted as an Olympic sport. South Korea has been the dominant nation in this sport, winning 17 Olympic gold medals. Norwegian and Finnish skaters won all the gold medals in world championships between the world wars, with Latvians and Austrians visiting the podium in the European Championships. Since artificial ice became common in the Netherlands, Dutch speed skaters have been among the worlds best in long track ice skating and marathon skating (Wikipedia, 2007).

**Figure 2.5: Jaap Eden, the First Official World Champion**



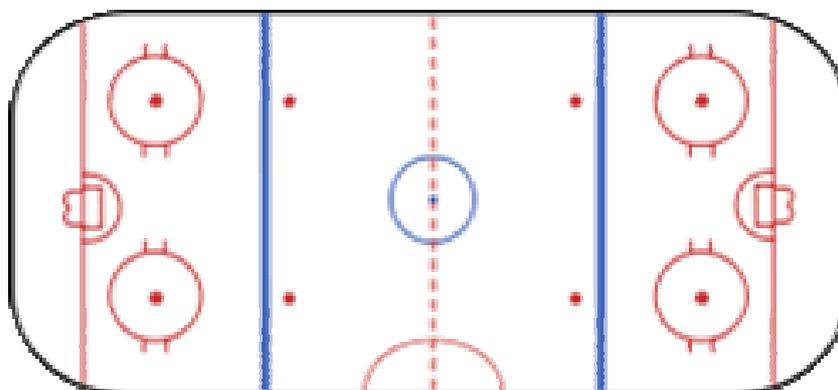
#### **2.1.4 Surface**

The Scandinavians and the Canadians had a great advantage in skating outdoors with their long frozen winters, when the lakes were frozen sufficiently for skating. Since the development of artificial ice (indoor rinks), colder climates, still water, and minimal snowfalls are now no longer

prerequisites for a strong skating community, and skating is now a year-round sport. Skating can be done for fun and recreational purposes, as a means of therapy, a form of competition, and as a profession (Leigh & Leigh, 1975; Smith & Ludington, 1989; Muller, Renstrom & Pyn, 1994). One of the first mechanically refrigerated ice rinks was built in London in 1876 using ether as a coolant. It had a surface of 12 m by 7.5 m. In the 1930's many artificial rinks were made and they became major centres of entertainment with the growth of ice-theatre. Today many large towns have ice- rinks. The engineers maintain the ice-making plant and keep the surface in the right condition for skating (Leigh & Leigh, 1975). The first covered rink in North America was erected in Quebec City, Canada, in 1858, followed the next year by the Victoria Skating Rink in Montreal. Australia's first ice rink, the Melbourne Glaciarium, opened in 1904, and South Africa's first in Johannesburg in 1909 (Bass, 1980b).

The average ice surface is 200 by 85 ft (61 by 26 m) or smaller. Ice-hockey is played on an oval ice that measures approximately 61 m by 30.5 m and is generally played indoors. The typical layout of an ice-hockey rink is shown in Figure 2.6. The ice surface usually has a temperature of  $-8^{\circ}\text{C}$ . Large outdoor rinks are built to professional standards with freezing pipes and plant and everything but a roof (Leigh & Leigh, 1975; Gilder & Grogan, 1993; Snyder & Foster, 1994).

**Figure 2.6: Typical Layout of an Ice-Hockey Rink Surface**



(Wikipedia, 2007).

## 2.2 Basic Rules and Requirements in Ice-Hockey

### 2.2.1 Basic Rules of Ice-Hockey

While the general characteristics of the game are the same wherever it is played, the exact rules depend on the particular code of play being used. The two most important codes are those of the International Ice Hockey Federation (IIHF) and of the North American NHL. North American amateur hockey codes, such as those of Hockey Canada and USA Hockey, tend to be a hybrid of the NHL and IIHF codes, while professional rules generally follow those of the NHL (Wikipedia, 2007).

During normal play, there are six players per side on the ice at any time. There are five players, three forwards and two defensemen, and one goaltender per side. The forward positions consist of a centre and a right- and left wing that often play together as units or lines, with the same three forwards always playing together. The defensemen usually stay together as a pair, but may change less frequently than the forwards. A substitution of an entire unit at once is called a line change. Substitutions are permitted at any time during the course of the game. When players are substituted during play, it is called changing on the fly. A new NHL rule added in the 2005-2006 season prevents a team from changing their line after they ice the puck. In international play, the teams change ends for the second period, again for the third period, and again after ten minutes of the third period. In many North American leagues, including the NHL, the last change is omitted. Recreational leagues and children's leagues often play shorter games, generally with three shorter periods of play. Ice-hockey teams generally have about 15 players (three or four lines of forwards and two or three lines of defensemen). Under IIHF rules, each team may carry a maximum of 20 players and two goaltenders on their roster. NHL rules restrict the total number of players per game to 18 plus two goaltenders (Snyder & Foster, 1994; Cox *et al.*, 1995; Arnett, 1996; Wikipedia, 2007).

The objective of the game is to score goals by shooting a hard vulcanized rubber disc, the puck, into the opponent's goal net, which is placed at the opposite end of the rink. The players control the puck using a long stick with a blade that is curved at one end. Players may also redirect the puck with any part of their bodies, subject to certain restrictions. Players can angle their feet so the puck can redirect into the net, but there can be no kicking motion. Players may not intentionally bat the puck into the net with their hands. Since the 1930s, hockey is an "offside" game, meaning that forward passes are allowed, unlike in rugby. The boards surrounding the ice help keep the puck in play (they can also be used as tool to play the puck), and play often proceeds for minutes without any interruption. When play is stopped, it is restarted with a face-off (Wikipedia, 2007).

## **2.2.2 Task Analysis**

### **a) Total Duration of a Game**

An ice-hockey game consists of three periods of twenty minutes each, with a 15 minutes rest interval following periods one and two, and the clock running only when the puck is in play. The actual playing time may be substantially less; approximately from 15 minutes to 35 minutes of intermittent play (Green *et al.*, 1976; Léger, Seliger & Bassard, 1979; Minkhoff, 1982; Snyder & Foster, 1994; Cox *et al.*, 1995; Arnett, 1996; Wikipedia, 2007). Due to the fact that there are fewer defensemen, they generally play for more minutes than forwards do (Snyder & Foster, 1994).

The actual playing time increases over the 3 periods (+17.4 %), as well as the playing time per shift (+18.7 %), the playing time between play stoppages (+13.3 %), and the time taken to resume play after stoppage (+22.0 %) (Green *et al.*, 1976). Refer to Appendix A.

## b) Phases of Play (Stoppages)

Ice-hockey is a high intensity, high speed game, involving a complicating number of intermittent exercise (lasting 45 to 60 s, seldom exceeding 90 s) and rest schedules within one another, rather than simple exercise-recovery phases (Snyder & Foster, 1994; Cox *et al.*, 1995; Arnett, 1996; Petrella *et al.*, 2007).

The length of a shift can vary from several seconds to greater than two minutes. The average amount of time on the ice during a shift being 91.2-126.3 s, up to 150 s, (that can be repeated 4.5 to 5.8 times during a period, and 13.5 to 17.4 times during a game); with three to four minutes of rest in between. Within a shift, there were 5 to 7 bursts ranging in duration from 2.0 to 3.5 s. Total burst time per game averages 4 to 6 minutes (Thoden & Jette, 1975; Paterson, 1979; Minkhoff, 1982; Twist & Rhodes, 1993a; Bracko, 2001; Spiering *et al.*, 2003; Hoff, Kemi & Helgerud, 2005; Montgomery, 2006). Rest periods are often also used to describe a phase of skating known as the glide phase, where a player is neither accelerating, stopping or in the process of a change in direction (Petrella, 2006; Petrella *et al.*, 2007).

Defensemen have a longer playing time than forwards (+21.2 %, Green *et al.*, 1976 to +33 %, Green, 1978) and have a greater number of shifts (between +26.1 %, Green *et al.*, 1976 and +17 %, Green, 1978). Green *et al.* (1976) state that for defensemen each shift is shorter in duration (-7.4 %), but Green (1978) reported that defensemen had a longer playing time per shift (+21 %). Defensemen have less recovery time between shifts (-37.1 %, Green *et al.*, 1976, to -35 %, Green, 1978). Additionally defensemen have shorter continuous play time (-10.1 %), and longer in the time taken to resume play (+12.9 %) (Green *et al.*, 1976). In contrast, according to Léger, Seliger & Bassard (1980) forwards and defensemen have similar (88.5 versus 84.9 s, respectively) playing time per shift, and since the defensemen spend

less time on the bench between shifts, the ratio of bench time:ice-time is higher for the forwards (2:3) than defensemen (2:1).

### **c) Distance Skated During a Game**

The reported distance skated during a game varies from, 4860 to 5620 m (Czechoslovakian national team, Seliger *et al.*, 1972), 5553 m (during 24 minutes of actual playing time, Green *et al.*, 1976), to between 6400 and 7200 m (top-performance players, Montgomery, 1988).

### **d) Skating Velocity**

Ice-hockey requires high intensity, whole body exercise characterized by fast, explosive skating and sudden changes in direction, coordinated with spontaneous bursts of muscular strength and power (Twist & Rhodes, 1993a). Skating speed is one of the main components of performance in professional hockey. An ice-hockey shift demands short bursts of maximal effort as the forwards and defensemen skate rapidly from goal line to goal line. A primary factor in a hockey player's success is his ability to develop great amounts of muscular tension very rapidly, ultimately generating skating speed. The ability to accelerate from a stationary position, the ability to decelerate rapidly, as well as technical skill in skating, shooting, and passing while reacting to rapidly changing environment, are requirements for success in ice-hockey. Backward skating speed and agility may be considered as indicators for discriminating between good, average, and poor skaters (Mascaro, Seaver & Swanson, 1992; Twist & Rhodes, 1993a; Cox *et al.*, 1995; Bracko, 2001; Canadian Sports Therapy, 2003).

Velocity is pivotal in power skating, and the ability to accelerate quickly characterizes the elite hockey player. Skilled skaters are able to exceed a velocity of  $8 \text{ m s}^{-1}$  after just four strides. Unlike running, power skating is slow, taking almost half the length of the arena to reach peak velocity

(Minkhoff, 1982; Montgomery, 1988; Snyder & Foster, 1994). Green *et al.* (1976) state that the average velocity (calculated on the basis of distance covered divided by continuous play time) remained relatively constant during the first two periods and then showed a 5.2 % decline in the third period. Skating velocities between 50 and 400 m min<sup>-1</sup> (approximately 3-24 km h<sup>-1</sup>) can be expected during game play (university players however, average only 227 m min<sup>-1</sup>; approximately 13.62 km h<sup>-1</sup>). More recently Gilder & Grogan (1993) stated that forward skating speeds average 56 km h<sup>-1</sup> (35 MPH) backward speeds average 24 km h<sup>-1</sup> (15 MPH), and gliding speed can be up to 24 km h<sup>-1</sup> (15 MPH).

Vertical jump has been found to be a reliable predictor of sprinting speed (Bracko & Fellingham, 2001). Mascaro, Seaver & Swanson (1992) found that the best predictor of 54.9 m skating time for forwards and defensemen was the vertical jump anaerobic power as determined by the Lewis formula.

Defensemen, on average, skate slower than forwards, and the average velocity of defensemen is only 61.6 % of that of forwards (Green, 1978; Minkhoff, 1982; Gilder & Grogan, 1993). Other authors report no difference between positions. Even though skating velocity represents a major component of work intensity, its singular use would underestimate energy expenditure. Changing acceleration, frequent turning, shooting and checking are activities that add to exercise intensity but are not evident from velocity analysis (Smith, Quinney & Steadward, 1982; Twist & Rhodes, 1993b; Agre *et al.*, 1988; Hoff, Kemi & Helgerud, 2005).

## 2.2.3 Physical, Muscular, and Metabolic Characteristics and Requirements

### a) Physical Characteristics and Requirements

In the 1920's, the average height of a player for the Montreal Canadiens was 175 cm, in 2003, the average height was 185 cm (an increase of 10 cm), and it is suggested that players will continue to gain height, as the trend appears to be linear over the period 1917 to 2003. In the 1920s, the average mass was approximately 75 kg, and in 2003 the average mass was 92 kg (an increase of 17 kg, representing a 23% increase in body mass). This gain in mass that appears to be due to increased height and muscle tissue, as percent body fat has remained relatively unchanged in the last 22 years (ranging from 8% to 12%). Twist & Rhodes (1993b), state that ice-hockey players are mesomorphic in structure. In the 1930s, the BMI averaged 24.3 kg/m<sup>2</sup>, by 2000, the mean BMI had increased to 26.6 kg/m<sup>2</sup> (a gain of 2.3 kg/m<sup>2</sup>). This shows that currently players are not just larger, but they are larger relative to their height compared with players in the 1930s and later decades (Hoff, Kemi & Helgerud, 2005; Montgomery, 2006).

There are no physical differences between defenders and forwards (Smith, Quinney & Steadward, 1982; Agre *et al.*, 1988; Hoff, Kemi & Helgerud, 2005), except that junior defensemen are heavier than forwards (Hoff, Kemi & Helgerud, 2005). Hoff, Kemi & Helgerud (2005) state that elite ice-hockey males are older (6.6 years) and heavier (11.9 kg) than junior players. In contrast, and more recently Vescovi, Murray & Van Heest (2006) state that among elite ice-hockey players (18.0±0.6 years) defensemen were heavier and/or taller, and that goalkeepers showed greater body fat percentage when compared to forwards. Vescovi, Murray & Van Heest (2006) concluded that the use of anthropometric measurements, upper body strength, and anaerobic capacity may effectively distinguish among positions for elite ice-hockey players.

In summary, performance in ice-hockey depends on several factors, such as genetic endowment, physiological fitness, level of skill, psychological and social ability, environment, and coaching. However, physiological profile plays a very important role, with the most skilled players being bigger and having greater levels of  $\dot{V}O_2$  max. A successful transition from junior to elite requires increased lean body mass and strength (Cox *et al.*, 1993; Hoff, Kemi & Helgerud, 2005). Refer to Appendix B.

### **b) Muscular Characteristics and Requirements (Power, Strength, Endurance)**

Ice-hockey is characterized by intense body checking (often resulting in injury) and power skating, with rapid changes in velocity and direction, eccentric contractions, and deceleration contribute to fatigue and require a large lean body mass and exceptional strength. Total body fitness is compulsory, and strength and power share importance with aerobic endurance (Cox *et al.*, 1995; Spencer *et al.*, 2005).

Ice-hockey requires absolute strength because the athlete must have strength to increase mass and to lower the centre of gravity, increasing dynamic stability to withstand impact. Lower body strength contributes to on-ice acceleration and agility, while upper body strength contributes to enhanced body checking, shooting, and puck control skills. Lean muscle mass and strength development are critical for reduction of the risk and severity of injury. Muscle balance is also important for injury prevention and enhanced performance. Hockey players strive to achieve a hamstring/quadriceps ratio of 60 %. Smith, Quinney & Steadward (1982) state that ice-hockey players have torque outputs in the knee and hip flexion and extension that are good at slow speed (30°/s) in relation to other athletes, but lower at higher speed (180°/s), suggesting that little emphasis has been placed on development of power at high speeds in these athletes.

Relative strength of junior and elite ice-hockey players in maximal bench press is 1.0 and 1.2 kg/kg body mass, and 1.9 and 2.4 kg/kg body mass for maximal squat strength. Elite players have greater relative 1RM squat and bench press strength (Hoff, Kemi & Helgerud, 2005). Grip strength of the 1980 Canadian Olympic Hockey Team ranged between 53.0 and 79.5 kg (Smith, Quinney & Steadward, 1982).

In ice-hockey, most upper body activity is superimposed on intense, lower limb activity. The upper body activity can involve anything from impulse type movement such as shooting where large torques must be developed at high velocities, to a sustained intense isometric, or low velocity activity which can occur in corner play or in the frequent exercise of sweater grabbing, and body checking (Green *et al.*, 1976). Hockey skating skills place a greater emphasis on impulse (force exerted over a given period) rather than stretch-shortening cycle actions. Maximum rather than reactive leg strength may be a more vital aspect of skating speed. Hockey also involves significant balance or stability challenges because of the small surface area (skate blades) in contact with a low-friction surface (ice) (Behm *et al.*, 2005). The execution of upper body skills is critically dependent on maintaining control of balance and coordination of the lower body (Green, 1987). Refer to Appendix C.

### **c) Metabolic Characteristics and Requirements (Aerobic and Anaerobic capacity)**

#### *Aerobic Capacity*

Ice-hockey is a game that relies heavily on both aerobic and anaerobic energy production systems (Green *et al.*, 2006). A hockey player must be physically prepared to produce and sustain moderate to maximal energy output at any given time during the shift. Ice-hockey has traditionally been thought of as being predominantly an anaerobic sport, and the importance of the aerobic energy system often goes unrecognized and can often be overlooked. A

necessary first stage of physiological development from a training perspective is the development of the athlete's aerobic capacity (Twist & Rhodes, 1993a; Petrella, 2006; Petrella *et al.*, 2007).

In 1979, Patterson demonstrated the intense cardiorespiratory demands of ice-hockey, reporting an estimated average intensity of 70 to 80% of  $\dot{V}O_2$  max. Johansson, Lorentzon & Fugl-Meyer (1989) and Reilly & Borrie (1992) include hockey among sports with a 30 % aerobic and 70 % anaerobic contribution to energy expenditure. The relative contribution of these two energy systems is still an area of considerable debate. Ice-hockey is metabolically unique and physically demanding and is a classic example of interval or intermittent work, requiring finely trained aerobic and anaerobic energy pathways. It is aerobically demanding, due to the protracted duration of performance (Green, 1987), requiring a high  $\dot{V}O_2$  max; with frequent though brief anaerobic efforts superimposed. The involvement of the anaerobic system may be dependent on the efficiency of the aerobic system (Seliger *et al.*, 1972; Houston & Green, 1979; Léger, Seliger & Bassard, 1979; Reilly & Borrie, 1992; Cox *et al.*, 1995).

Green (1979) suggested that optimal performance in ice-hockey depends on maximal involvement of the aerobic system for the ATP resynthesis while maintaining the glycolytic involvement, and that the tempo of the game is, in large part, determined by the potential of the aerobic system (Green, 1979). The intermittent nature of play necessitates the use of both anaerobic and aerobic energy systems. Phosphocreatine and glycolytic pathways meet the high-rate energy demands of intense work intervals, while oxidative phosphorylation during rest periods is necessary to achieve sufficient recovery before initiating the next bout of work.

In addition, a well developed cardiovascular system facilitates lactate clearance during recovery. Performance may be hindered if disproportional emphasis is placed on either energy system. A high dependence on anaerobic

energy production will lead to accelerated glycogen depletion, elevated lactate concentrations, and muscle lactic acidosis, thus impeding sustained performance. Primary reliance on the aerobic system hinders energy production and power output during sprint-like activities. Therefore an ice-hockey player must develop a balance between energy systems to maximize game performance (Minkhoff, 1982; Twist & Rhodes, 1993a; Snyder & Foster, 1994; Bracko, 1998; Bracko, 2001; Bracko & Fellingham, 2001; Spiering *et al.*, 2003).

In ice-hockey, there is a major utilization of all major muscle groups of the body which places extreme demands on the energy systems for the provision of an adequate supply of ATP and the removal of by-products of metabolism. While aerobic contribution to a single, short-duration sprint is relatively small, there is an increasing aerobic contribution during repeated sprints, and the relative contribution of anaerobic glycolysis is reduced during the performance of subsequent sprints, which is partially explained by an increase in aerobic metabolism. Aziz, Chia & Teh (2000) found an inverse and moderate correlation between  $\dot{V}O_2$  max and repeated sprint performance (40 m x 8). The glide phases between bursts of high intensity activity are in part responsible for the regeneration of ATP and creatine phosphate (PCr), which maximizes the aerobic contribution to recovery (Petrella, 2006; Petrella *et al.*, 2007). Following this type of effort, lactate removal and the recovery of pH characteristics of the muscle is a relatively slow process, with full recovery of the muscle estimated to take 60 minutes. Phosphocreatine resynthesis is not completed for 20 minutes. The efficient resynthesis of these energy sources relies on the capabilities of the oxidative energy system. It is during these bouts of rest that the aerobic energy system is of extreme importance, as it accounts for 60 to 70% of the body's energy requirements during moderate activity and rest (Twist & Rhodes, 1993a; Bracko, 2001). The more effective the oxidative energy system, the faster one can replenish the energy stores in the working muscles (recover) and be ready to perform another bout of high intensity activity. In summary, a well developed aerobic system will reduce

the depletion of glycogen, and reduce the lactate formed from glycolysis, consequently minimizing the acid-base disturbances (Green, 1979; Green, 1994; Arnett, 1996; Spencer *et al.*, 2005; Denadai, Gomide & Greco, 2005).

In 1979 Léger, Seliger & Bassard reported  $\dot{V}O_2$  max values of ice-hockey players to be between 58.6 and 62.1 ml kg<sup>-1</sup> min<sup>-1</sup> and associated this to the faster (higher) game pace. In 1980 58% of players examined had a  $\dot{V}O_2$  max of less than 55 ml kg<sup>-1</sup> min<sup>-1</sup>, but in 1991 only 15% of players had a  $\dot{V}O_2$  max of less than 55 ml kg<sup>-1</sup> min<sup>-1</sup> (Cox *et al.*, 1993). Over the last 10 to 15 years  $\dot{V}O_2$  max has increased from approximately 55 ml kg<sup>-1</sup> min<sup>-1</sup> to 62.8 ml kg<sup>-1</sup> min<sup>-1</sup> (Hoff, Kemi & Helgerud, 2005), this may in part be due to changes in conditioning methods.

Success in ice-hockey necessitates a highly developed aerobic system. Hoff, Kemi & Helgerud (2005) state that elite ice-hockey males have higher absolute (but not relative)  $\dot{V}O_2$  max scores than non-elite players. Minkhoff (1982) found a reduction in an NHL team's winning percentage with decreases in  $\dot{V}O_2$  max in the second half of the season.

Defensemen, on average have lower  $\dot{V}O_2$  max values (optimally above 50 ml kg<sup>-1</sup> min<sup>-1</sup>) than forwards (optimally above 60 ml kg<sup>-1</sup> min<sup>-1</sup>), despite their greater quantity of ice time (approximately 50% of the game compared to approximately 35% for forwards), possibly due to the larger body mass in defensemen, with goalkeepers generally having the lowest  $\dot{V}O_2$  max values (Minkhoff, 1982; Twist & Rhodes, 1993b; Snyder & Foster, 1994). According to Montgomery (1988) defensemen are usually taller and heavier than forwards, so it is not surprising that the defensemen had lower  $\dot{V}O_2$  max (ml kg<sup>-1</sup> min<sup>-1</sup>) values. Goal tender play is characterized by quick, explosive movements that are short in duration, interspersed with periods of rest and sub-maximal activity. The goal tender relies on the aerobic system for recovery between their commonly high intensity shifts, and to supply energy for occasional sub maximal-efforts (Twist & Rhodes, 1993b).

Cunningham, Telford & swart (1976) states that the capacity of the cardiovascular system of young athletes appears to be similar to that of mature highly successful athletes involved in the same sport. A  $\dot{V}O_2$  max of 56.6 ml kg<sup>-1</sup> min<sup>-1</sup> has been reported for boys involved in a competitive league (Montgomery, 1988), thus implying that the successful ice-hockey player at age 10 already displays a cardiovascular capacity (in terms of body weight), similar to that of the elite athlete. Green *et al.* (2006) state that only  $\dot{V}O_2$  max significantly predicts players net scoring chances, and suggests a relationship between a players conditioning level and on-ice performance. Refer to Appendix D.

### *Anaerobic Capacity*

In game situations, a player must repeat physical effort several times during a period; thus, there is a requirement for high intensity, intermittent work (anaerobic power). HR values representing 90% of HR<sub>max</sub> have consistently been recorded throughout hockey games, but NHL players spend only six minutes at or above lactate threshold HR during an entire 60 minutes game. Of equal importance is the ability of the cardiovascular system to recover from high intensity exercise. The ability to recover is important in hockey because the work bouts (shifts) are repeated over 60 minutes of playing time (Green, 1979; Houston & Green, 1976; Cox *et al.*, 1995; Bracko, 2001). Even though players are on the ice for an average of one minute at a time, the workout is one of the most intense in professional sports. Due to the high intensity and short duration of ice-hockey skating, high anaerobic power and large anaerobic capacity would seem to be important attributes for a hockey player (Montgomery, 1988; Snyder & Foster, 1994).

Anaerobic threshold may be more important for ice-hockey than aerobic capacity, as ice-hockey players rarely ever function at levels approaching their  $\dot{V}O_2$  max (Minkhoff, 1982). The ability to perform repeated sprints with minimal recovery between sprint bouts (known as repeated-sprint ability),

may be an important aspect of team-sport competition (Spenser *et al.*, 2005). This pattern of intermittent short bursts of high output over the space of one hour requires great muscle power and a combination of aerobic and anaerobic capabilities. Thus, ice-hockey is unsteady state exercise, of variable demand on aerobic and anaerobic energy delivery systems (Paterson, 1979; Minkhoff, 1982; Twist & Rhodes, 1993a; Boyle, Mahone & Wallace, 1994; Bracko, 2001; Spiering *et al.*, 2003; Hoff, Kemi & Helgerud, 2005; Montgomery, 2006).

Ice-hockey is not simply a lower limb activity. Upper body activity adds to the total energy expenditure. Battling for the puck in corners, attempting to maintain position in front of the net, shooting, and occasionally fighting are upper body activities that can elevate lactate in the exercising arms as well as alter the blood flow to the legs. Montgomery (1988) has shown that four bouts (60 second duration) of intermittent exercise can elevate leg muscle lactate, decrease phosphocreatine, and result in increased utilization of muscle glycogen. This study implies that if a hockey shift involves excessive upper body activity combined with maximal skating activity, there may be deterioration in performance in subsequent shifts. The superimposition of arm exercise, if heavy enough, on heavy leg exercise can lead to an elevation of blood lactate in the exercising arms and a reduction in blood flow as well as oxygen uptake in the legs. The net effect is to force a greater anaerobic metabolism in the legs, resulting premature fatigue, deterioration of performance, and/or loss of coordination in the limb muscles of the upper body promoted by anaerobic metabolites (Green, 1976).

The capacity to perform high-intensity intermittent exercise may be influenced by factors such as muscle glycogen, creatine phosphate, lactate, and pH (Denadai, Gomide & Greco, 2005). According to Montgomery (1988), there is a large energy contribution from anaerobic glycolysis during a hockey game. Venous blood samples taken at the end of each period of play have been used as an indicator of the intensity of play. Green *et al.* (1976) found that values of blood lactate in Canadian university players were highest during the

first and second periods (mean 8.7 and 7.3 mmol L<sup>-1</sup>, respectively) then declined during the third period (mean 4.9 mmol L<sup>-1</sup>). The forwards and defensemen had similar values despite markedly different skating velocities. The additional number of shifts played by the defensemen and the shorter recovery time between shifts probably accounted for the similar values. The goaltender had only a small elevation in lactate from the pre-game value. Green (1978) found lower lactate values, which were attributed to shorter shift durations. Blood lactate values averaged 5.5 mmol L<sup>-1</sup> for the forwards and 2.9 mmol L<sup>-1</sup> for the defensemen. It appears that European hockey is characterized by higher levels (9 to 11 mmol L<sup>-1</sup>) of blood lactate. Both blood lactate concentration and HR vary according to the calibre of the opposing team. One explanation for the relatively low lactate values seen during a hockey game is that within a shift there are typically 2 to 3 play stoppages. Continuous play averages about 30 s. This pause provides sufficient time for 60 to 65 % of the phosphocreatine to be resynthesized and available for the next phase of the shift. Time-motion analysis reveals many changes in tempo. A typical shift is interspersed with short bursts of high intensity skating followed by longer periods of gliding. During a typical shift, there are many opportunities for substantial anaerobic glycolysis. Elite players have probably learned to optimize the high intensity bursts. Since hockey demands precise coordination of many muscle groups, excessive increases in lactate would interfere with the execution of hockey skills (Montgomery, 1988). Cox *et al.* (1995) state that lactate accumulation depends on fitness level, state of training, active muscle mass, muscle fibre composition, nutritional status, blood flow and fatigue. These same variables may affect recovery time and lactate clearance.

Green (1978) had ice-hockey players either skate continuously for 60 minutes (~55 % of VO<sub>2</sub> max) or perform intermittent exercise (ten 1 minute bouts with 5 minutes recovery between each, ~75 % of VO<sub>2</sub> max). Muscle lactate concentration was 10 fold higher following the intermittent exercise than following the continuous exercise. During this study, lower lactate values

were observed during continuous running (treadmill) and continuous skating (FAST), than during intermittent skating (SMAT).

Montgomery (1988) states that the half-life for removal of lactate is estimated at 9.5 minutes. A five minute active recovery (slow skating and gliding) was used in this study, before lactate was measured. Watson & Hanley (1986) state that following high intensity skating that blood lactate was elevated, and that bench-stepping during recovery was shown to enhance lactate removal over resting recovery. Skating during the recovery period was not significantly different from bench stepping, but they speculate that perhaps gliding was the main activity during low intensity skating so that relatively little lactate was metabolized. Furthermore, they state that it appears that ice-hockey players might well be advised to perform low-intensity physical activities rather than sit during the intermission periods if they wish to reduce blood lactate concentrations before the next shift on the ice. Conversely, in a study using ice-hockey players, Lau *et al.* (2001) stated that although active recovery appeared to increase skating distances, the result was not significant, and concluded that active recovery did not enhance lactate removal or subsequent performance of repeated work bouts in simulated hockey play. In this study, subjects glided and skated very slowly around the perimeter of the ice for five minutes before lactate was measured, allowing for lactate to peak, but not long enough for its removal.

A study on speed skaters by Quirion *et al.* (1988) states that blood lactic acid concentrations are generally lower in the cold. Increasing lipid oxidation during exercise has been shown to slow the rate of glycolysis and inhibit lactate formation while rising blood free fatty acid concentration. Cold exposure increases the plasma glucagons while the levels of insulin and blood lactate remain unaltered. Cold stress rapidly induces a rise in glucagon levels which enhances the rate of hepatic gluconeogenesis and the increase in oxygen consumption results in a rapid rise in glucagon and free fatty acids. Subjects with a high anaerobic threshold are likely to have less glycogen

depletion during prolonged exercise because muscle glycogen utilization for ATP regeneration is 18 to 19 times faster via glycolysis as compared to oxidative phosphorylation. Thus, training increases the capacity to produce work without blood lactate accumulation and glycogen utilization.

Forwards are often involved in more intense (anaerobic) bouts of play than defensemen. When the peak power and anaerobic endurance values are expressed relative to body weight, forwards and defensemen have similar scores. Because defensemen are heavier than forwards, their absolute scores on the cycle ergometre test are higher. Peak power for ice-hockey players in the Wingate test has been reported to be  $11.0 \pm 0.8 \text{ W kg}^{-1}$ , whereas mean power was  $8.8 \pm 0.6 \text{ W kg}^{-1}$  (Montgomery, 1988; Snyder & Foster, 1994). Refer to Appendix D.

## 2.3 Bioenergetics, Energy Cost & Efficiency

### 2.3.1 Energy Cost (Running versus Skating)

Energy cost of locomotion represents the amount of energy spent per unit distance and mechanical efficiency is the ratio between the mechanical work and the metabolic energy expended, and the aptitude to minimize external resistance (Millet, *et al.*, 2002). The cost of skating is much higher for ice-hockey players than for speed skaters (Léger, Seliger & Bassard, 1979). The energy cost of skating in females wearing figure skates is similar as a whole to males wearing hockey skates but higher than males wearing speed skates (Léger, 1981). Skating is much more efficient than running, but this has only been demonstrated with forward skating. If other types of motion are done, the energy cost could increase sharply as shown with the skating back and forth on a 20 m course (Léger, Seliger & Bassard, 1979; Léger, 1981). Green *et al.* (1976) estimated energy expenditure from HR telemetry to be 70 to 80 % of  $\dot{V}O_2$  max. Conly & Krahenbuhl (1980) state that the energy cost could

explain 65% of the performance variability in a group of runners of a comparable level. Upper body activity (battling for the puck, body checking, grabbing, and shooting) adds substantially to the energy expenditure of ice-hockey players (Green, 1979; Twist & Rhodes, 1993b).

According to Léger, Seliger & Bassard (1979) the use of a sport-specific skating test for ice-hockey is more preferable due to the fact that hockey players are more efficient on the ice than on the treadmill. Léger, Seliger & Bassard (1979) demonstrated that ice-hockey players as compared to runners had a greater mechanical efficiency while skating on the ice (difference of 15%) and a lower mechanical efficiency on the treadmill (difference of 7.9%). Léger, Seliger & Bassard (1979) also state that testing a hockey player who is a poor skater, but a good runner might render imprecise information as to his ability to perform aerobic skating.

Martinez *et al.* (1993) found no differences in HR at submaximal workloads between treadmill running, cycling, and roller skating, but  $\dot{V}O_2$  max,  $HR_{max}$ , and exercise time to exhaustion were higher during running than cycling. Blood lactate during maximal running was significantly lower than during cycling or roller skating. There were no differences between cycling and roller skating with regard to  $HR_{max}$ , blood lactate,  $\dot{V}O_2$  max, or exercise time. Melanson *et al.* (1996) found  $\dot{V}O_2$  and energy expenditure to be significantly higher during running than during over-ground in-line skating at self selected intensities.

Carroll *et al.* (1993) compared the metabolic cost of ice-skating and in-line skating in collegiate hockey players, at three different velocities (12.5 km h<sup>-1</sup>, 16.5 km h<sup>-1</sup>, and 20 km h<sup>-1</sup>). In-line skating produced significantly higher HR values and absolute oxygen uptake values than ice-skating at all three velocities. In-line skating also generated significantly greater relative oxygen uptake values at 16.5 km h<sup>-1</sup> and 20 km h<sup>-1</sup>. Carroll *et al.* (1993) thus concluded that the metabolic cost of in-line skating is greater than that of ice-

skating when skating at three velocities similar to those skated during game situations. Although peak  $\dot{V}O_2$  values during treadmill skating do not approach those achieved during treadmill running, the evaluation of skater in a sports-specific laboratory test appears to be congruent with performance and demonstrates potential in addressing the unique physiological demands of skating (Rundell, 1996).

The rate of energy expenditure among forwards is higher than defensemen, because forwards tend to cover more ice which requires more energy (Twist & Rhodes, 1993b). Considerable variations in the efficiency of running exist. Trained subjects appear to be more efficient than untrained subjects. Children appear to be less efficient than adults in running, with a 2% increase in the gross estimated cost of running for each year of age from 18 years to 8 years (Léger & Mercier, 1984).

### 2.3.2 External Load (Equipment)

Di Prampero *et al.* (1976) state that the energy expenditure per unit body weight and unit distance increases with speed and increased air resistance may lead to an increase in oxygen consumption ( $\dot{V}O_2$  max). Both projected area and drag coefficient decreased progressively from walking and running, to cycling and to skating. When hockey players are wearing full ice-hockey kit and skate with their hockey sticks, air resistance is increased. Any increase in the mass carried by the hockey player increases frictional resistance during skating (Montgomery, 1988).

The effect of equipment weight on aerobic skating performance is evident from the results of Léger, Seliger & Bassard (1979). Hockey players performed a 20 m shuttle skating test to determine  $\dot{V}O_2$  max. While the  $\dot{V}O_2$  max was similar, with and without equipment, the test duration was reduced from 6.4 to 5.1 minutes (20 %). Final skating speed decreased by 7 m min<sup>-1</sup>

(2.9 %). For a particular speed, the mechanical efficiency ratios indicated a 4.8 % additional energy cost of skating with hockey equipment (7.3 kg).

A hockey player may carry excess mass in the form of fat weight or equipment weight. This was investigated by using the repeat skate (RSS) test of hockey fitness. Added mass caused a significantly slower performance on both the speed and anaerobic endurance component of the hockey fitness test. When carrying 5 % excess mass, anaerobic endurance time increased by 4 %. Excess body mass increases the energy required to skate at a particular velocity so that energy systems are taxed to maximum at a slower velocity, and results in a significantly slower performance on the speed component of a hockey fitness test. It also shortens the time that a player can maintain the pace. Elite players should be encouraged to decrease body fat and to wear as light a uniform as possible without sacrificing protection (Montgomery, 1988; Mascaro, Seaver & Swanson, 1992).

In addition, performance time increases due to increased mass of the skates worn. Chomay *et al.* (1982) investigated the effect of experimental alterations in skate weight on performance in the repeat skate test. Subjects performed the repeat sprint skate test under three conditions, namely, with normal skate weight; 227 g of weight added to each skate; and 55 g of weight added to each skate. During the added skate weight conditions, there was a significant increase in performance time resulting in slower performance on both speed and anaerobic endurance components of the hockey fitness test. When purchasing skates, players should use skate mass as an important selection criterion.

Millet *et al.* (1998) examined the effects of external loading on the energy cost and mechanics of roller ski skating. Subjects performed a roller skiing test at 19.0 km h<sup>-1</sup> without additional load, and with loads of 6 % and 12 % body mass. Millet *et al.* (1998) concluded that external loading of up to 12 % of body mass does not change significantly the energy cost of roller ski

skating and has no significant effect on joint kinematics, muscle cycle rate and change of velocity within a cycle, indicating that all mechanical power outputs increased proportionally with total mass (with the exception of rotational kinetic power and power to overcome aerodynamic drag). The independence of aerodynamic and rotational kinetic powers with external mass can explain the slight and non significant increase in  $\dot{V}O_2$  expressed per kg of total mass. This suggests that the efficiency of the muscles of the lower limbs was not altered by load despite the occurrence of stretch shortening cycle in roller ski skating.

### **2.3.3 Drafting**

Drafting can decrease the aerodynamic drag and therefore improves the energy cost of an athlete directly behind another one in ice-skating, cross country skiing, cycling, swimming, kayaking, and running (Millet *et al.*, 2003). Millet *et al.* (2003) reported a 3-12 % decrease in energy consumption while drafting in in-line skating. The decrease was higher at moderate than high velocity, and there were no differences between drafting at the closest distance or further from the lead skater.

### **2.3.4 Air & Ice Friction**

The air resistance experienced by speed skaters can account for approximately 50 % to 65 % of the energy cost of skating, and it may be more appropriate to express  $\dot{V}O_2$  max in absolute terms rather than relative terms (Nemoto *et al.*, 1988). At similar speeds, the energy expended per unit body surface area against air resistance is similar for speed skating, running, and cycling, but when expressed per unit body mass, energy expenditure is greater for skating and cycling than for running. Due to the high velocities associated with speed skating and cycling, the total resistance attributed to

air friction is quite large compared to than for running at a slower pace (Snyder & Foster, 1994).

In ice-hockey, forward propulsions are impeded by the air resistance (which is increased by hockey equipment), drag, contact from opponents, and frictional resistance of the ice. External power is equal to the product of the work per stroke and the stroke frequency (Montgomery, 1988).

The metal blade of the skate can glide over the surface of the ice with very little friction. When slightly leaning the blade over and digging one of its edges into the ice ("rock over and bite") the friction increases, allowing more control of movement (Wikipedia, 2007). Experiments show that ice has a minimum kinetic friction at  $-7^{\circ}\text{C}$  ( $19^{\circ}\text{F}$ ), and many indoor skating rinks set their system to a similar temperature. On the surface of any body of ice at a temperature above about  $-20^{\circ}\text{C}$  ( $-4^{\circ}\text{F}$ ), there is always a thin film of liquid water, ranging in thickness from only a few molecules to thousands of molecules. The thickness of this liquid layer depends almost entirely on the temperature of the surface of the ice, with higher temperatures giving a thicker layer. However, skating is possible at temperatures much lower than  $-20^{\circ}\text{C}$ , at which there is no naturally occurring film of liquid. When the blade of an ice skate passes over the ice, the ice undergoes two kinds of change in its physical state: an increase in pressure, and a change in temperature due to kinetic friction and the heat of melting. Direct measurements show that the heating due to friction is greater than the cooling due to the heat of melting. Although high pressure can cause ice to melt, by lowering its melting point, the pressure required is far greater than that actually produced by ice skates. Frictional heating does lead to an increase in the thickness of the naturally occurring film of liquid, but measurements with an atomic force microscope have found the boundary layer to be too thin to supply the observed reduction in friction (Wikipedia, 2007).

The condition of the ice can also affect skating performance. An increase in  $\dot{V}O_2$  of up to 20 % during skating on “bad” ice has been reported. Temperatures less than or greater than the optimal  $-4^\circ\text{C}$  to  $-7^\circ\text{C}$  cause mechanical disruption of the ice surface, and foreign substances on the ice (e.g. snow, ice crystals, and dirt) all increase the coefficient of friction of the ice, reducing skating performance (Snyder & Foster, 1994; Wikipedia, 2007).

Any increase in the mass carried by the hockey player increases frictional resistance during skating. At maximal speed, the stride consists of 82 % single support and only 18 % double support. During single support, there is a propulsion phase and a glide phase. Since the glide phase begins during the initial stages of the single support time and because the coefficient of friction is low in skating it may be argued that added body mass can be supported by the skates so that a moderate excess of fat may not be a decrement in skating (Montgomery, 1988).

In summary, frictional resistance of the ice, air resistance, drafting and drag, equipment, and opposition affect the efficiency of ice-hockey players.

### **2.3.5 Efficiency with Specific Regard to Technique**

Ice-skating is a highly skilled activity and it takes many years to develop a high level of skill. Large differences exist in the expenditure of energy to cover a certain distance at a certain rate, and there is a substantial interindividual difference in skating efficiency (Green, 1979). Efficiency may be a more significant indicator of fatigability than low  $\dot{V}O_2$  max (Green, 1979). According to Montgomery (1988) the individual variability of  $\dot{V}O_2$  max ( $\pm 15\%$ ) found during ice skating is considerably larger than the 5 to 7 % difference between trained and untrained runners. Even though skaters are well trained, considerable differences sometimes exist in the skill of skating. Large variations in  $\dot{V}O_2$  at similar speeds have been demonstrated in cyclists

performing on the track (cycling economy) (Marion & Léger, 1988). Adults are systematically less efficient than children and adolescents (Léger, 1997). Petrella (2006) states that the less efficient skater will expend more energy and have different physiological responses than the more efficient skater. Petrella *et al.* (2007) suggested that females are less efficient and have greater skating metabolic demand than males.

A major component of the physical workload is skating in an upright position, but players spend a considerable amount of time dribbling the puck or battling for possession of the puck in a semi-crouched position, which is ergonomically uneconomical (Paterson, 1979; Minkhoff, 1982; Twist & Rhodes, 1993a; Boyle, Mahone & Wallace, 1994; Bracko, 2001; Spiering *et al.*, 2003; Hoff, Kemi & Helgerud, 2005; Montgomery, 2006). In speed skating, there is a physiologic disadvantage to skating in the low position, but a substantial biomechanical advantage. Blood flow is restricted during speed skating and the very low, crouched body position assumed by speed skaters accentuates this restriction. HR is significantly higher at all skating velocities in a low position (speed skating) compared to a high position, as is blood lactate (Foster *et al.*, 1999). Rundell (1996) found that HR<sub>peak</sub> was significantly lower in low skating posture while skating on a skate-treadmill, than during treadmill running. Relative  $\dot{V}O_2$  peak and time to exhaustion was also significantly lower during the low skating posture than treadmill running or upright skating.

Another factor that will influence the maximum velocity of movement and the energy requirements at a given velocity is skating efficiency. Skating mechanical efficiency is calculated by measuring the oxygen cost of skating at a set velocity.

$$\text{Mechanical efficiency} = \frac{\text{Velocity (m min}^{-1}\text{)}}{\dot{V}O_2 \text{ max (ml/kg/min)}} \times 100$$

(Montgomery, 1988).

According to Snyder & Foster (1994), the ice-hockey skating stroke, like that of the speed skater, involves three components, a glide with a single leg support; propulsion with a single leg support; and propulsion with a double leg support. The propulsion begins approximately half-way through the single leg support phase through the end of the double leg support (Montgomery, 1988; Snyder & Foster, 1994). When extending the knee joint in the skating thrust, the quadriceps develop the large contractile forces. The hamstrings and gastrocnemius muscles act to stabilize the knee during the weight shift and push off the skating thrust. It has been suggested that technique modifications could minimize the duration of the glide phase and maximize propulsion (Montgomery, 1988). Hockey coaches teach the player to attempt full extension of the hip (using hamstrings and gluteus maximus), knee (Quadriceps), and ankle (gastrocnemius and soleus) in order to accelerate quickly. Page (1975) reported significant differences between maximum skating velocity and knee extension at toe-off as well as knee flexion prior to propulsion.

Marino (1977) reported that stride rate among hockey players was highly related to skating velocity ( $r=0.76$ ) but stride length was unrelated ( $r=0.05$ ). Differences in performance level were a result of differences in work per stroke. Faster skaters showed better timing in push-off mechanics resulting in effective direct push-off perpendicular to the gliding direction of the skater. Elite skaters were able to sustain the gliding phase for a longer period of time. With larger muscle power, they are able to extend their knees in a shorter push-off time. Elite skaters can perform more work per stroke. Marinao (1984) states that an increase in maximal horizontal velocity of hockey players during the ages 8 to 15 years is accompanied by increasing skating stride length with no significant changes in skating stride rate. Montgomery (1988) states that as a skater fatigues skating velocity decreases, and this is a result of decrease in stride rate. With fatigue, there is slower extension of the leg and a longer glide phase (Montgomery, 1988).

By moving along curved paths while leaning the body radially and flexing the knees, skaters can use gravity to control and increase their momentum. They can also create momentum by pushing the blade against the curved track which it cuts into the ice. The force generated during skating push-off can reach 1.5 to 2.5 times the player's body weight (Gilder & Grogan, 1993; Wikipedia, 2007).

Technical modifications to the skate boot may also enhance the hockey player's ability to achieve greater forward impulse and possibly achieve a higher maximum skating velocity. When ankle support is removed from the ice-hockey boot by altering the skate design, the hockey player is able to achieve greater forward impulse during the heel-off to toe-off phase of the stride due to greater range of motion about the ankle (Montgomery, 1988).

## **2.4 Aerobic Assessment/ Bioenergetic Aptitude Assessment (Including Aerobic and Anaerobic)**

### **2.4.1 Purpose of Testing (Why is it Necessary?)**

The measurement of performance characteristics by means of physiological testing assists in identifying physical strengths and weakness (in relation to the sport), inadequacy in conditioning, as well as identifying specific types of injuries that can be reduced or eliminated; and can also monitor fatigue and prevent overtraining. Furthermore, testing is an educational process by which athletes learn to better understand their body and the demands of the sport (Merrieffield & Walford, 1968; Hawley & Burke, 1998; Montgomery *et al.*, 1990; Mac Dougall & Wenger, 1991; Cox *et al.*, 1995; Bracko & Fellingham, 2001).

Physiological testing can assist in improving performance, differentiate between elite and non-elite players, and establish baseline performance data.

Comparing post-season or post-injury data with pre-season or pre-injury baseline data is an appropriate method of approach, and provides the team trainers and physicians with the necessary objective evidence they need to make ethical medical decisions. Physiological assessments provide the basis on which to evaluate rehabilitation and a player's readiness to return to the game following an injury. A test-retest approach helps the coach to track the individual progress of every player and the effectiveness of scientifically based training programs and determine whether the team is progressing at the desired level by repeating tests at regular intervals (on- and off-ice). Performance testing can also serve to motivate players. It provides them with a target to work towards, as it can yield consistent and comparable results (team and individual scores can be compared to the larger population). Furthermore, testing can improve time management and if it is sport specific, it can be done when needed and where training takes place; and thus, save money. Performance testing may also assist in player selection and recruitment. In the selection of athletes for teams, physiological tests should only augment the information that is already available on actual performances or field observations. Laboratory testing should be considered primarily as a training aid, not as a magical tool for predicting future gold medallists, as it has severe limitations for identifying potential talent (Montgomery *et al.*, 1990; Mac Dougall & Wenger, 1991; Cox *et al.*, 1995; Hawley & Burke, 1998; Bracko & Fellingham, 2001).

In the seventies the primary emphasis during player selection was placed on skill (puck handling, shooting, and passing), with an absence of fundamental understanding of the physiological systems involved. Coaches differentiated between players on the aspect with which they were most familiar, skill (Houston & Green, 1976).

In the eighties, along with the availability of more sophisticated equipment (e.g. gas analysers and isokinetic testing equipment), it became progressively more popular to profile individuals and teams in sports, but still, the specific

value with respect to many sports, including professional ice-hockey remained questionable, and Minkhoff (1982) demonstrated no apparent relationship between success in ice hockey and  $\dot{V}O_2$  max. The question at this time was if ice-hockey was primarily an anaerobic sport, and whether ice hockey success was mostly due to natural talent, with hockey skills being more valuable than level of conditioning in rating performance (Minkhoff, 1982; Agre *et al.*, 1988).

For the first century of the existence of ice-hockey, Canada was the dominant nation. Today the game is popular in North America and Europe with top teams coming from Canada, Czechoslovakia, Finland, Sweden, the USA, and the former USSR. The increased interest during the last two decades in international competition has created opportunities for physiological evaluation of elite teams (Montgomery, 1988). In 1993, the NHL adopted centralized physiological testing for NHL entry draft players. The physiological results are available to all teams before player selection (Montgomery, 2006).

Cardiorespiratory endurance is generally recognised as a major component of evaluating physical fitness and maximal oxygen consumption ( $\dot{V}O_2$  max) is considered the most important, valid and the most accurate single measure of an individual's circulatory and respiratory capacity, and is accepted as the criterion measure of cardiorespiratory fitness. Sport-specific tests are highly valued in exercise science, including tests of cardiorespiratory endurance and maximal oxygen consumption. (Cunningham, Telford & swart, 1976; Gabbard, 1992; Thompson, 2005; ACSM, 2006).

One of the most important factors that influence exercise intensity is the player's  $\dot{V}O_2$  max. Both anaerobic threshold and running economy have been shown to be increased by increased  $\dot{V}O_2$  max (Chamari *et al.*, 2004). It remains possible that a high level of aerobic fitness enhances other aspects of performance of match play in games like soccer and hockey (Aziz, Chia & Teh, 2000). When a player is more physically fit than the rest of the team,

the player will stand out among the others. Ice-hockey is unsteady state exercise of variable demand on aerobic and anaerobic energy delivery systems. The use of hockey sticks and a puck that may speed at over 100 MPH produces considerable visual coordination, thus a professional hockey team requires cardiovascular, muscular and visual evaluation (Paterson, 1979; Minkhoff, 1982; Boyle, Mahone & Wallace, 1994; Bracko, 2001; Spiering *et al.*, 2003; Hoff, Kemi & Helgerud, 2005; Montgomery, 2006).

#### **2.4.2 Criteria of a Fitness Test**

As with all sports, in order for the athletes to benefit from scientific testing, the assessment must be specific to the sport (i.e. there must be a high correlation between the test measure and subsequent competitive performance), meaningful and applicable to training development; and use measures that are valid and reproducible (reliable), but be easy to administer and interpret, and should not be time-consuming or require sophisticated equipment. Furthermore, tests should be scientifically sensitive to detect small changes in the athlete's state of fitness and performance, must allow the athletes to set goals, and be conducted on a regular schedule (Hawley & Burke, 1998; Snyder & Foster, 1994; Cox *et al.*, 1995).

When testing ice-hockey players, the overall evaluation should include measurement of both the general and specific components of physical fitness. Tests should be carefully selected and testing conditions and equipment should be standardized. In reality, most tests carry some small error of validity or reliability, or both. It is part of the expertise of the sport scientist to recognize and take account of this when interpreting the results of a test to the coach and athlete (Hawley & Burke, 1998). In some sports, such as ice-hockey, it may be preferable to assess athletes by field tests (on-ice) rather than by using laboratory-based protocols. Undertaking testing in the field under specific conditions of training and competition is a useful exercise to

bridge the gap between sports science (academics) and the athlete and coach, and is often time- and cost effective. In the end, any results obtained from either laboratory or field-testing should complement the observations of the coach, and neither should ever be considered a replacement for the other (Hawley & Burke, 1998).

Consistency is crucial if the results of various physiological tests undertaken at different stages of the athlete's preparation are to be comparable. Laboratory testing should be conducted under consistent and standardized conditions. The area where athletes are tested should be a dedicated quiet area which is free from other influences and disturbances. Tests should be conducted in a well ventilated area, with the laboratory temperature 20-22 °C and the relative humidity at less than 60 %. The same practitioner must be employed in subsequent testing; and all laboratory equipment should be calibrated before testing according to the procedures and instructions for that specific apparatus (Hawley & Burke, 1998).

Before testing is begun, the practitioner must confirm that the athlete is not suffering from any condition which may adversely affect performance, such as illness or injury. An athlete with a viral infection should not be allowed to perform any test, no matter how mild the condition may be considered to be. The athlete should be rested and should not have undertaken any intensive training or competition for 48 hours prior to a test, and should not have performed a similar test within the previous 72 hours. Maximal testing should take place at least two hours after the last meal. Fluids such as carbohydrate-electrolyte solutions or water should be taken without restriction in the hours before the test. Prior to any test procedure, the athlete should perform their own warm-up routine, which must then be standardized for subsequent tests. Furthermore, the subject should utilize the same equipment as during training and competition (e.g. racing shoes, clothing and other specialized gear) (Hawley & Burke, 1998).

Additionally, the athlete should be familiar with all the test equipment, and understand, in detail, all the test procedures. Usually it takes two or three performances (depending on the test) before the rests reflect true performance. For the most valid and reliable results, physiological tests should be scheduled during the mid-to-late afternoon or early evening period, when strength and endurance are optimal (Hawley & Burke, 1998).

### **2.4.3 Specificity of Physiological Testing (Laboratory Based vs. Field Tests)**

In general, results gained from field tests are not as reliable as those gained from laboratory tests but are often more valid because of their greater specificity. Because scientists cannot control variables such as wind velocity, temperature, humidity, and playing surface, athlete performance varies more in the field setting (Mac Dougall & Wenger, 1991).

Once the athletes have attained a general fitness level, they strive to attain a higher level of sport-specific physical fitness. Such specificity can vary considerably from one sport to another. In 1969, Ferguson, Marcotte & Monpetit made the point that the physiological assessment of athletes in their environment is worthwhile in providing information on the acute adaptation to specific activities, which may be different to the adaptations found in the laboratory during treadmill running and cycling. Testing can be conducted in a variety of ways. Often these services even though done with highly skilled experts and state-of-the-art equipment, may be impractical and very expensive. It is imperative that the testing protocol consist of a good selection of tests that are specific to the demands of the sport (ice-hockey) (Montgomery, 1988; Montgomery *et al.*, 1990).

Anaerobic fitness is an important performance variable in ice-hockey, and  $\dot{V}O_2$  max is primarily influenced by the aerobic character of muscle. Information

about on-ice fitness is important. Skating ability and testing skating ability are important aspects in hockey performance and player selection, as ice-hockey is a complex motor skill. The sport scientist is concerned with eliminating the skill factor to produce objective results, whereas the coach is interested in a player's fitness and skating ability. On-ice testing provides the opportunity to analyse both by using valid and reliable tests as it is hard to emulate the coordination and physical demands with off-ice testing. Furthermore, the skating actions during training are not mirrored by either bicycle or treadmill tests and, therefore, may not adequately reflect the specific aerobic power developed in ice-hockey players (Smith, Quinney & Steadward, 1982; Bracko, 2001).

Snyder & Foster (1994) state that maximal values of aerobic power are generally higher in athletes when they perform specific skills rather than generic skills. When trained subjects (female canoeists and rowers) are subjected to an unspecific load (bicycle ergometre), the values recorded of percentage  $\dot{V}O_2$  max at the ventilatory threshold were close to values characteristic for an untrained population. However, when the same athletes were tested by a specific workload (paddling or rowing ergometre) the values obtained were typical for highly trained athletes (Bunc *et al.*, 1987). When rowers perform a simulated competitive effort on a Concept II rowing machine (over 2000 ms),  $\dot{V}O_2$  max values are typically 6-7 % higher than those recorded during a standard rowing ergometre test of increasing intensity (Hawley & Burke, 1998). Similarly, movement patterns in tests of aerobic- and anaerobic threshold in speed skaters (usually laboratory based cycling protocols) are not a specific exercise modality, and due to the high importance of technical and coordination skills bicycle ergometry is not as meaningful for speed skaters as for athletes in other sports disciplines (Nemoto *et al.*, 1988). Léger, Seliger & Bassard (1979) state that  $\dot{V}O_2$  max during skating is either higher or similar to the values obtained during treadmill running. In contrast Snyder & Foster (1994) found that speed skaters reached no more than 85-90 % of the  $\dot{V}O_2$  max they reached during

running or cycling, possibly due to the smaller muscle mass utilised in skating, or more likely to a reduced blood flow caused by the isometric muscle actions of the hip and knee extensors during the gliding phase of the skating stroke (Snyder & Foster, 1994). Di Prampero *et al.* (1976) found that  $\dot{V}O_2$  max during speed skating is about 15 % lower than in treadmill running. HR and oxygen uptake response is lower in speed skating as opposed to cycling (Smith & Roberts, 1990).

Ice-hockey is a sport whereby development and progression is limited by the inability of researchers and game enthusiasts to create a game or practise-simulated task in a laboratory setting (Petrella, 2006). A number of approaches are available to measure physiological components of ice-hockey players, but, the most appropriate is to measure physiological components during actual skating.

The NHL draft held annually is the primary means by which junior or college prospects enter the league. The decisions to select players are based on extensive on-ice player evaluations by NHL scouts. Additional information is gathered through the NHL combine, held before each year's draft by the Central Scouting Service. The combine involves two days of physical and physiological testing designed to elicit supplemental qualitative information. The assessment battery includes anthropometry and performance tests that examine musculoskeletal, aerobic, and anaerobic fitness. The protocol includes standing height, bench-press, push-ups, upper body push-pull strength, sit-and-reach test, curl-ups, vertical jump, medicine ball throw, Wingate anaerobic cycling test, and an aerobic cycle ergometre test for aerobic fitness (Vescovi *et al.*, 2006). Surprisingly, the protocol only uses off-ice tests. Thus, it remains questionable whether non-specific off-ice tests can be used to identify superior on-ice, hockey-specific performance.

Vescovi *et al.* (2006) concludes that off-ice tests cannot predict ice-hockey playing ability in an elite group of athletes. Recent technological

developments such as portable gas analysis systems and the skating treadmill are certainly allowing for more sport specific testing of ice-hockey players, however, the availability and large financial cost of this kind of equipment limits their widespread utilization (particularly where teams are concerned). Field tests are, however, often more specific and practical as well as being less expensive. Thus, the development of three new field tests to determine on-ice skating aerobic capacity is a welcome development in ice-hockey. The examination of these tests in the current study, is a necessary step in providing information that could assist the Central Scouting Service in deciding to add more sport specific testing to their testing protocol for potential NHL players.

#### **2.4.4 Examples of Sport Specific Testing in Other Sports**

Field-based tests have been designed for many different sports with the aim of testing athletes in sport specific conditions, such as cross-country skiing (Doyon *et al.*, 2001; Vergès, Flore & Favre-Juvin, 2003; Vergès *et al.*, 2006), badminton (Chin *et al.*, 1995), and soccer [Loughborough intermittent shuttle test (LIST), Nicholas, Nuttall & Williams (2000); Probst field test, Labsy *et al.*, (2004); Interval shuttle run test (ISRT), Lemmink, Verheijen, & Visscher (2004); Intermittent anaerobic running test (IAAnRT), Psotta *et al.*, (2005); Yo-Yo intermittent recovery test, Thomas *et al.* 2006]. Sport specific tests for swimming (Monpetit *et al.*, 1981); water polo (Rechichi, Dawson & Lawrence, 2000); cycling (Marion & Léger, 1988) and speed skating (Beneke & von Duvillard, 1996) have also been used effectively.

## 2.4.5 Off-Ice Non Skating Tests

### a) Laboratory Treadmill and Cycling Tests (Traditional Modes of Testing)

The physiological demands imposed during a hockey game are not confined to the anaerobic systems. Improving aerobic capacity reduces fatigue and improves player performance.  $\dot{V}O_2$  max is considered to be the most accurate single best measure of an individual's circulatory and respiratory capacity (Cunningham, Telford & Swart, 1976), and is perhaps the most commonly employed laboratory procedure in exercise physiology. This measurement determines an athlete's ability to take in, transport and utilize oxygen.  $\dot{V}O_2$  max is however, not the single best predictor of athletic potential because it is only one of many physiological variables positively related to successful endurance performance (Hawley & Burke, 1998). But, Bunc *et al.* (1987) state that persons with greater endurance may perform exercise of an endurance character with a higher intensity of the submaximal load without an increase in their lactic acid concentration in the blood than people with low endurance. This is the result of the positive dependence of  $\dot{V}O_2$  on the intensity of the load.

The most frequently employed laboratory protocols for assessing  $\dot{V}O_2$  max of hockey players are progressive, incremental exercise tests to exhaustion (usually for seven to ten minutes) on either a cycle ergometer or a motor-driven treadmill, with very few actual skating tests of  $\dot{V}O_2$  max having been performed. Treadmill testing usually gives values that are 10 % higher than the cycle ergometer (Van Ingen Schenau, de Groot & Hollander, 1983; Montgomery, 1988; Snyder & Foster, 1994; Hawley & Burke, 1998).

Throughout a maximal test, the athlete wears a nose clip, while the expired air is collected through a mouthpiece and instantly analyzed by a computer for volume, as well as oxygen and carbon dioxide content. The ratio of the

athlete's carbon dioxide production to their oxygen consumption, the respiratory exchange ratio (RER), allows an estimate of the type of fuel being used during exercise to be determined, and the heat rate/  $\dot{V}O_2$  relationship assessed during incremental laboratory exercise testing appears to be stable and reliable (Crisafulli *et al.*, 2006).

The cycle ergometre is also frequently used to evaluate the aerobic and anaerobic capabilities of hockey players in the laboratory settings, and some research has indicated that the glycogen depletion patterns and muscles used in cycling are similar to those used in skating (Green, 1978). The PWC<sub>170</sub> test has been shown to be reliable (0.60 to 0.84) for estimating  $\dot{V}O_2$  max in ice-hockey players aged 9.9 to 10.9 years of age (Cunningham, Telford & swart, 1976; Larivière, Lavallée & Shepard (1976).

In ice-hockey, anaerobic capacity has been tested by using a modified 30 s Wingate cycle ergometre test and a lengthened version of 40 s (Twist & Rhodes, 1993b). Montgomery (1988) developed an intermittent cycle ergometre test (validated by, Montgomery *et al.*, 1990) that is a measure of the anaerobic endurance of ice-hockey players. The test consists of six repetitions, each 15 s in duration with each repetition separated by a 15 s recovery interval, resulting in a total work time of 90 s and with an exercise to recovery ratio of 1:1 (RACE). Cycle test results have been compared with on-ice maximal skating performance using the repeat sprint skate test. Correlation coefficients of  $r=-0.87$  for peak power/kg on the laboratory test and speed index on the repeat sprint skate test, and  $r=-0.78$  for total power/kg on the lab test and time on the ice test provided support to establishment of validity. The test was able to discriminate between varsity, junior varsity and non-varsity players (Montgomery *et al.*, 1990). Members ( $n=27$ ) of the Finnish National team (1978) were tested using two 60 s all-out efforts on a cycle ergometre. The tests were separated by a 3 minute recovery period (Montgomery, 1988).

On-ice testing of anaerobic fitness may be more appropriate than using laboratory based cycle protocols as skating is very different from cycling, being weight bearing, and having air and ice resistance (Bracko & Fellingham, 2001). Léger, Seliger & Bassard (1979) state that functional skating capacity test or a performance test appears more informative than the  $\dot{V}O_2$  max score to establish the ability of a player to perform aerobic skating. This does not imply that the  $\dot{V}O_2$  max is unimportant in ice-hockey, as the player with the highest but same skating efficiency as others, will be the best one to perform aerobic skating.

## **b) Field Tests**

Most field tests measure performance of specific tasks that are not always reproduced during the sporting activity (Boddington *et al.*, 2004). Meyer *et al.* (2003) state that field tests with incremental running protocols do not result in higher  $\dot{V}O_2$  max measurements compared to laboratory treadmill exercise, although a better running economy on the track results in higher maximal velocities and longer exercise durations being sustained.

### *University of Montréal Track Test (UM-TT) (Léger & Boucher, 1980)*

UM-TT is a continuous maximal indirect multistage running field test based on the energy cost of running. The first stage is 5 Mets, thereafter the speed increases by 1 Met very two minutes. Subjects are paced by sound signals emitted at specific frequencies. Léger & Boucher (1980) and Léger & Lambert (1982) examined the reliability of the UMTT and both studies found significant coefficients of correlation between test- and re-test (0.97 and 0.98, respectively) and reported it to be valid ( $r=0.96$ ). Mercier & Léger (1986) concluded that the UMTT is a valid test ( $r=0.72$  to  $0.98$ ) to predict running performance and that maximal aerobic power can be predicted from performance

### *Cooper 12 Minute Test*

The Cooper 12 minute walk/run test predicts  $\dot{V}O_2$  max from the distance covered during 12 minute (Cooper, 1968). Grant *et al.* (1995) rated the Cooper walk run test to be the best predictor of  $\dot{V}O_2$  max among three different tests for assessing  $\dot{V}O_2$  max, and reported the correlation coefficient to be 0.92 relative to the treadmill  $\dot{V}O_2$  max. Hockey & Howes (1979) compared skaters' HR and predicted caloric expenditure during a 12-minute skate test and a 12-minute run test (the obtained correlation coefficient between the 12-minute run test and  $\dot{V}O_2$  max was 0.62, while that between the 12-minute skate test and the  $\dot{V}O_2$  max was 0.60).

### *5 Minute Maximal Running Test*

Berthon *et al.* (1997) compared the validity of the 5 minute maximal running field test in two groups of subjects. Subjects are required to run a maximal distance in 5 minutes on a running track. A sound signal is given every minute, and a countdown is announced for the last 10 s. Berthon *et al.* (1997) concluded that the 5 minute maximal running field test is a valid ( $r=0.84$  to  $0.86$ ) aerobic field test for maximal aerobic assessment for sub-elite runners as well as for sportsmen of other disciplines, regardless of the physical fitness of the subjects (less than 1% error). Correlation coefficients of the repeatability of the maximal aerobic velocity estimated during the 5 minute running field test has been shown to range from 0.94 to 0.98, indicating that the 5 minute running field test is reliable when using homogeneous groups with various characteristics as well as in a heterogeneous population from only one trial (Dabonneville *et al.*, 2003).

### *40 m Shuttle Running*

Baker, Ramsbottom & Hazeldine (1993) used a maximal shuttle run test over a distance of 40 m (on a 20 m course). The protocol consists of sprinting from

the midpoint of the course (10m) to the first marker (a distance of 10 m), turning, running 20 m (to the opposite end of the course) to the second marker, turning and running again to the mid-point of the course again, a total distance of 40 m. Each sprint is started with a 5 s countdown. Eight sprints in total are completed. A 20 s recovery is permitted between each successive sprint. Baker, Ramsbottom & Hazeldine (1993) indicated that the test-retest correlation for this test to be  $r=0.86$  for the fastest 40 m shuttle run times,  $r=0.95$  for  $HR_{max}$  and  $r=0.98$  for peak lactate concentration. Baker, Ramsbottom & Hazeldine (1993) concluded that the 40 m maximal shuttle run test was both reliable and reproducible.

### *20 Metre Multistage Shuttle Run Test (20 MST)*

The 20 MST originally designed by Léger & Lambert (1982), and later refined (Léger *et al.*, 1988) is a popular field test of aerobic power. The test is maximal and progressive with frequent stop-and-go, is practical and less time consuming than direct measurements. The 20 MST is inexpensive and a safe maximal test that utilizes the same protocol for all groups, and can test large groups at the same time in field settings, making it possible to do longitudinal or cross sectional comparisons at all ages (Léger & Lambert, 1982; Van Mechelen, Hlobil & Kemper, 1986; Boreham *et al.*, 1990). Grant *et al.* (1995) state that the 20 MST is relevant to sports such as soccer and hockey, where turning is a feature of the game. The test appears to be highly reliable ( $r=0.975$ ; Léger & Lambert, 1982); and there is a linear relationship between oxygen consumption and running velocity, and a strong correlation between running performance and  $\dot{V}O_2$  max when individuals with a large range of  $\dot{V}O_2$  max values are represented (Ramsbottom, Brewer & Williams, 1988). According to Léger *et al.* (1988) the 20 MST test was found to be reliable both in children ( $r=0.98$ ) and adults ( $r=0.95$ ), with no significant difference ( $p>0.05$ ) between the test and retest. Van Mechelen, Hlobil & Kemper (1986) also validated the 20 MST and state that it is a suitable tool for the evaluation of maximal aerobic power and that it is a better predictor of  $\dot{V}O_2$  max than

endurance runs. Mc Naughton *et al.* (1996) also found that the 20 MST (Léger *et al.*, 1988) to have a high correlation ( $r=0.87$ ) with laboratory measured  $\dot{V}O_2$  max. St Clair Gibson *et al.* (1998) found the relationship between  $\dot{V}O_2$  max as predicted from the 20 MST and those measured during the treadmill test was stronger in runners ( $r=0.71$ ) than in squash players ( $r=0.61$ ). They concluded that there are sport specific differences when predicting  $\dot{V}O_2$  max from the 20 MST. Léger & Gadoury (1989) indicated that the 20 MST with one minute stages is a valid test. Correlations between maximal shuttle run speed ( $r=0.90$ ) and retro extrapolated  $\dot{V}O_2$  max ( $r=0.87$ ) were good.

Studies evaluating the accuracy of the 20 MST in predicting laboratory  $\dot{V}O_2$  max and maximal velocity have reported contradictory results. Ahmaidi *et al.* (1992) showed that the maximal velocity determined during the 20 MST revealed a lower value than treadmill testing (16.3 %), but no difference between  $\dot{V}O_2$  max values were found. Mc Naughton *et al.* (1996) state that the 20 MST overestimates the  $\dot{V}O_2$  max, while St Clair Gibson *et al.* (1998) state that the 20 MST underestimates the  $\dot{V}O_2$  max.

Wilkinson, Fallowfield & Myers (1999) investigated the incidence of subject drop-out on a modified incremental shuttle run test in which speed was increased by  $0.014 \text{ m s}^{-1}$  every 20 m shuttle. No obvious drop-out pattern was observed, and it was concluded that the modified incremental shuttle run test and provides a reliable measure of peak shuttle running speed (95% confidence limits  $\pm 0.11 \text{ m s}^{-1}$ ) and a valid estimation of  $\dot{V}O_2$  max ( $r=0.91$ ; standard error of estimation  $\pm 2.6 \text{ ml kg}^{-1} \text{ min}^{-1}$ ).

It can thus be concluded that the maximal multistage 20 MST, with stages increasing by  $0.5 \text{ km h}^{-1}$  or 1 MET ( $3.5 \text{ ml O}_2 \text{ kg}^{-1} \text{ min}^{-1}$ ) every minute from a starting speed of  $8.5 \text{ km h}^{-1}$  or 7 MET (Léger *et al.*, 1988), appears to be valid and reliable (highly reproducible) in predicting the maximal aerobic power of both males and females, alone or in groups, on most types of gymnasium surfaces (rubber floor and vinyl-asbestos tiles) (Léger & Lambert, 1982; Van

Mechelen, Hlobil & Kemper, 1986; Paliczka, Nichols & Boreham, 1987; Léger *et al.*, 1988; Boreham *et al.*, 1990).

Very recently, Flouris, Metsios & Koutedakis (2005) introduced prediction models to increase the efficacy of the 20 MST to accurately evaluate aspects of health and fitness, and claims to be the first direct clinical appraisal of the 20 MST as a screening tool for specific cardiorespiratory fitness cut off points such as  $\dot{V}O_2$  criterion.

### *Interval Shuttle Run Test (ISRT)*

ISRT was developed by Lemmink, Verheijen, & Visscher (2004) was based on the 20 MST (Léger & Lambert, 1982, and Léger *et al.*, 1988), but is intermittent in nature. The ISRT requires subjects to run back and forth on a 21 m course. The frequency of the sound signals on a pre-recorded cassette increase the running speed by 1 km h<sup>-1</sup> every 90 s from a starting speed of 10 km h<sup>-1</sup>, and by 0.5 km h<sup>-1</sup> every 90 s starting from 13 km h<sup>-1</sup>. Each 90 s period is divided into two 45 s periods, in which subjects run for 30 s and walk for 15 s. Running and walking periods are announced on the pre-recorded cassette. The ISRT is a reliable test with an intra-class correlation coefficient of 0.90, but is moderately correlated with direct measurements of  $\dot{V}O_2$  max on the treadmill ( $r=0.77$ ) in amateur soccer players. The intra-class correlation coefficient for HR per running speed ranges from 0.93-0.99. The relative reliability of the ISRT for the number of runs is high (0.98) (Lemmink *et al.*, 2004).

### *The Modified 5-m Multiple Shuttle Test (5-m MST)*

The 5-m MST for field hockey consists of six cones placed 5 m apart in a straight line to cover a distance of 25 m. the subject begins in line with the first cone, and begins sprinting (5 m) upon an auditory signal to the second cone, where the subject touches the ground with his/her hand adjacent to the

cone, then turns and returns to the first cone, again touching down adjacent to the cone. The subject then turn and sprints back to the 3<sup>rd</sup> cone (10 m), and back. The subject continues in this manner until 30 s of exercise has been completed. The distance covered by the subject is recorded to the nearest cone during each 30 s shuttle. The subject is allowed 35 s of recovery after each shuttle. This 30 s shuttle and 35 s rest is performed six times. Peak distance, total distance, delta distance, and fatigue index can be calculated (Boddington, Lambert & Waldeck, 2004). Boddington, Lambert & Waldeck (2004) found the 5m shuttle run test to be a reliable measure of total and peak distances ( $R=0.98$  and  $R=0.86$  respectively), HR ( $R=0.65$  to  $0.97$ ), and RPE ( $R=0.85$  to  $0.91$ ) response and that it is sufficiently reliable to track changes in fitness over a season. Delta distance ( $R=0.74$ ) and fatigue index ( $R=0.74$ ) were not found to be as reliable and should be interpreted with caution. Boddington, Lambert & Waldeck (2004) established direct ( $R=0.74$ ), criterion ( $R=0.92$ ), and construct validity of the 5-m MST for the fitness assessment of field hockey players. The strongest relationship occurred between the  $\dot{V}O_2$  max data estimated from the 20 MST and the total distance covered during the 5-m MST ( $r=0.92$ ), indicating that a player with a higher  $\dot{V}O_2$  max would cover a greater distance on their first sprint and maintain that greater work throughout the 5-m MST. Boddington, Lambert & Waldeck (2004) concluded that the 5-m MST is a reliable and valid test and should be so for other sports that have similar demands to field hockey.

### *Repeated Sprint Test for Field Hockey*

Spencer *et al.* (2006) assessed the reliability of a hockey-specific repeat-sprint test. The test consists of 6 x 30 m over-ground sprints departing on 25 s, with an active recovery (approximately 3.1-3.3 m/s) between sprints. Reliability was assessed by the typical error of measurement (TE). The total sprint time was very reliable (TE=0.7%). However, the percent sprint decrement was less reliable (TE=14.9%).

## 2.4.6 Off-Ice Skating Tests

### a) Skating Treadmill

Because of the importance of a high  $\dot{V}O_2$  max for good hockey performance, testing  $\dot{V}O_2$  max has become a regular part of the physiological assessment of many hockey teams (Dreger & Quinney, 1999). This has led to the development of several laboratory (Rundell, 1996; Dreger, 1997; Dreger & Quinney, 1999; Nobes *et al.*, 2003) and on-ice protocols (Leone, Léger, & Comtois, 2002, unpublished; Kuisis, 2003; Petrella, *et al.*, 2005). However, it is still unclear which of these tests is the most practical, time and cost effective, reliable, valid and sport specific.

The skating treadmill is the most recent modality of testing the skating performance of ice-hockey players. A commercially manufactured motorized treadmill has recently been introduced onto the market. The treadmill has a special skating surface of between 1.80-1.83 m wide and 1.78-2.13 m long and consists of a parallel series of polyethylene slats (1.82 m long x 3.1 cm wide x 0.64 cm thick). The slats are secured to a rubberized belt that rotates around a set of drums, similar to a belt on a traditional running treadmill. An electric motor drives the track, allowing for adjustments in speed from zero to 25 km h<sup>-1</sup>, and the surface of the treadmill may be elevated to a maximum angle of 32°. Creating a surface permitting subjects to perform wearing their own ice-skates, and execute a regular skating stride. During testing subjects usually wear a safety harness that is attached to an overhead track as a safety precaution should a fall occur (Rundell, 1996; Nobes *et al.*, 2003; Dreger, 1997).

Rundell (1996) tested speed skaters on a skating treadmill while continuously measuring HR, oxygen consumption, ventilation (VE), and respiratory exchange ratio. Stage duration was 4 minutes, and the initial stage velocity was 5 MPH (2.24 m s<sup>-1</sup>), skating speed was increased by approximately 0.45

$\text{m s}^{-1}$  ( $1 \text{ m h}^{-1}$ ) at each successive stage, while the elevation remained constant. The second part of the test began with an incline of 5 % and a speed of  $4.03 \text{ m s}^{-1}$ , increasing elevation by 1 % at the end of each minute. This procedure was continued until volitional exhaustion.

Dreger & Quinney (1999) tested elite ice-hockey players on the skating treadmill, using an intermittent skating protocol. Subjects skated in their own hockey skates at a self-selected, constant speed ( $14.4$  to  $16 \text{ km h}^{-1}$ ) throughout the test. Initial grade was set at 0%. Subjects skated for a 2 minute stage, followed by a 2 minute rest period. The grade was then increased by 2% and another 2 minute stage was attempted, followed by a 2 minute rest period. This process was repeated until volitional exhaustion. Unless subjects stopped skating within 15 s of completing a stage, a verification process was performed. This process began after a 2 minutes recovery period, and the subject then skated to exhaustion at one load greater than the last load completed. The highest  $\dot{V}\text{O}_2$  achieved ( $\dot{V}\text{O}_2$  peak) was considered  $\dot{V}\text{O}_2$  max. Dreger & Quinney (1999) observed no significant differences between  $\dot{V}\text{O}_2$  max on the skating treadmill and cycle ergometre in 6 elite ice-hockey players, but breathing frequency was significantly higher during the skating treadmill protocol. The skating treadmill protocol also produced significantly higher  $\text{HR}_{\text{max}}$  compared with the cycle ergometre protocol.

Nobes *et al.* (2003) examined skating economy and  $\dot{V}\text{O}_2$  max comparing treadmill skating to on-ice skating at skating speeds of 18, 20, 22  $\text{km h}^{-1}$  (for skating economy), and starting at 24  $\text{km h}^{-1}$  for  $\dot{V}\text{O}_2$  max (increasing by 1  $\text{km h}^{-1}$  every minute). Nobes *et al.* (2003) used a skating treadmill protocol for ice-hockey players, while continuously measuring oxygen consumption. Skating economy was measured at three submaximal velocities (again at 18, 20, and 22  $\text{km h}^{-1}$ ), separated by 5 minutes of passive recovery. A  $\dot{V}\text{O}_2$  max test followed the submaximal tests and commenced at 24  $\text{km h}^{-1}$  with the velocity increasing by 1  $\text{km h}^{-1}$  every minute until volitional fatigue. The

grade remained at 0% for the skating economy and maximal tests.  $\dot{V}O_2$  was significantly lower at 18, 20, and 22 km h<sup>-1</sup> on the ice. The mean on-ice  $\dot{V}O_2$  max was similar to that on the skating treadmill. Stride rate, stride length, and HR were significantly different on-ice compared to the skating treadmill. Thus at submaximal velocities,  $\dot{V}O_2$ , HR, and stride rate are higher on the skating treadmill compared to on-ice.  $\dot{V}O_2$  max was similar while HR<sub>max</sub> was higher on the skate treadmill compared to on-ice (confirming the higher intensity when skating on the treadmill compared to ice). The on-ice stride rates were significantly lower than the treadmill values. Stride rates were similar at 18, 20, and 22 km h<sup>-1</sup> during the treadmill tests. On-ice stride rate significantly increased from 32.0 strides min<sup>-1</sup> at 18 km h<sup>-1</sup> to 39.3 strides min<sup>-1</sup> at 22 km h<sup>-1</sup>.

The utilization of the skating treadmill, however, may represent some technical problems such as greater sliding resistance due to the synthetic surface, absence of wind resistance, no turns, breaking or change of direction permitted, which is in conflict with the nature of ice-hockey in game situations (Leone *et al.*, 2007). Additionally, greater physical effort is required when performing the cross-over strides to skate the curves on an oval course on-ice, as compared to only forward skating on the treadmill (Nobes *et al.*, 2003). Although the skating treadmill attempts to simulate skating and is more sport specific than the cycle ergometre or treadmill running, as seen from the abovementioned protocols, skating speed seems to be limited by the treadmill, which necessitates an elevation in the grade. This modifies the biomechanics of skating and consequently affects the type and amount of muscular involvement as compared to skating on-ice (Leone, Léger, & Comtois, 2002, unpublished).

## **b) Slide Board**

The slide board is a means of testing skaters' off-ice, but in a more sport specific manner than cycling or running, but there is almost no research on

this modality of testing. The athlete attaches a gliding board to the bottom of the shoes, which slide on a mat the width of two leg lengths. The athlete slides sideways from one end of the mat to another at a rhythm set by a cadence metre or metronome. Clenin *et al.* (2006) used a slide board test to evaluate the endurance capacity of junior elite ice-hockey players. The pace started at a cadence of 18 min<sup>-1</sup> and increased to 31 min<sup>-1</sup>. Clenin *et al.* (2006) compared this progressive stage slide board test to a progressive on-ice test and to a laboratory lactate threshold test on a cycle ergometre. They measured maximal speed, heart rate, lactate, and RPE in 29 subjects, and found a low correlation between the slide board test and the on-ice test. They concluded that the slide board test was not an adequate test to measure endurance capacity of ice-hockey players.

#### **2.4.7 On-Ice Skating Tests**

##### *Tests of Speed, Hockey Ability, Agility, and Anaerobic Capacity*

Cox *et al.* (1995) state that on-ice testing of ice-hockey players can be highly task specific, but may suffer from problems of reliability. Nevertheless, the ice surface can be a good venue to test aerobic power, anaerobic power and capacity. Few studies have reported a sport specific protocol to measure aerobic power of ice-hockey players using a predictive process, and there is currently a lack of cohort specific information describing aerobic power in hockey players based on evaluations utilizing an on-ice continuous skating protocol (Petrella *et al.*, 2007).

In 1968 Merrifield & Walford developed six tests for measuring selected basic skills in ice-hockey. These tests included forward skating speed, backward skating speed, skating agility, puck carrying, shooting, and passing. Most tests specific to ice-hockey measure variables related to anaerobic metabolism. Speed tests over varying distances have been used to test ice-

hockey players: 2.1 m sprint (Doyle-Baker, Fagan & Wagner, 1993); 6.10 m acceleration (20 ft) (anaerobic power can be calculated by using the formula by Watson & Sargent, 1986); 16.3 m full speed (Bracko, 1998); 44.80 m (147 ft) speed (Bracko, 1998; Bracko, 2001; Bracko & George, 2001); 54.9 m sprint (Mascaro, Seaver & Swanson, 1992); 56.4 m sprint (Doyle-Baker, Fagan & Wagner, 1993); and maximum speed between the blue lines (Behm *et al.*, 2005).

Behm *et al.* (2005) used an on-ice unanticipated stop test: skater starts at the goal line. Skater begins skating on own discretion with the intension of reaching near maximal speed by the centre zone (between the blue lines). A whistle is blown when the skater is within the centre zone, indicating that the skater should stop as abruptly as possible with the dominant leg outside.

Many different tests for hockey ability and on-ice agility have also been used: cornering s-turn (length from goal line to finish line was 18.90 m, and the width was 22.55 m) (Bracko, 1998; Bracko, 2001; Bracko & George, 2001); short-radius turns test (Behm *et al.*, 2005); cone agility test where the skater starts at the blue line, at the signal of a whistle, and skates as fast as possible around 3 pylons situated at the centre of the red line (2 cones) and blue line (2 cones) (Behm *et al.*, 2005); Illinois agility skate test, Finish Skills Test, and the Hermiston Hockey ability test (Hermiston, Gratto, & Teno, 1979)

Tests of anaerobic capacity are also common, Smith, Quinney & Steadward (1982), Bracko (1998), and Bracko (2001) used an on-ice repeat sprint test adapted from the University of Ottawa protocol, the Reed Repeat Sprint Skate Test (Reed *et al.*, 1979). A modified version (4 repetitions) of the repeat sprint skate test has been used with young hockey players (Montgomery, 1988; Arnett, 1996), whereas Bracko & George (2001), used modified repeat skate test (reduced from 6 repeats to 3 repeats). Another skating test of anaerobic capacity is the Sargeant Anaerobic Skate Test (SAS<sub>40</sub>), (Bracko, 2001; Bracko & Fellingham, 2001). Doyle-Baker, Fagan & Wagner (1993) used an anaerobic

capacity test consisting of six backward and forward repetitions of 18.3 m, and a 10, 15, 10 lap all-out aerobic test.

### *Tests of Aerobic Capacity/Power*

The first known test of  $\dot{V}O_2$  max while skating was developed by Ferguson, Marcotte & Monpetit (1969). Subjects performed the test wearing full hockey equipment (the equipment plus the gas collection apparatus weighed 10 kg). The workloads consisted of skating for 3 minutes on a 140 m oval course at increasing velocities of 350, 382, 401, 421 and 443 m min<sup>-1</sup> (in order to obtain increases in  $\dot{V}O_2$  of approximately 300 ml min<sup>-1</sup>). The workloads were increased until maximum voluntary physical work capacity was attained. Test re-test correlation for  $\dot{V}O_2$  max was 0.94.

In 1976 Larivière, Lavallée, & Shepard designed an on-ice skating protocol to determine  $\dot{V}O_2$  max. The test consisted of a 100 ft course, with cones at 20 ft intervals, and demarcated at both ends. Players were required to skate as many lengths as possible in 5 minutes. Hockey and Howes (1979) used a 12-minute skate test and a 12-minute run test to compare skaters' heart rates and predicted caloric expenditure. A correlation of 0.60 between a 12 minute skate test and  $\dot{V}O_2$  max was as high as the correlation between a 12 minute run test and  $\dot{V}O_2$  max for a team of Bantam All-Stars (Hockey & Howes, 1979). The somewhat low correlation was partially explained by the homogeneity of the group. Similar heart rates were obtained on the 12 minute skate test and run test. This group averaged 355 m min<sup>-1</sup> during the skate test.

Léger, Seliger & Bassard (1979) used a 20 m on-ice test with, and without equipment (timed by an audio signal) to determine the  $\dot{V}O_2$  max of ice-hockey players, as well as a 140 m on-ice course (without equipment) to determine the  $\dot{V}O_2$  max of ice-hockey player and runners (who also played hockey). Again, in 1981 Léger used an on-ice 140 m oval course (measuring HR and

expired air during the 5<sup>th</sup> minute) with skating paced by an audio signal to determine the energy cost of figure skating with skaters of different skating skill levels (poor, good, and excellent). Montgomery (1988) used 8 minute skate test, also on an oval course (140 m). Players were required to skate as far as possible in 8 minutes.

Carroll *et al.* (1993) tested collegiate ice-hockey players using an on-ice test and an over-ground in-line skating test to determine the metabolic cost of skating. Skating speed was determined using four equidistant reference markers on both skating surfaces. Subjects had to reach each a reference marker every 8 s (12.5 km h<sup>-1</sup>), every 6 s (16.5 km h<sup>-1</sup>), and every 5 s (at 20 km h<sup>-1</sup>). Each lap was 110 m. Each stage lasted 3 minutes and subjects were allowed to recover to within 10% of their resting HR before starting the next stage. Skater's paced themselves to the desired velocities with assistance from the investigator, who announced the number of seconds in the appropriate increments. HR was recorded and gases were collected during the last 30 s of each stage.

Nobes *et al.* (2003) used a 140 m oval on-ice test (also using the Cosmed K4b<sup>2</sup>, Italy for simultaneous gas analysis) with markers every 35 m for the purpose of pacing, with velocity controlled via an audio tape system (4 beeps per lap). The hockey players synchronized their speed with the audio signals and the four cones. Subjects skated for 4 minutes at 18, 20, and 22 km h<sup>-1</sup> with 5 minutes of recovery between each test. The  $\dot{V}O_2$  max test was initiated at 24 km h<sup>-1</sup> with increments of 1 km h<sup>-1</sup> each minute until maximal volitional exhaustion was reached.

Recently, Leone, Léger, & Comtois (2002, unpublished) designed a practical on-ice test to predict the maximal aerobic power ( $\dot{V}O_2$  max) in professional ice-hockey players, called the skating multistage aerobic test (SMAT). The SMAT is a 45 m intermittent (with a work/rest ratio of 1 minute/0.5 minute), progressive, maximal, multistage shuttle skate test that has a stop-an-go

nature. Players are tested wearing full kit and holding the hockey stick in one hand, and the SMAT can be performed in groups of up to 20 players. Subjects skate back and forth over a distance of 45 m (abrupt stop-and-go) while following a pace set by audio signals. The initial velocity is  $3.5 \text{ m s}^{-1}$  with increments of  $0.2 \text{ m s}^{-1}$  at every stage. A cone is placed at the midpoint along the course, and skating velocity is adapted to meet the midpoint of the course in synchrony with the audio signal, and, without stopping, subjects are required to continue skating to reach the end of the course in synchrony with the next auditory signal. At the end of each stage subjects skate slowly to the nearest line and rest passively before the next stage.  $\dot{V}O_2 \text{ max}$  is predicted from the maximal skating velocity. Leone *et al.* (2007) validated the SMAT, to predict  $\dot{V}O_2 \text{ max}$  in elite age-group ice-hockey players. Leone *et al.* (2007) conclude that the SMAT is highly specific, valid (strongly accurate) ( $r=0.97$ ), and highly reproducible ( $r=0.92$ ) for the prediction of  $\dot{V}O_2 \text{ max}$  of ice-hockey players. Although the SMAT may be administered for both age-group and professional ice-hockey players, the correct regression equation need to be used in each case to ensure a high degree of accuracy for the prediction of  $\dot{V}O_2 \text{ max}$  (Leone *et al.*, 2007).

Kuisis & van Heerden (2001) investigated the estimated (indirect) and simultaneous direct  $\dot{V}O_2 \text{ max}$  in ice-hockey players and figure skaters. The original 20 MST (Léger *et al.*, 1988) protocol was used on-ice (skating). The relative  $\dot{V}O_2 \text{ max}$  ( $\text{ml kg}^{-1} \text{ min}^{-1}$ ) estimated during the skated MST highly over-predicted the simultaneous directly measured  $\dot{V}O_2 \text{ max}$  of both ice-hockey players and ( $62.4 \pm 4.6$  vs.  $43.7 \pm 6.6$ ;  $p < 0.01$ ) and figure skaters ( $80.6 \pm 5.1$  vs.  $38.9 \pm 3.5$ ;  $p < 0.0001$ ). Kuisis & van Heerden (2001) concluded that, the 20 MST as originally designed for use over-ground is unsuitable to assess aerobic fitness in ice-hockey players and figure skaters.

In 2003 Kuisis, modified the 20 MST for application to ice-sports. A repeated measures design was adopted to determine velocity of motion (VOM), oxygen cost and mechanical efficiency (ME) on-ice and over-ground. Accordingly, the

on-ice test velocity for the initial stage was  $10.1 \text{ km}\cdot\text{h}^{-1}$  and increased ( $\sim 0.5 \text{ km h}^{-1}$ ) for each subsequent level. Mean test-retest, on-ice reliability measures for predicted  $\dot{V}\text{O}_2 \text{ max}$  were highly consistent ( $r=0.87$ ;  $p\leq 0.001$ ). Similarly mean test-retest measures of predicted  $\dot{V}\text{O}_2 \text{ max}$  with over-ground running 20 MST (Léger *et al.*, 1988) showed significant ( $r=0.73$ ;  $p\leq 0.01$ ) concurrent validity. It was concluded that the skating 20 MST is a test with surface specific utility, but that a direct validation (as apposed to concurrent validity) would be necessary before the test can utilized accurately.

A third new field test for ice-hockey that has recently emerged is the Faught Aerobic Skating Test (FAST) (Petrella, *et al.*, 2005). This test uses an on-ice continuous skating protocol to induce a physical stress on the aerobic energy system, and incorporates the principle of increasing workloads at measured time intervals during a continuous skating exercise. Regression equations were developed for males and females according to Hockey Canada age groups divisions (Atom, Peewee, Bantam, Midget, juvenile, varsity). The most consistent predictors were weight and final stage completed of the FAST. Age-group specific predictors included height in males aged 11-15 years, and years of ice-hockey experience in males aged 15-18 years. The results support the application of the FAST to estimate aerobic capacity among hockey players (Petrella, *et al.*, 2005; Petrella, 2006). Petrella, *et al.* (2005) assessed the reliability of the FAST final stage completed (f-stage) and the players  $\text{HR}_{\text{max}}$  (FAST-HR) upon completion of the FAST. The f-stage was shown to be reliable ( $r=0.81$ ), but the FAST-HR was not. Petrella *et al.* (2005) do however state that the FAST-HR is less important in the estimation of aerobic capacity with the FAST. Thus, it was concluded that the FAST is a reliable on-ice measure of aerobic capacity. Petrella *et al.* (2007) showed a strong correlation ( $r=0.77$ ;  $p<0.01$ ) between the predicted  $\dot{V}\text{O}_2 \text{ max}$  during the FAST and true  $\dot{V}\text{O}_2 \text{ max}$ . Weight (kg), height (m), gender and final attempted length of the FAST (F-length) were found to be significant predictors of skating aerobic power.

In a small study (using only six boys aged 15-16 years) Strömberg (2006) attempted to modify the 20 MST for ice-hockey in order to predict aerobic capacity in ice-hockey players from a skating test. A 17.2 m course was used, and subjects skated back and forth along the course, following the pace set by audio signals, which increased in frequency every minute. A correlation of 0.86 ( $p < 0.05$ ) was reported between skating predicted  $\dot{V}O_2$  max and laboratory cycling  $\dot{V}O_2$  max.

Clenin *et al.* (2006) used a figure eight (160 m in length) progressive on-ice test with full hockey equipment to evaluate endurance capacity of junior elite ice-hockey players. The initial pacing was 15 km h<sup>-1</sup>, with an increase of 1 km h<sup>-1</sup> for every 320 m. They did however, not measure  $\dot{V}O_2$  max, but only final speed, heart rate, and RPE, and compared this test to laboratory cycling and a slide board test. Clenin *et al.* (2006) found a good correlation between the figure of eight skating test and an incremental lactate threshold test on a cycle ergometre.

$\dot{V}O_2$  max is specific to the muscle mass used in any given type of locomotion (Léger, Seliger & Bassard, 1980), and researchers are attempting to make aerobic testing more ice-hockey specific. All three of the above-mentioned aerobic skating tests were intended for use in the evaluation of hockey players where the opportunity and time required to utilize laboratory equipment is not available. One or more of the three field tests used in the current study will better serve to evaluate players in their sport specific environment and assist in on-ice training of the important physiological requirements of the ice-hockey game.

#### 2.4.8 Off-Ice Testing *versus* On-Ice Testing

There are several reasons for including off-ice measurement as an important part of the overall hockey player evaluation process. The performance of the player is dependent on several factors and some of these factors are more appropriately measured in off-ice conditions, while other factors such as aerobic and anaerobic capacity should be measured on-ice. Several studies have examined the specificity of on-ice testing versus laboratory testing of hockey players (Di Prampero *et al.*, 1976; Léger, Seliger & Bassard, 1979; Daub *et al.*, 1983; Smith & Roberts, 1990; Montgomery *et al.*, 1990; Nobes *et al.*, 2003).

Canadian hockey players appear to have the same  $\dot{V}O_2$  max when tested on the ice and on the treadmill (Larivière, Lavallée & Shepard, 1976; Léger, Seliger & Bassard, 1979; Montgomery, 1988). In an investigation of the specificity of the  $\dot{V}O_2$  max response, runners and hockey players were tested on-ice and on the treadmill (Léger, Seliger & Bassard, 1979). Hockey players had the same  $\dot{V}O_2$  max and lactate when tested on the treadmill, while skating a continuous 140 m oval course, and skating the 20 m shuttle course with or without equipment. Compared with runners, the hockey players required 15 % less energy to skate at a given velocity. However, the hockey players required 7 % more energy to run on the treadmill. Léger, Seliger & Bassard (1979) recommend a functional skating test or a performance test to establish a hockey player's aerobic skating ability. The mechanical efficiency of skating contributes to these findings. During the  $\dot{V}O_2$  max testing, both runners and hockey players had a 10 beats  $\text{min}^{-1}$  lower  $\text{HR}_{\text{max}}$  on-ice as compared with the treadmill run test of similar duration. The arena temperature (10 °C) was cooler than the laboratory temperature (22 °C). Beneke & von Duvillard (1996) state that the ambient temperature during speed skating is lower compared to laboratory testing, and in ice-hockey there is additional stress on the thermoregulatory system due to poor heat elimination in the uniformed, helmeted player, placing greater stress on the

cardiorespiratory system (Patterson, 1979). Laboratory testing of ice-hockey players thus eliminates the component of cold temperatures (Petrella, 2006).

Watson & Sargeant (1986) also compared laboratory and on-ice tests of anaerobic power. University and junior players (n=24) performed a 40 s Wingate test, and two on-ice tests (repeat sprint skate test and the Sargeant anaerobic skate test). It was concluded that the 40 s Wingate test does not demonstrate a high relationship with on-ice measures of anaerobic endurance and power.

In summary, the results from aerobic and anaerobic laboratory tests should be used with caution if the objective is to evaluate the fitness of elite ice-hockey players. On-ice performance tests are recommended as an essential part of the hockey player's physiological profile (Montgomery, 1988).