

**COMPARITIVE VALIDITY OF ICE-SKATING
PERFORMANCE TESTS TO ASSESS AEROBIC CAPACITY**

by

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SUMMARY

Comparative Validity of Ice-Skating Performance Tests to Assess Aerobic Capacity

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Three multistage aerobic ice skating field tests have recently been introduced: 1) MS20MST (Modified Skating 20 MST; Kuisis, 2003), a maximal continuous multistage stop-and-go test over 20 m; 2) SMAT (Skating Multistage Aerobic Test; Leone *et al.*, 2002), a maximal intermittent multistage shuttle test with stop-and-go over 45 m (both using full ice-hockey equipment); and 3) FAST (Faught Aerobic Skating Test; Petrella *et al.*, 2007), a maximal continuous multistage 160 ft (48.8 m) ice-skating shuttle test with wide turns wearing only gloves, hockey stick and helmet. The aim of the study was to 1) compare the MS20MST, SMAT, and FAST to determine how they relate to each other and to determine their common variance, 2) 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 and predicted $\dot{V}O_2$ max from original equations of the SMAT and FAST (a regression was developed in this study to predict $\dot{V}O_2$ max for the MS20MST). Each test was also compared to the 20 MST (Léger *et al.*, 1988; to determine concurrent validity), 3) determine which test is rated by the players as being the best suited and most functional test (using a 7-point Likert Resemblance Scale), and 4) to determine if these on-ice skating tests are in effect better than the over-ground 20 MST.

Twenty-six adult ice-hockey players of various fitness levels but with good skating skills participated in the study. Expectedly, maximal speed increased from MS20MST to SMAT and to FAST protocols but the latter shows lowest Borg RPE, lactate_{max} and HR_{max} ($p \leq 0.05$, Repeated ANOVA and Tukey test). Similitude with the intensity of a hockey game and suitability as an aerobic test for ice-hockey was also judged lowest by the subjects for the FAST test on a 7 point subjective Likert Resemblance Scale. Compared to treadmill $\dot{V}O_2$ max, correlations were 0.74, 0.73, 0.41 and 0.84 for MS20MST, SMAT, FAST and the 20 MST, respectively. Correlations were slightly better with treadmill max speed (0.75, 0.78, 0.53 and 0.94, respectively) due to small but common accuracy problem of $\dot{V}O_2$ measure. Thus using the treadmill test as a standard, the FAST is less valid than the two other skating protocols implying that the ice skating protocol that elicits the highest $\dot{V}O_2$ max values would be a better standard. Nevertheless lower HR_{max} and lactate_{max} values for the FAST do not support that test. Correlations between the MS20MST, SMAT and the 20 MST were approximately 0.7 but lower between these tests and FAST (approximately 0.4). Based on these results, it is recommended to either use MS20MST or SMAT protocols in elite players if ice time is available, alternatively, the 20 MST. Future study is needed to identify which test yields highest $\dot{V}O_2$ max values on ice.

Keywords: ice-hockey, aerobic power, skating, modified skating 20 MST, SMAT, FAST.

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LIST OF ABBREVIATIONS

%	percentage (one part in every hundred)
°/s	degrees per second (measurement of angular velocity)
°C	degree Celsius (measurement of temperature)
20 MST	20 Metre Multistage Shuttle Run Test (field test that predicts maximal oxygen consumption)
MS20MST	Modified (Skating) 20 Metre Shuttle Test
ft	foot (linear measurement of distance)
FAST	Faught Aerobic Skating Test
g	gram (unit of mass)
HR	heart rate (measured in beats per minute)
HR max	maximal heart rate (measured in beats per minute)
kg	kilograms (unit of mass)
km h⁻¹	kilometres per hour (unit of speed or velocity)
cm	centimetre (linear measurement of distance)
m	metre (linear measurement of distance)
min	minutes (unit of time)
m min⁻¹	metres per minute (unit of speed or velocity)
m s⁻¹	metres per second (unit of speed or velocity)
m min⁻¹	metres per minute (unit of speed or velocity)
MET	metabolic equivalent (a way of expressing energy cost of an activity; a standard quantity of oxygen required for maintenance of life, on a per kilogram body weight basis, per minute under quiet

resting conditions; as a standard value it is equal to 3.5 millilitres of oxygen per minute)

ml	millilitre (unit of volume or capacity)
ml kg⁻¹ min⁻¹	millilitre per kilogram of body mass per minute (unit of oxygen consumption)
mmHg	millimetres mercury (unit of measure of barometric pressure)
mmol L⁻¹	millimole per litre (unit of molecular weight of a substance; unit of measurement of blood lactic acid)
m h⁻¹	miles per hour (unit of speed or velocity)
n	number of participants in a group
NHL	National Hockey League
O₂	oxygen
pH	negative decimal logarithm of hydrogen-ion concentration in moles per litre, giving measures of acidity or alkalinity of a solution
r	correlation
r²	coefficient of determination
RSS	Reed Repeat Sprint Skate Test (requires players to skate 55 m six times every 30 seconds)
s	seconds (unit of time)
SAS₄₀	Sargeant Anaerobic Skate Test (consists of players skating back and forth along pylons placed at a distance of 55 m on the ice for a total of 40 seconds)
SD	standard deviation (the number by which scores deviate from the mean)
SEE	standard error of the estimate (also called standard error of prediction), the amount of error expected in a prediction
SMAT	Skating Multistage Aerobic Test
STPD	the volume of gas expired under standard conditions of temperature (0 °C), pressure (760 mmHg), and dry (no water vapour)

USA	United States of America
VE	minute ventilation (the amount of air expired in one minute)
$\dot{V}O_2$	oxygen consumption (expressed in text as $\dot{V}O_2$)
$\dot{V}O_2 \text{ max}$	maximal oxygen consumption (measured in litres per minute or as millilitres per kilogram per minute); expressed in text as $\dot{V}O_2 \text{ max}$
W kg⁻¹	watt per kilogram (unit of power)
yr	year (unit of time)

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 PWC₁₇₀ 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 ± 1.8 years old) and nine adolescent female figure skaters (15.3 ± 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±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 (~5 ml kg⁻¹ min⁻¹, p≤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±4.3 years) from one National League team yielded r=0.969, SEE=2.06 ml kg⁻¹ 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 PWC₁₇₀ 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)
Source	Léger <i>et al.</i> (1988)	Kuisis (2003)	(Leone, Léger, & Comtois, 2002, unpublished)	Petrella <i>et al.</i> (2007)
Displacement Technique	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
Protocol Type	Max Multistage Continuous Linear	Max Multistage Continuous Linear	Max Multistage Intermittent Linear	Max Multistage Continuous Curvilinear
Speed vs. Stage				
Stage duration	1 min	1 min	1 min	45 s → 19.5 s*
Rest interval	0 s	0 s	30 s	0 s
Initial speed	8.5 km h ⁻¹	10.0 km h ⁻¹	12.6 km h ⁻¹	15 s(11.7 km h ⁻¹)
Speed increase	0.5 km h ⁻¹	~0.5 km h ⁻¹	0.72 km h ⁻¹	-5 s (0.4→2.0 km h ⁻¹)
Equipment	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 14th 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



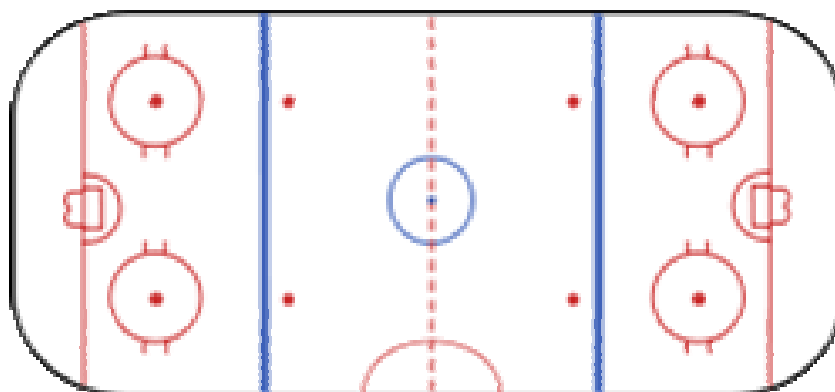
2.1.4 Surface

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°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 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⁻¹ (approximately 3-24 km h⁻¹) can be expected during game play (university players however, average only 227 m min⁻¹; approximately 13.62 km h⁻¹). More recently Gilder & Grogan (1993) stated that forward skating speeds average 56 km h⁻¹ (35 MPH) backward speeds average 24 km h⁻¹ (15 MPH), and gliding speed can be up to 24 km h⁻¹ (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/m², by 2000, the mean BMI had increased to 26.6 kg/m² (a gain of 2.3 kg/m²). 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⁻¹ min⁻¹ 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⁻¹ min⁻¹, but in 1991 only 15% of players had a $\dot{V}O_2$ max of less than 55 ml kg⁻¹ min⁻¹ (Cox *et al.*, 1993). Over the last 10 to 15 years $\dot{V}O_2$ max has increased from approximately 55 ml kg⁻¹ min⁻¹ to 62.8 ml kg⁻¹ min⁻¹ (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⁻¹ min⁻¹) than forwards (optimally above 60 ml kg⁻¹ min⁻¹), 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⁻¹ min⁻¹) 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⁻¹ min⁻¹ 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_{max} 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⁻¹, respectively) then declined during the third period (mean 4.9 mmol L⁻¹). 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⁻¹ for the forwards and 2.9 mmol L⁻¹ for the defensemen. It appears that European hockey is characterized by higher levels (9 to 11 mmol L⁻¹) 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 VO₂ max) or perform intermittent exercise (ten 1 minute bouts with 5 minutes recovery between each, ~75 % of VO₂ 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⁻¹, 16.5 km h⁻¹, and 20 km h⁻¹). 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⁻¹ and 20 km h⁻¹. 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⁻¹

(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⁻¹ 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°C (19°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°C (-4°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°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°C to -7°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_{peak} 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 PWC₁₇₀ 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 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 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 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⁻¹ every 90 s from a starting speed of 10 km h⁻¹, and by 0.5 km h⁻¹ every 90 s starting from 13 km h⁻¹. 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 3rd 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⁻¹, 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⁻¹), skating speed was increased by approximately 0.45

m s^{-1} (1 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 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 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 HR_{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 km h^{-1} (for skating economy), and starting at 24 km h^{-1} for $\dot{V}\text{O}_2$ max (increasing by 1 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 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 km h^{-1} with the velocity increasing by 1 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⁻¹ 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_{max} 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⁻¹ during the treadmill tests. On-ice stride rate significantly increased from 32.0 strides min⁻¹ at 18 km h⁻¹ to 39.3 strides min⁻¹ at 22 km h⁻¹.

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⁻¹ and increased to 31 min⁻¹. 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 (SAS₄₀), (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⁻¹ (in order to obtain increases in $\dot{V}O_2$ of approximately 300 ml min⁻¹). 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⁻¹ 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 5th 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⁻¹), every 6 s (16.5 km h⁻¹), and every 5 s (at 20 km h⁻¹). 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 K4b², 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⁻¹ with 5 minutes of recovery between each test. The $\dot{V}O_2$ max test was initiated at 24 km h⁻¹ with increments of 1 km h⁻¹ 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 m s^{-1} with increments of 0.2 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 ± 4.6 vs. 43.7 ± 6.6 ; $p < 0.01$) and figure skaters (80.6 ± 5.1 vs. 38.9 ± 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 $\dot{V}O_2 \text{ max}$ were highly consistent ($r=0.87$; $p\leq 0.001$). Similarly mean test-retest measures of predicted $\dot{V}O_2 \text{ max}$ 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 HR_{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 $\dot{V}O_2 \text{ max}$ during the FAST and true $\dot{V}O_2 \text{ max}$. 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⁻¹, with an increase of 1 km h⁻¹ 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 min^{-1} lower HR_{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).

CHAPTER 3

METHODOLOGY

3.1. Subjects

Twenty-six male ice-hockey players voluntarily participated in the study. With the help of coaches and various contacts, subjects were recruited from different clubs approximately six weeks before the start of the ice-hockey competitive season. The subjects were frequent and experienced ice-hockey players participating at club, elite or collegiate level in Montréal (Quebec, Canada). Subjects were proficient skaters, but had a wide variety of fitness levels, some having trained relatively regularly during the summer and some had just returned to Montreal after their summer holiday, having done no training (Figure 3.1 and 3.2).

Figure 3.1: Two Subject Participants and the Researcher



To be recruited and included in the study, subjects had to fulfil the following criteria:

1. be aged between 18 and 50,
2. be in good health and successfully complete the PAR-Q (Physical activity Readiness Questionnaire) of the Canadian Society of Exercise Physiology (Appendix E),
3. be proficient skaters (with good agility), that had mastered their skating skills (start, stop, forward acceleration, skating turns), and
4. be willing to participate and give their informed consent.

Exclusion criteria were as follows:

1. goalies were excluded from the study,
2. failure to meet inclusion criteria described above,
3. injury sustained during the testing period, or
4. any contraindications to participation as indicated by his medical doctor.

Figure 3.2: Subject Participants After the Running 20 MST



3.2. Ethical Considerations

The rights and privacy of subjects was adhered to. This study was approved after institutional review by the relevant Ethics committees of both the University of Pretoria and the University of Montreal (Appendix F). To participate in the study, each subject was required to read and sign an informed consent form (Appendix G). This was done after meeting the subject and before the administration of the first test.

All the tests were done in the Centre d'éducation physique et des sports de l'UdeM (CEPSUM, University of Montreal) where an emergency procedure was in place. The head of the human performance laboratory was a qualified CPR instructor, and the primary researcher administering the tests was CPR and AED certified.

3.3. Study Design

In accordance with the aim of this study a repeated measures design was adopted to:

1. compare the MS20MST(2003) (Modified Skating 20 MST, Kuisis, 2003), SMAT (Skating Multistage Aerobic Test, Leone, Léger, & Comtois, 2002, unpublished), and FAST (Faight Aerobic Skating Test; Petrella *et al.*, 2007) ice-skating tests to determine which one is better suited for the evaluation of maximal aerobic power of ice hockey players,
2. assess the external and relative validity of the three new practical ice-skating tests to predict maximal aerobic power ($\dot{V}O_2$ max), using direct treadmill $\dot{V}O_2$ max as the "gold standard" criterion variable,
3. determine which test is subjectively rated by the players as being the best suited and most functional test for ice-hockey, and

4. determine if these on-ice skating tests are better than the established over-ground 20 MST (20 m shuttle running test, Léger *et al.*, 1988).

Twenty-nine subjects thus performed five maximal multistage aerobic tests on separate days. The subjects were not permitted to participate in more than one test per day on any two consecutive days, where after a minimum period of 24 hours rest was required before the next test. All five tests were however completed within three weeks. Due to the fact that there were up to four subjects participating in the field tests at the same time, test order could not be totally randomized. However, tests were done in mixed order (refer to Appendix H) to avoid any systematic ordering of the tests. Field tests were done in small groups (less than or equal to four subjects), to stimulate competitive spirit, to avoid high cost of ice-time and for better monitoring and control over pacing. All ice-tests were done on resurfaced ice.

3.4. Procedures and Instrumentation

Subjects were instructed not to engage in heavy physical activity 24 hours before the test, to arrive for the tests approximately three hours postprandial, after a light meal. An attempt was made to test each subject at the same time of day for each different test (to avoid diurnal biological variation), but owing to the fact that participants had to return for testing on five separate occasions, this was logistically (availability of ice and subject) not possible and thus tests took place at approximately the same time of day.

Biographic Data

The following biographical data was collected during the first meeting with each subject before the first test was completed (refer to Appendix I):

- name and surname,
- date of birth,

- age,
- position of play,
- right or left shoot,
- years of ice-hockey experience;
- level of best play,
- age of best play, and
- date and time of the test.

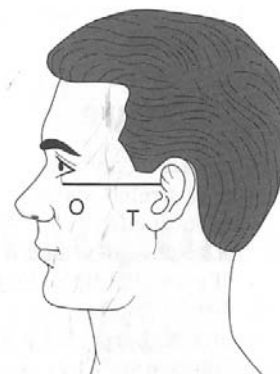
Physical Data

The following physical data was collected on the day of treadmill testing, before the test:

Stature

A Steel measuring tape was mounted against the wall. Stature was recorded as the maximal distance between the soles of the feet (measured in cm) to the vertex of the head, when an imaginary line between the lower margin of the orbital and the upper margin of the zygomatic bone is parallel to the ground (the Frankfort plane) (Figure 3.3). The subject stood barefoot with the arms hanging at the sides. The heels, buttocks, upper back and head were in contact with the wall. Prior to measurement the subject was instructed to look ahead and take a deep breath, without lifting the heels. The measurement was recorded to the nearest mm (Norton *et al.*, 2000).

Figure 3.3: The Frankfort Plane



Mass

Body mass was recorded on a calibrated balance scale (Detecto, Webb City, Mo, USA) and recorded to the nearest 100g. The subject was weighed in running shorts and without shoes, approximately three to four hours postprandial (Norton *et al.*, 2000). Subjects were also weighed in full kit, skates and stick on a balance scale, in the ice arena, prior to performing the MS20MST or SMAT (Figure 3.4). A small sub sample of four subjects were also weighed wearing a tracksuit, helmet, stick, and gloves, as required for the FAST.

Environment

Temperature (°C) was measured from a wall mounted mercury thermometer; humidity (%) was measured from a wall mounted hygrometer, and barometric pressure (mmHg) was measured from a wall mounted barometer, all in the human performance laboratory.

Figure 3.4: A subject Being Weighed With Full Kit



Warm-up and Recovery Procedures

Warm-up before running tests consisted of four to five minutes low intensity jogging ($6-8 \text{ km h}^{-1}$), followed by five minutes of stretching. Upon completing the running tests, subjects recovered actively for four to five minutes by walking on the treadmill or in the vicinity of the testing area (for the running 20 MST).

Warm-up procedures for all ice protocols consisted of five minutes of submaximal skating around the outer perimeter of the ice (alternating direction), followed by a few easy stop and go drills, for the modified skating 20 MST and SMAT. Finally four to five minutes of stretching was performed. Upon completing the skating tests, subjects recovered actively for four to five minutes by skating slowly and gliding around the ice. Before any of the field tests were begun, the compact disc of the specific test was played, consisting of a brief explanation of the test, leading to a countdown of the start itself. The following data was collected during all of the tests:

Heart Rate

HR was measured with a Polar pulse monitor (Polar Electro Oy, Kempele, Finland). HR measurement was continuous. Submaximal HR values were recorded at 15 s intervals to establish a HR-Speed curve of each test and to compare how quickly the degree of difficulty evolved/progressed in each test. HR_{max} value was recorded at the end of each test as an indication of the overall difficulty or intensity of each test.

Blood Lactate

Finger prick (capillary) blood samples using a Lactate Pro (Arkray, Inc, Kyoto, Japan) for the determination of blood lactate concentration were obtained between five and eight minutes of recovery, and at the end of a five minute

active recovery period. The finger tip was cleaned with alcohol, dried, and pricked with a lancet. Blood lactate was considered another indication of the overall intensity of the tests, indicating the gross anaerobic contribution of the test.

Oxygen Consumption ($\dot{V}O_2$)

$\dot{V}O_2$ was measured every 30 s with the open circuit method (Moxus Modular $\dot{V}O_2$ System, AEI Technologies, Pittsburgh, Etats-Unis; Figure 3.5). The $\dot{V}O_2$ system was calibrated with standard reference gases and for volume approximately five min prior to each treadmill test. Direct oxygen uptake was measured during the treadmill running test, where $\dot{V}O_2$ values were recorded every 30 s. Sub maximal values of HR and $\dot{V}O_2$ were used to establish an individual calibration curve in order to estimate the energy requirement at sub maximal level of the other field tests. $\dot{V}O_2$ max values for field tests were estimated by applying the specific regression equation for each test, and were used as dependant variable as a function of maximal speed in each field test to assess their respective validity.

Figure 3.5: Moxus Modular $\dot{V}O_2$ System



Rating of Perceived Exertion

The Borg Rating of Perceived Exertion (RPE) (Borg, 1970) (refer to Appendix J) was established on a 6 to 20 point scale from "very very easy" to "very very difficult" and was used as a subjective indicator of the overall difficulty of each test. The Borg RPE scale was used for every test upon termination of the test to determine the final perceived intensity of the tests.

Likert Resemblance Score

A Likert resemblance score (Likert, 1932) (refer to Appendix K) was obtained on a subjective seven point scale. This measurement was done after the completion of each test, recovery and lactate measurement. Each of the tests performed by the subjects was evaluated at five levels:

1. the similarity of the technical skating skills (not stick/puck handling) of the test with those of the hockey game,
2. the resemblance between the maximal intensity of the test and maximal intensity of the hockey game,
3. how the test is suited to evaluate aerobic fitness of the hockey players,
4. how the test is suited to evaluate overall fitness (including cardiovascular and muscular fatigue) of the hockey players, and
5. how the test is suited to evaluate overall hockey ability (fitness and technical skating skills) of the hockey players

3.5. Maximal Multistage Laboratory Treadmill Running Test

All maximal treadmill running tests were conducted in the human performance laboratory of the Kinesiology Department of the University of Montréal located in the CEPSUM (see Figure 3.6). Mean temperature in the laboratory was $20.7 \pm 0.6^\circ\text{C}$, mean humidity was $62.4 \pm 7.9\%$, and mean barometric pressure was 747.7 ± 21.7 mmHg. Subjects performed the maximal treadmill running test on a Quinton 65 (Series 90) treadmill (Figure 3.7). The Moxus Modular $\dot{V}\text{O}_2$ system was calibrated before the start of each test. Subjects performed the test wearing shorts, running shoes and socks. The HR monitor was attached to the subject and adjusted before the warm-up. Subject information was entered into the system while the subject warmed-up.

Figure 3.6: Human Performance Laboratory



Figure 3.7: Quinton 65 Treadmill



Before the test started, test procedures were recapped, as well as the starting position on treadmill and breathing technique (through the mouth, as a nose clip was placed on the subject's nose and worn throughout the test to prevent air from escaping). Subjects were unable to talk during the test due to the mouthpiece (Figure 3.8 and Figure 3.9), and thus, hand signals were confirmed to indicate all OK, what the subject thought would be the last 30 s of the test, and, when the subject indicated he wished to stop). Lastly, the subject was briefed on what he needed to do in the event of an emergency stop.

Figure 3.8: Mouthpiece Components



Figure 3.9: Mouthpiece Assembly



A fan was placed behind the treadmill at a low speed for subject comfort. A headset (Figure 3.10) and mouthpiece was positioned on the subject's head and adjusted for good fit. The subject was then connected to the Moxus Modular $\dot{V}O_2$ system, which analyzed the expired air for volume, as well as oxygen and carbon dioxide content. $\dot{V}O_2$ was measured every 30 s. The subject then stood on the treadmill with feet on either side of the belt, and was given the final instructions.

Treadmill Protocol

The belt was started and the subject initially started walking, then running, while the speed of the treadmill was slowly increased and when a speed of 10 km h⁻¹ was reached, the test was started and recordings begun. The test was a continuous multistage test with initial speed set at 10 km·h⁻¹ with 1 km h⁻¹ increment per stage thereafter. Stage duration was two minutes. The researcher communicated with the subject at regular intervals to monitor the subject's progress. Subjects were urged to run until completely fatigued and to give a maximal effort. The subject ran until volitional exhaustion, and the highest $\dot{V}O_2$ achieved ($\dot{V}O_2$ peak) was considered $\dot{V}O_2$ max. Similar procedures were used by Dreger & Quinney (1999).

At the end of the test, the treadmill belt was stopped; the subject was instructed to continue breathing for an additional 30 s while still connected to the machine. The head set was then removed and the treadmill restarted at a low speed (walking), and a recovery period of five minutes began. The Borg RPE scale was then administered. After four minutes of active recovery the treadmill was stopped, the subject was seated and prepared for lactate measurement. While lactate was being analyzed by the Lactate Pro, the Likert resemblance scale was administered. Maximal speed was the performance score of each test, and was recorded as the speed of the last completed stage. Finally, a follow-up appointment for next test was arranged before the subject was dismissed from the session. Preparation, participant information

and participation in each test required approximately 45 minutes (see Figure 3.11).

Figure 3.10: Headset



Figure 3.11: Subject Participant during a Maximal Treadmill Test



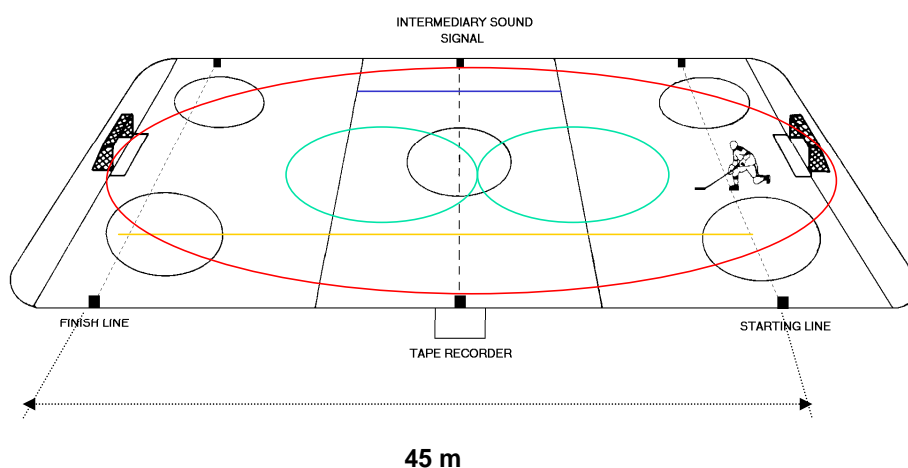
3.6. Field Tests

All ice tests took place in the ice arena (55 m x 26 m) at the CEPSUM (Figure 3.12 and 3.13).

Figure 3.12: Ice Arena in the CEPSUM



Figure 3.13: Ice Layout for Field Tests



Note 1: The red line indicates the FAST, the yellow line indicates the SMAT, and the blue line indicates the MS20MST.

3.6.1. Modified (Skating) 20 MST (MS20MST, Kuisis, 2003)

The nature of this test was continuous, multistage and linear with frequent stop and go. Subjects were required to wear full ice-hockey kit (shoulder, elbow, and shin pads, hockey jersey, gloves, socks and pants and helmet) and were required to hold the hockey stick in one hand. The HR monitor was attached to the subjects and adjusted before the warm-up. Before the test started, test procedures were recapped. The subjects were instructed to skate until completely fatigued and to give a maximal effort. The test involved skating back and forth consecutively between two cones placed on the ice, 20 m apart. The subjects started at one cone and were given a signal to start. The subjects were required to reach the cone at the other end of the 20 m course within a certain time (7.1 s for the first stage), indicated by an audio signal emitted by a pre-recorded compact disc. The subjects were then required to stop, turn and return to the cone at the other end of the 20 m course. The initial velocity was 2.82 m s^{-1} or 10.14 km h^{-1} , increasing by $\sim 0.5 \text{ km h}^{-1}$ every minute (thus decreasing the time interval between the beeps) and the subjects were required to adjust their skating velocity when necessary. The recording indicated the end of each length (shuttle), as well as each level.

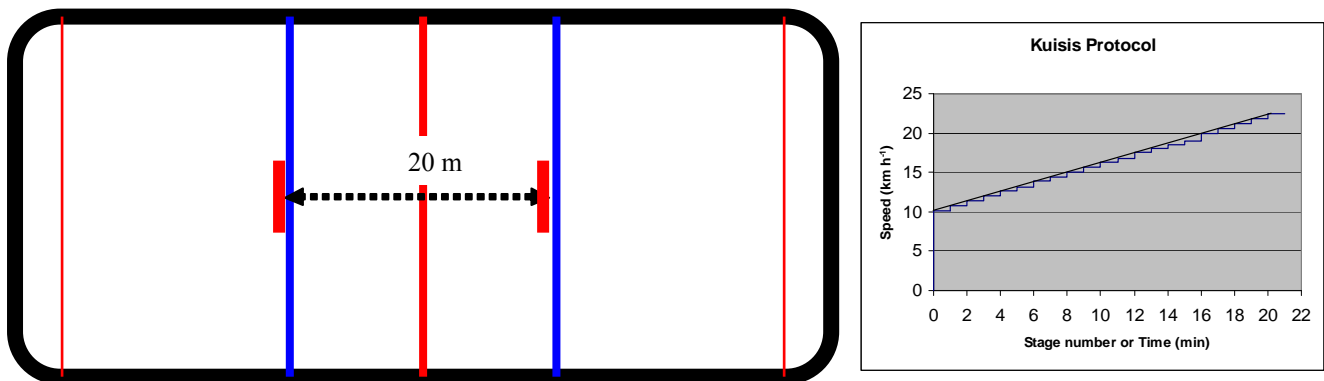
The test was terminated when the subject voluntarily stopped or could no longer follow the set pace. The last fully completed stage number was recorded, the HR monitor was stopped and a recovery period of five minutes began. The Borg RPE Scale was then administered. After approximately four minutes of active recovery, the subject was prepared for lactate measurement. Lactate was measured between five and eight minutes after the end of the test depending on the number of subjects who performed the test at the same time. While lactate was being analyzed by the Lactate Pro, the Likert Resemblance Scale was administered. Finally, a follow-up appointment for next test was arranged before the subjects were dismissed

from the session. Preparation, participant information and participation in this test required approximately 30 minutes. See Figure 3.14 and 3.15.

Figure 3.14: Subject Performing the MS20MST



Figure 3.15: Ice Layout of the Modified (Skating) 20 MST



The predicted $\dot{V}O_2$ max was calculated by using the following equation (developed in this study, reported in Chapter 4):

$$\dot{V}O_2 \text{ max} = -33.337 + 6.24 * \text{Speed}$$

Where:

- $\dot{V}O_2$ max is expressed in $\text{ml kg}^{-1} \text{min}^{-1}$,
- Speed is the final speed reached during the tests and is in km h^{-1} .

3.6.2. Skating Multistage Aerobic Test (SMAT) (Leone, Léger, & Comtois, 2002, unpublished)

The nature of this ice-skating field test is linear (over a distance of 45 m with stop-and-go), maximal, and multistage, but intermittent (1 minute:0.5 minute work:rest ratio). Subjects were required to wear full ice hockey equipment (shoulder, elbow, and shin pads, hockey jersey, gloves, socks and pants, and helmet) and required to hold the hockey stick in one hand. The HR monitor was attached to the subject and adjusted before the warm-up. Before the test started, the pre-recorded audio compact disc containing test procedures and instructions were played and then recapped by the researcher. The subjects were instructed to skate until completely fatigued, and give a maximal effort.

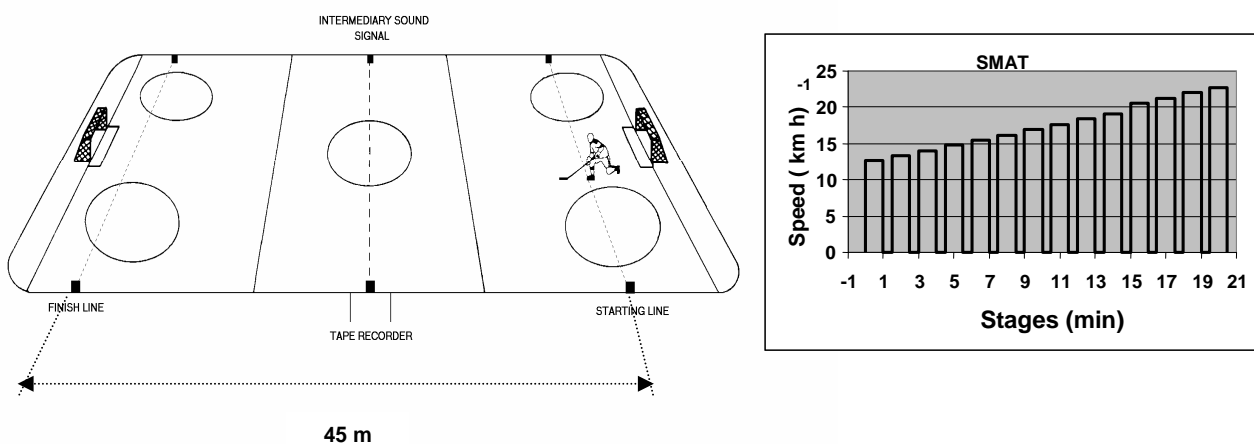
Two cones were placed on the ice, 45 m apart. The subjects were required to skate back and forth over a distance of 45 m (stop and go) while following the pace fixed by an audible signal. At the start of each stage, the subjects rested upright with the front skate parallel to the starting line of the 45 m shuttle course. At the sound of the first signal the subjects began skating, without stopping, and if necessary adjusting the skating velocity, the subjects continued skating to reach the end of the course and where he then stopped abruptly in time with the auditory signal. The subjects would immediately turn and start skating in the opposite direction (stop and go), and so on till the end of the one minute stage. At the end of the one minute stage, the subjects skated slowly to the closest end of the 45 m shuttle course for a 30 s rest before the start of next stage (Figure 3.16).

The original test required a cone at the halfway mark (22.5 m) as well as a half-length audio signal with the intent of helping subjects to pace themselves and adjust the skating velocity to meet the mid-point of the course in synchrony with the second audible signal. After experimentation with this test, researchers decided to remove the halfway marker and audio signal as it proved to be of little value in helping subjects keep to a set pace; in fact it

was confusing to the subjects. Leone *et al.* (2007) showed the half stage difference between the pre- and post-test values not to be significant.

The initial velocity was 12.6 km h^{-1} ($3.5 \text{ m}\cdot\text{s}^{-1}$) with increments of 0.72 km h^{-1} ($0.2 \text{ m}\cdot\text{s}^{-1}$) at every stage. The subjects were required to adjust their skating velocity when necessary. The test was terminated when the subject voluntarily stopped or could no longer follow the pace set by the audible signal and was not within three metres of the line after the sound signal, on two consecutive occasions. The last fully completed stage number was recorded, the HR monitor was stopped and a recovery period of five minutes began. The Borg RPE scale was administered. After approximately four minutes of active recovery, the subjects were prepared for lactate measurement. Lactate was measured between five and eight minutes after the end of the test depending on the number of subjects who performed the test at the same time. While lactate was being analyzed, the Likert Resemblance Scale was administered. Finally, a follow-up appointment for next test was arranged before the subjects were dismissed from the session. Preparation, participant information and participation in each test required approximately 30 minutes. The entire test procedure would last approximately 15 minutes (including the 30 second rest periods).

Figure 3.16: Ice Layout of the Skating Multistage Aerobic Test



The $\dot{V}O_2$ max was calculated by using the following equation (for adult males, aged 17 years and older):

$$\dot{V}O_2 \text{ max} = 16.151(\text{maximal skating velocity}) - 29.375.$$

Where:

- a) $\dot{V}O_2$ max is expressed in $\text{ml kg}^{-1} \text{min}^{-1}$,
- b) skating velocity is in m s^{-1} .

In practice, Table 2.1 may be used for rapid estimating $\dot{V}O_2$ max values.

Table 2.1: The Skating Multistage Aerobic Test (SMAT) Maximal Oxygen Consumption Prediction Table for Adult Male Professional Hockey Players.

Stage	$\dot{V}O_2$ max ($\text{ml kg}^{-1} \text{min}^{-1}$)	Time (min)	Velocity (m s^{-1})	Velocity (km h^{-1})
1	27.2	1.5	3.5	12.6
2	30.4	3.0	3.7	13.3
3	33.6	4.5	3.9	14.0
4	36.8	6.0	4.1	14.8
5	40.1	7.5	4.3	15.5
6	43.3	9.0	4.5	16.2
7	46.5	10.5	4.7	16.9
8	49.8	12.0	4.9	17.6
9	53.0	13.5	5.1	18.4
10	56.2	15.0	5.3	19.1
11	59.5	16.5	5.5	19.8
12	62.7	18.0	5.7	20.5
13	65.9	19.5	5.9	21.2
14	69.1	21.0	6.1	22.0
15	72.4	22.5	6.3	22.7

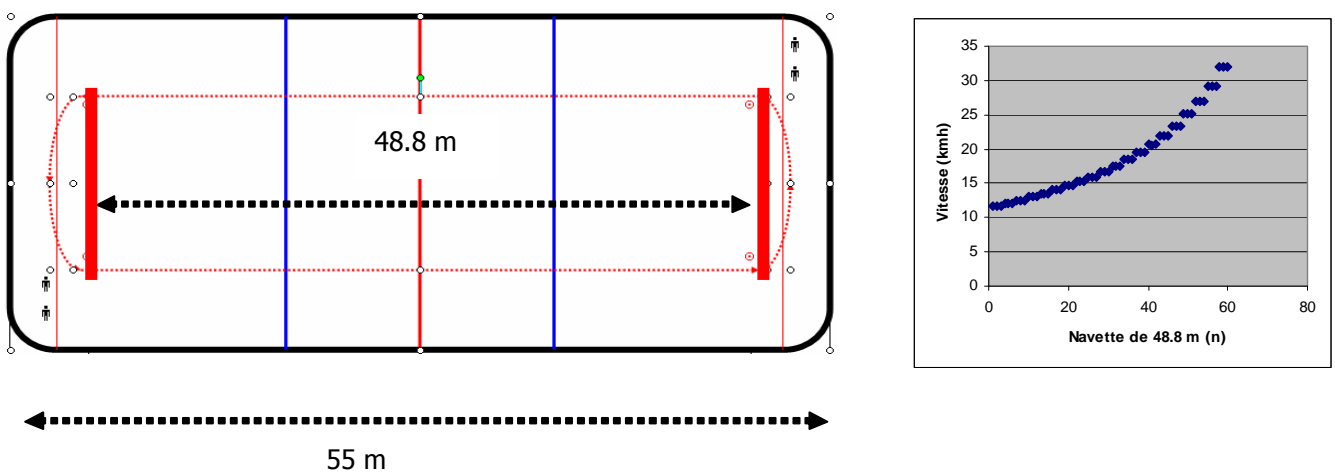
*Based on the following regression equation: $\dot{V}O_2 \text{ max} = 16.151 \times (\text{velocity}) - 29.375$; $r = 0.969$; $\text{SEE} = 2.06 \text{ ml kg}^{-1} \text{min}^{-1}$; $n = 37$

3.6.3. Faught Aerobic Skating Test (FAST) (Petrella, 2007)

The nature of this ice-skating field test is maximal, multistage, continuous and curvilinear, over a distance of 48.8 m. When performing the FAST each subject was instructed to wear skates, gloves, helmet, and carry a stick. A Polar HR monitor was attached to the subject and adjusted before the warm-up. Before the test started, test procedures and instructions were played off the compact disc and then recapped by the researcher. The subject was instructed to skate until completely fatigued, and give a maximal effort.

The procedure consisted of skating a 48.8 m distance from one end of the ice to the other, making a wide turn around the cone on the ice, in the allotted stage time indicated by a fixed audible signal. The duration of the first stage (first three lengths) is 15 s. Stage duration then decreased by 0.5 seconds after every third length (one stage). The initial velocity is 11.7 km h^{-1} ($3.25 \text{ m}\cdot\text{s}^{-1}$) with increments of 0.72 km h^{-1} ($0.2 \text{ m}\cdot\text{s}^{-1}$) at every stage (three lengths). The subjects were required to adjust their skating velocity when necessary. Figure 3.17.

Figure 3.17: Ice Layout of the Faught Aerobic Skating Test (FAST)



The test was terminated when the subject voluntarily stopped; or could no longer follow the pace set by the audible signal. The last fully completed stage number was then recorded (F-stage), the HR monitor was stopped and a recovery period of five minutes began. The Borg RPE scale was administered. After approximately four minutes of active recovery, the subject was prepared for lactate measurement. Lactate was measured between five and eight minutes after the end of the test depending on the number of subjects who performed the test at the same time. While lactate was being analyzed, the Likert Resemblance Scale was administered. Finally, a follow-up appointment for next test was arranged before the subject was dismissed from the session. Preparation, participant information and participation in each test required approximately 30 minutes.

The following equations are used to calculate $\dot{V}O_2$ max:

$$\dot{V}O_2 \text{ max} = \{0.428(\text{F-length})\} - \{0.348(\text{weight})\} + \{25.434(\text{height})\} - \{11.09(\text{gender})\} + 27.196 \text{ (Petrella } et \text{ al., 2007)}$$

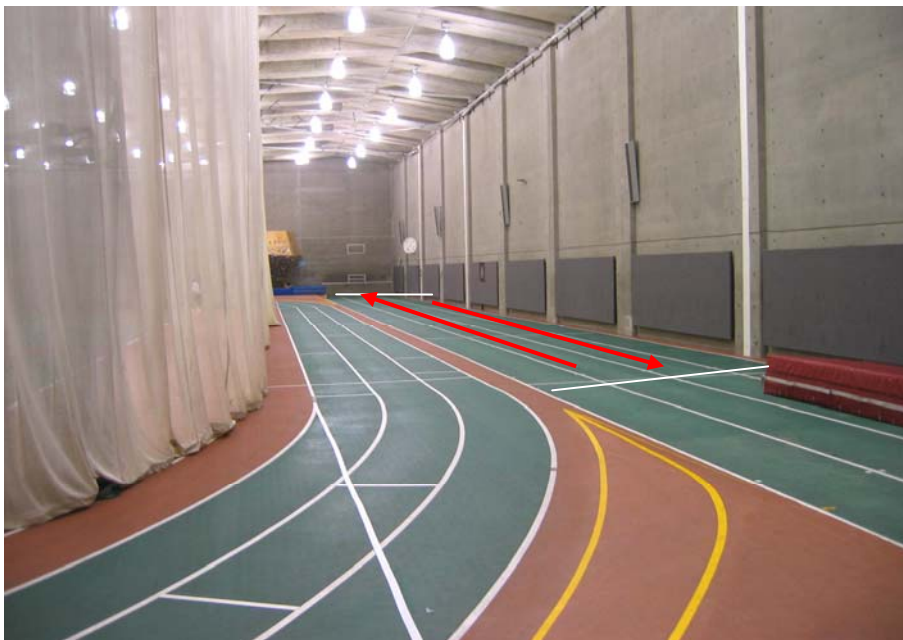
Where:

- a) $\dot{V}O_2$ max is expressed in $\text{ml kg}^{-1} \text{ min}^{-1}$;
- b) F-stage is the final stage, i.e. the number of lengths completed
- c) Weight is in kg
- d) Height is in m
- e) In the second equation: 1= male, and 2= female (1 in this study, as all subjects were males)

3.6.4. 20 Metre Multistage Shuttle Run Test (20 MST) (Léger *et al.*, 1988)

All running 20 MST tests were conducted on the indoor running track at the CEPSUM (Figure 3.18). The nature of this test was continuous and linear with frequent stop and go. The test is maximal and progressive. Subjects performed the 20 MST wearing running shorts, running shoes and socks. The HR monitor was attached to the subject and adjusted before the warm-up. Subjects were instructed to run until completely fatigued, giving a maximal effort, and to attempt to reach as high a level as possible, until they could no longer keep up with the required pace.

Figure 3.18: Indoor Running Track at the CEPSUM



The test involved running back and forth along a 20 m course consecutively between two cones placed 20 m apart. The subjects started at one cone after a signal to start. The subjects were required to reach the cone at the other end of the 20 m course within a certain time, indicated by an audio signal emitted by a pre-recorded compact disc. The subjects were then required to stop, turn and return to the cone at the other end of the 20 m course by the time the next signal was emitted (subjects were not permitted to run wide circles). Subjects were instructed to always place one foot either on or behind

the 20 m mark at the end of each shuttle. If subjects arrived at the end of a shuttle before the bleep sound, they would turn around and wait for the bleep, then resume running and adjust their speed. The initial velocity was 8.5 km h^{-1} (2.38 m s^{-1}) allowing 8.4 s in which to run each 20 m shuttle, increasing by 0.5 km h^{-1} every minute. The subjects were required to adjust this running velocity when necessary. The first running speed was referred to as "Level 1", the second speed as "Level 2", and so on. The end of each shuttle was denoted by a single bleep; the end of each level was denoted by a triple bleep and was announced by the recording on the compact disc.

The test was terminated when the subjects voluntarily stopped or it became apparent that the subjects were dropping behind the required pace, and failed to reach the end of the shuttle before the bleep. The last fully completed stage number was then recorded, the HR monitor was stopped and a recovery period of five minutes began. The Borg RPE scale was administered. After approximately 4 minutes of active recovery, the subjects were prepared for lactate measurement. While lactate was being analyzed, the Likert Resemblance Scale was administered. Finally, a follow-up appointment for next test was arranged before the subjects were dismissed from the session. Preparation, participant information and participation in each test required approximately 30 minutes.

The $\dot{V}O_2$ max was calculated by using the following equation (for subjects 18 years or older):

$$\dot{V}O_2 \text{ max} = 31.025 + 3.238(\text{running speed}) - 3.248(18) + 0.1536(18)(\text{running speed}) \text{ (Léger } et al., 1988)$$

Where:

- a) $\dot{V}O_2$ max is expressed in $\text{ml kg}^{-1} \text{ min}^{-1}$; and
- b) running speed is the speed at the last completed stage expressed in km h^{-1}

3.7. Statistical Analysis and Treatment of Data

Statistical analyses were performed using SPSS software package (Version 15.0). Descriptive statistics (mean \pm SD) were conducted for all variables.

1. Multiple regression analysis was employed to construct an equation to predict $\dot{V}O_2$ max from the MS20MST. Direct $\dot{V}O_2$ max from the treadmill test was used as the dependant variable and, maximal MS20MST speed, height and weight, as the independent variables.
2. Comparisons of maximal values of different variables ($\dot{V}O_2$ max, HR_{max} , speed max, lactate_{max}, test duration, Borg RPE max, and Likert scores) were done using a repeated one-way ANOVA to assess the similarity in physiological difficulty of each test (HR_{max} , speed max, lactate_{max}, Likert scores, Borg RPE scores). A posteriori test (Tukey) was used to determine exactly where the differences are (as ANOVA only determines whether or not differences exist).
3. Pearson correlation coefficients were also estimated for each of the following values obtained from each test
 1. Heart rate
 2. $\dot{V}O_2$ max
 3. Speed
 4. Lactate_{max} values
 5. Test duration
 6. Rating of perceived exertion
4. Regression analysis (scatter plot, Pearson correlation and SEE) was applied between direct treadmill $\dot{V}O_2$ max and maximal speed for each of the four tests to establish a predictive model, to determine the external validity (vs. literature model) and to compare validity of each field test in a pair design. Statistical validation will consist of a complete residual analysis as well as testing for co-linearity between the independent variables in the model.

CHAPTER 4

RESULTS & DISCUSSION

In line with the aims of this study, first descriptive data of the subjects sampled for this study, and their representativeness as ice-hockey players is presented and discussed. This is followed by ANOVA comparisons of maximal physiological responses in each of the tests, and the development of a regression for the Modified Skating 20 MST (MS20MST). Thereafter, correlations and regressions between treadmill $\dot{V}O_2$ max as the criterion and performance achieved (maximal speed) in each field test to identify the best test for ice-hockey players. Finally, subjective rating of the tests by the subjects is presented.

4.1. Subject Characteristics and Experimental Conditions

From the original pool of twenty-six subjects (Table 4.1) who participated in the study, only sixteen (Table 4.2) performed all the tests and were used in most calculations (paired comparisons) unless otherwise specified (e.g. for the development of the MS20MST regression equation, $n=21$). We point out immediately that a repeated ANOVA with missing data procedure was also run including all the subjects yielding the same results but a fully paired sample was used to report descriptive statistics and ANOVA results. The mean age of subjects in this study was 32.2 ± 12.2 years, older than those reported in other studies of ice-hockey players, which range from 10.8 to 27.3 years (refer to Appendix B). The mean height and weight of subjects in this study was 177.2 ± 6.8 cm and 80.1 ± 12.8 kg. This is at the lower range of the physical characteristics of adult male ice-hockey players reported in other studies where height ranges from 176.2 to 187.7 cm, and weight ranges from 77.9 to 93.9 kg (Appendix B). Subjects in this study had a wide variety of fitness

levels, some having trained relatively regularly during the summer and some had just returned to Montreal after their summer holiday, having done no training. This was an important aspect of the study, as $\dot{V}O_2$ max is a good predictor of endurance potential when a group of athletes with vastly different performance capabilities are studied, but is relatively poor predictor when athletes of similar ability are evaluated.

Table 4.1: Subject Characteristics of the Original Sample (n=26)

	Age (yrs)	Years of hockey (yrs)	Height (cm)	Weight in lab (kg)*	Weight with full kit (kg)**
Mean	32.2	22.2	177.2	80.1	91.8
SD	12.2	11.4	6.8	12.8	14.5

* measured in the laboratory on a calibrated balance scale on the day of treadmill testing

** measured in the ice-arena on a bathroom scale with subjects wearing full kit and holding hockey stick, on the day of MS20MST or SMAT

Table 4.2: Subject Characteristics of the Sample Used (n=16)

	Age (yrs)	Years of hockey (yrs)	Height (cm)	Weight in lab (kg)*	Weight with full kit (kg)**
Mean	32.1	22.0	176.7	78.7	88.6
SD	12.7	12.3	7.4	15.0	15.1

* measured in the laboratory on a calibrated balance scale on the day of treadmill testing

** measured in the ice-arena on a bathroom scale with subjects wearing full kit and holding hockey stick, on the day of MS20MST or SMAT

The mean number of years of ice-hockey experience that subjects in this study possessed was 22.0 ± 11.4 years, was higher than any of the literature reviewed in this study, that ranges between 3.8 to 10 or more years (refer to Appendix B) indicating that the subjects were experienced, proficient skaters. In a study by (Houston & Green, 1976) players had at least eight years intensive hockey training before reaching university levels.

The importance of applying on-ice skating fitness tests only to subjects who are proficient skaters was demonstrated by Léger (1981) who showed large

interindividual variations in the energy cost of skating, and a large standard error of estimate of the regression line ($6.3 \text{ ml kg}^{-1} \text{ min}^{-1}$ or 22 % on average) that were systematic and associated with the technical skills of the skaters. When a battery of ice-hockey tests is administered to young hockey players, the more complex the skill aspect, the greater the difference between competitive and recreational players (Montgomery, 1988). Forward skating speed is a less discriminative test in comparison with puck control or agility tests for overall hockey performance but is more discriminative to specifically assess aerobic fitness while skating, assuming that skating skill is sufficiently mastered. Experience in skating and technical skating skill is an important factor in obtaining accurate results. Compared to professional players, Leone, Léger, & Comtois (2002, unpublished) showed a higher energy cost of skating in younger elite age-group hockey players, which was explained by the age-group players having a lower mechanical efficiency. Leone *et al.* (2007) suggest that the greater the skill and experience in skating that the skater possesses, the greater the importance for on-ice assessment.

The ability to rapidly accelerate, maintain skating speed, rapidly decelerate, proficiency in cornering, and agility (ability to change direction quickly and accurately) were all important requirements in the tests performed in this study, in order to obtain accurate results. Young, James & Montgomery (2002) state that reactive strength of the leg extensor muscles has some importance in change-of-direction performance, but that other technical and perceptual factors that influence agility performance should also be considered.

Full hockey equipment (kit) includes shoulder, elbow, and shin pads, hockey jersey, gloves, socks, pants, helmet, and stick. Subjects in this study were weighed in the laboratory wearing only running shorts, and then again in the ice arena wearing full kit, with skates and hockey stick, before the SMAT or MS20MST. A small sub sample of four subjects were also weighed wearing a tracksuit, helmet, stick, and gloves, as required for the FAST. The mean

added mass when dressed in full kit was 9.9 ± 2.2 kg, and the added mass for the FAST ranged between 3.2 and 7.3 kg (measured in the ice-arena on a bathroom scale with subjects wearing a tracksuit, helmet, gloves and holding hockey stick). Although Léger, Seliger & Bassard (1979) state that equipment weight and design increases the cost of skating by 4.8 % and reduces the endurance time by 20.3 %, Leone *et al.* (2007) are of the opinion that hockey equipment has changed dramatically since then and that the effect of equipment, if any, today, is probably marginal, although tightness of some cloths may still impede the motion of skating. From the previously mentioned added mass in this study, one would surmise that $\dot{V}O_2$ (if directly measured) was higher in the tests where subjects were dressed in full kit and that maximal speed would be lower with equipment, thus yielding lower predicted $\dot{V}O_2$ max values. Therefore it is important to do the test in the same conditions used to develop normative data or regression to predict $\dot{V}O_2$ max (e.g. full kit for the MS20MST and SMAT, and partial kit for the FAST).

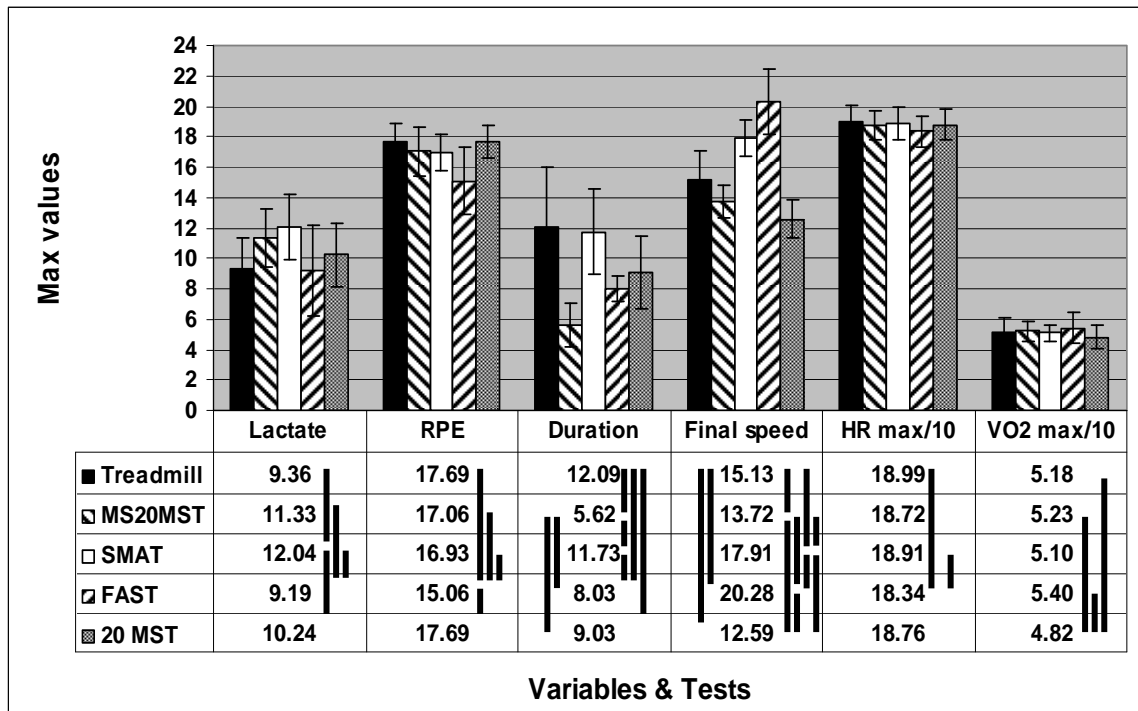
In this study, there were however, significant differences among the five tests with regard to test duration. Equipment weight may cause subjects to reach $\dot{V}O_2$ max at an earlier stage, thus reduce the duration of the test (and predicted $\dot{V}O_2$ max), but other factors (such as muscular fatigue due to stop-and-go, or inability to maintain a very high skating speed, and of course the duration of the stages, speed increase per stage and inclusion of a rest or not between stages) can also contribute to overall test duration.

Compared to a multistage oval ice skating protocol, Léger *et al.* (1979) state that the skated 20 MST with equipment more closely approximates the nature of skating seen in a game. Thus, an added advantage of both the MS20MST and the SMAT can both be performed on a regular arena ice surface with players wearing full hockey equipment, as in a game situation, thus proving to be very specific.

4.2. Comparison of Different Variables in All Five Tests

In accordance with the first aim of the study, to compare the MS20MST, SMAT, and FAST ice-skating tests to determine their common variance, repeated ANOVA (n=16) results are reported below according to each variable, namely maximal speed, test duration, maximal heart rate (final stage of the test), maximal Borg Rating of Perceived Exertion (RPE, using the 6-20 scale), maximal lactate, and maximal oxygen consumption ($\dot{V}O_2$ max). A posteriori test (Tukey-Kramer) was used to determine exactly where the differences are between each pair of tests since the ANOVA only determines whether or not differences exist among the five tests. The level of significance was set to $p < 0.05$. Pearson correlation coefficients were also estimated for each variable obtained from the five tests. Figure 4.1 gives an overall view except for the Likert scales assessments (presented later). The significance of the differences is shown in Figure 4.1 by vertical bars joining pairs of values that differ significantly, and are discussed in more detail when reporting each variable. A detailed analysis is presented separately for each variable thereafter.

Figure 4.1: Comparison of Variables Between Various Tests (n=16)



NOTE 1: Lactate is in mmol L⁻¹, RPE is on a scale of 6-20, duration is in min, and final speed is in km h⁻¹.

NOTE 2: HR and VO₂ max are divided by 10 so they could be plotted on the same graph. HR is in beats min⁻¹, VO₂ max is in ml kg⁻¹ min⁻¹

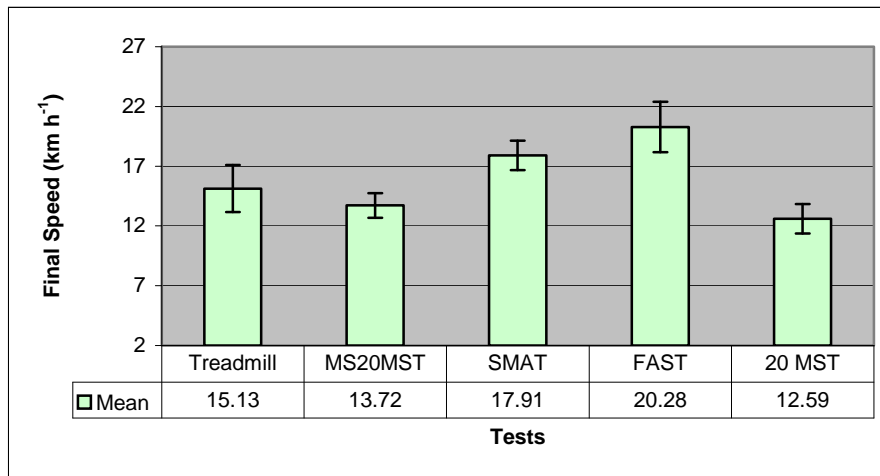
NOTE 3: Pairs of values joined by a vertical bar are significantly different (p≤0.05)

There appears to be very little difference among tests with regard to HR and $\dot{V}O_2$ max, but some of these differences are in fact significant, and are indicated by the bars in Figure 4.1. The FAST clearly has a higher mean maximal speed, but a lower mean maximal lactate (than all the other tests, except the treadmill test), as well as a lower RPE than the other tests. The MS20MST has lower test duration than any of the other tests.

4.2.1. Final Speed

Mean maximal speed was determined in all tests and is shown in Figure 4.2. Mean maximal skating speed was progressively higher from MS20MST, SMAT, and FAST (13.72, 17.91, 20.28 km h⁻¹, p≤0.01).

Figure 4.2: Mean Maximal Speed (km h⁻¹) Comparison Between Tests (n=16)



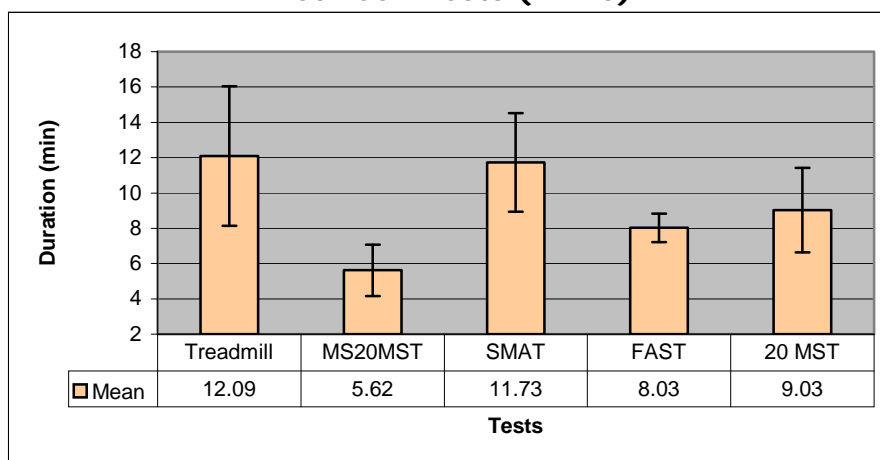
The fact that running and skating speed differ is not that important (because we know that the surface is different); however, it is interesting to compare maximal speed achieved for the three skating tests. Furthermore when comparing the skating field tests to each other, significant differences were observed between each of them (p≤0.01), which was expected. When comparing the MS20MST to the SMAT, they have a similar speed increment per minute, but the SMAT a 30 s rest period after each one minute stage, and has a longer course (45 m as apposed to 20 m in the MS20MST), requiring a lower frequency in direction changes and acceleration phases. Thus to reach the same speed in the SMAT is easier and for the same $\dot{V}O_2$ max as in the MS20MST, subjects reach higher speed in the SMAT. On the other hand, the FAST has no rest between stages, and has no stop-and-go pattern (the FAST is continuous and curvilinear), and the stages of the FAST become shorter and shorter meaning that the speed is increasing faster and faster (after

every third length of the ice, exponential increase in speed). In the FAST, subjects obtained much higher final skating speeds, as the course is continuous and curvilinear (without stop-and-go) and allows subjects to build up and maintain high skating speeds. In other words, as the test progresses the subjects have to maintain new speed for less time which enables them to reach higher speeds. So even if that was expected, it needed to be statistically confirmed which it has been. This indicates that maximal speeds achieved in each of these three skating tests are different and each test applies different stimuli and demands different skills from the subjects.

4.2.2. Duration

Mean test duration values are shown in Figure 4.3. The highest mean test duration was obtained in the treadmill test (12.09 minutes, possibly due to the fact that it was the only test with stages that were two minutes long), followed by the SMAT (11.73 minutes, probably due to the 30 second rest periods after each one minute stage), 20 MST (9.03 minutes), and FAST (8.03 minutes). The MS20MST had the lowest mean test duration at only 5.62 min.

Figure 4.3: Mean Test Duration (Min) Comparison Between Tests (n=16)



When each field test was compared to the treadmill “gold standard”, there were significant differences. The MS20MST duration was significantly less ($p \leq 0.0001$) than that of the treadmill test; in fact it was less than half of the treadmill duration. The FAST duration was also significantly lower than that of the treadmill ($p \leq 0.0001$). Furthermore, the 20 MST duration was also significantly lower than that of the treadmill test ($p \leq 0.0001$), which can probably be explained by the fact that the treadmill protocol had stages that were two minutes long, whereas those of the 20 MST were only one minute long.

When comparing the field tests to each other, they were all different ($p < 0.001$) from each other, except the FAST and the 20 MST. It seems that stages and acceleration in some protocols do not permit subjects to reach steady state at end of each stage making it difficult to eventually establish individual and valid $\% \text{HR}_{\text{max}} - \% \dot{V}\text{O}_2 \text{ max}$ calibration curve for training purposes or to estimate the average energy cost as a function of speed using end of stage $\dot{V}\text{O}_2$ values. Nevertheless as long as treadmill $\dot{V}\text{O}_2 \text{ max}$ and maximal speed are well correlated, maximal speed can be used to predict $\dot{V}\text{O}_2 \text{ max}$ which is the case for MS20MST and SMAT as is reported later.

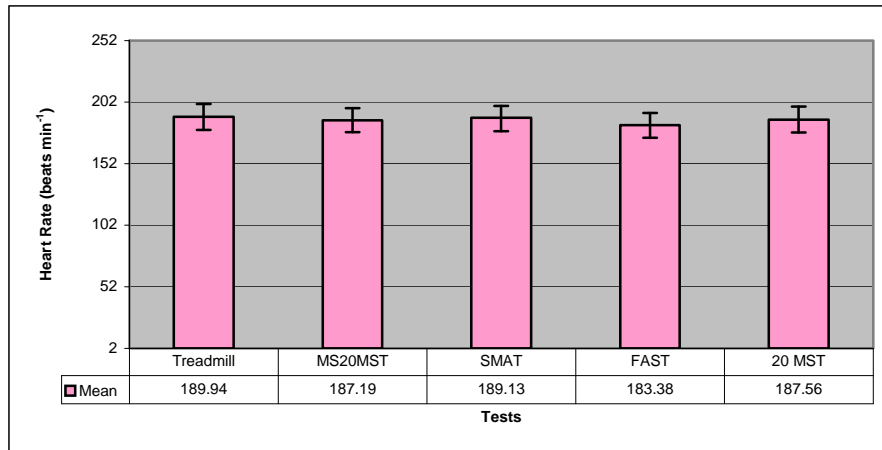
From another point of view, it is clear that MS20MST is the test with the shortest duration, making it the most time efficient. Thus, when ice-time is limited and expensive, it is still possible to administer an on-ice test, if it is time efficient, and for this purpose, the MS20MST would be the best.

4.2.3. Heart Rate

The maximal HR obtained in each test is an important factor in determining whether each test is as physiologically stressful as the others. The mean maximal HR for each test is shown in Figure 4.4. The FAST maximal HR was significantly lower than that obtained during the treadmill test (183.4 and

189.9 beats min^{-1} respectively, $p \leq 0.01$) while the other two skating tests also show a similar trend. Furthermore the FAST maximal HR was also significantly lower than that obtained in the SMAT (183.4 and 189.1 beats min^{-1} respectively, $p \leq 0.05$). No other maximal HR differences were observed.

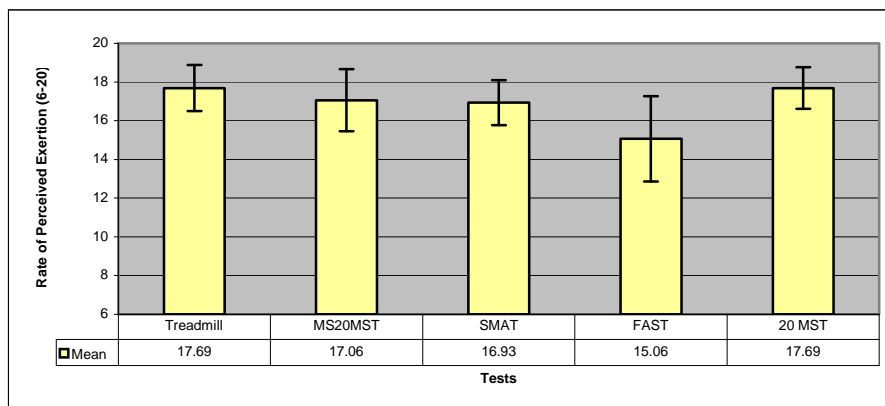
Figure 4.4: Mean Maximal Heart Rate (beats min^{-1}) Comparison Between Tests (n=16)



4.2.4. Rating of Perceived Exertion

The mean maximal Rating of Perceived Exertion (RPE) score on the 6-20 Borg scale (Appendix J) for each test is shown in Figure 4.5.

Figure 4.5: Mean Maximal Borg Rating of Perceived Exertion (RPE) Comparison Between Tests (n=16)



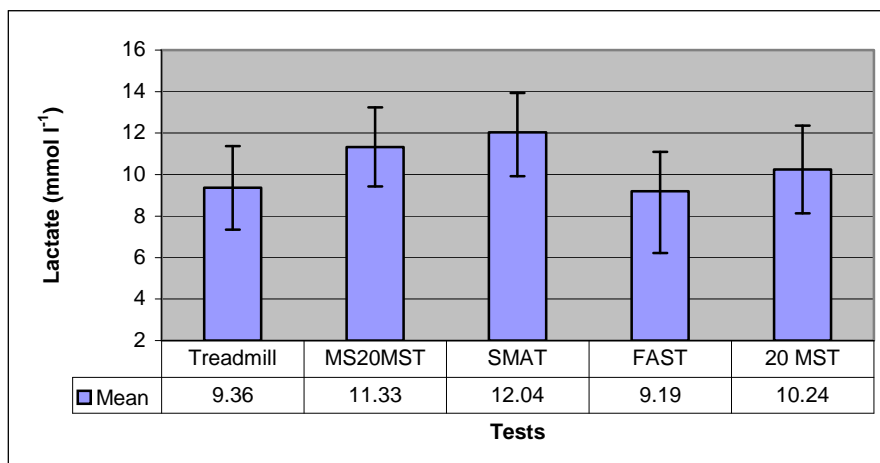
The FAST was subjectively perceived to be less difficult than any of the other four tests (15.06 vs. 16.93 and above; $p \leq 0.05$). No other differences were observed among the other tests. This perception is supported by the lower maximal lactate obtained in the FAST (see next sections). Furthermore, the perception of less physiological strain may be due to the fact that the FAST is curvilinear in nature (less muscular fatigue as it is continuous with no stop-and-go), and allows subjects to build up speed gradually, and maintain that speed, before the skating speed becomes very fast. Subjects were more often withdrawn from the test (whereas subjects in the other skating tests stopped voluntarily) because in the FAST subjects could not maintain the required speed of skating. Many of the subjects stated that they felt that the physiological strain was not as high as during the other skating tests, but that the skating speed required was too high to maintain, that being the reason for stopping in few cases or being withdrawn from the test, thus, explaining the lower RPE ratings of the FAST. The lower lactate values in the FAST indicate that subjects could possibly continue physical exertion, but were unable to due to the high speed of skating and the difficulty and dangerous cornering at those high speeds. It seems that the MS20MST and SMAT have similar perceived intensity despite longer test duration in SMAT.

In summary, from the above it is clear that the skating tests are perceived to be easier, but physiologically, they are as taxing as the running tests. This perception may be due to the fact that ice-hockey players are more comfortable in and familiar with their training environment than with running, demonstrating the need for on-ice aerobic tests. Among the skating tests, the MS20MST has the shortest distance, and has the lowest test duration, but it is perceived to be the most difficult of the skating tests (probably due to the high frequency of stop-and-go, which causes muscular fatigue) although it is physiologically not dissimilar to the other tests.

4.2.5. Lactate

Mean maximal lactate scores (mmol L^{-1}) for each test is shown in Figure 4.6. The MS20MST and the SMAT yielded the highest lactate values, and the FAST the lowest, indicating a higher anaerobic contribution in both the MS20MST and the SMAT, as compared to the FAST and the running tests. This may indicate that the MS20MST and the SMAT are more hockey-specific than the other tests. The SMAT was significantly higher than the treadmill, FAST and 20 MST lactate ($12.04, 9.36, 10.24 \text{ mmol L}^{-1}$ respectively; $p \leq 0.001$) and the MS20MST lactate was significantly higher than the FAST lactate (11.33 and 9.19 mmol L^{-1} respectively, $p \leq 0.05$). The lowest maximal lactate value was obtained in the FAST. This is almost certainly due to the fact that the FAST is continuous without stop-and-go. The speed in the FAST becomes very fast as the test progresses, but the dominance of the aerobic energy system is still maintained. Unlike in the other tests where subjects voluntarily stopped the tests, subjects in the FAST were withdrawn from the test most often because the skating speed became too fast (and subjects could not keep up with the set pace), not because subjects perceived it to be too physiologically taxing (see RPE in 4.24 above) or because of excessive muscular fatigue (shown here by the fact that the FAST has the lowest lactate score among the five tests). Additionally, the high speed of skating cornering becomes very difficult and dangerous at very high speeds.

Figure 4.6: Mean Maximal Lactate (mmol L^{-1}) Comparison Between Tests (n=16)



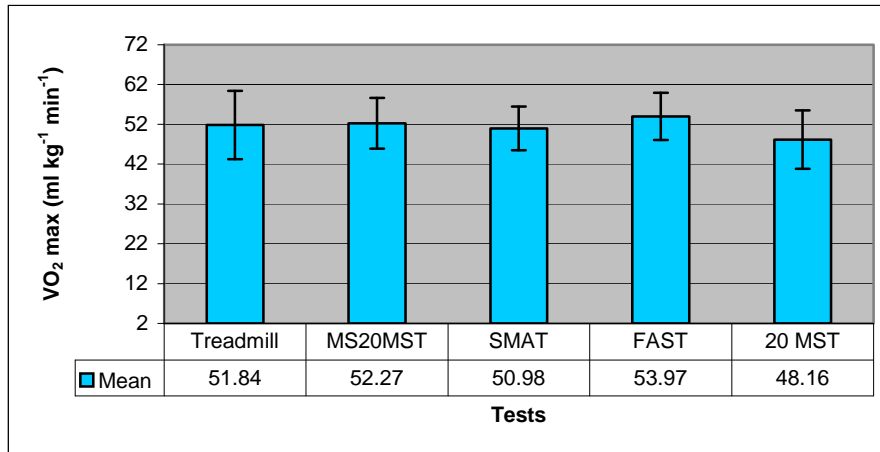
4.2.6. $\dot{V}O_2$ max

Predicted $\dot{V}O_2$ max values ($\text{ml kg}^{-1} \text{min}^{-1}$) for field tests were obtained using the original equation of each test and were compared to $\dot{V}O_2$ max directly measured on the treadmill and to each other. The mean maximal $\dot{V}O_2$ max for each test is shown in Figure 4.7. The highest mean $\dot{V}O_2$ max score was obtained in the FAST ($53.97 \text{ ml kg}^{-1} \text{min}^{-1}$), followed by the MS20MST, treadmill, SMAT, and 20 MST ($52.27, 51.84, 50.98$ and $48.16 \text{ ml kg}^{-1} \text{min}^{-1}$ respectively). The predicted 20 MST $\dot{V}O_2$ max ($48.16 \text{ ml kg}^{-1} \text{min}^{-1}$) was significantly lower than the other tests except SMAT (48.16 vs. 51.84 to $53.97 \text{ ml kg}^{-1} \text{min}^{-1}$, $p \leq 0.05$). As found in this study where $\dot{V}O_2$ max did not differ significantly among skating tests (or among skating tests and the treadmill test), Léger, Seliger & Bassard (1979) found no difference between the $\dot{V}O_2$ max of ice-hockey players in three ice tests (20 m on-ice course with and without equipment, and 140 m oval on-ice course) and an incremental treadmill test.

The $\dot{V}O_2$ max obtained from the MS20MST was not significantly different from treadmill, which is expected since the regression was developed from treadmill. The mean of the 16 subjects used for the ANOVA is lower than the mean of 21 subjects used for the development of the equation (which was developed from all possible pairs of X and Y). If the equation was developed with the same 16 subjects, both means would be identical. The direct $\dot{V}O_2$ max measure obtained from laboratory treadmill running can be systematically high or low (Babineau *et al.*, 1999.), thus, it cannot be said for sure that the 20MST prediction underestimates $\dot{V}O_2$ max. 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 values 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.

Figure 4.7: Mean maximal $\dot{V}O_2$ max ($\text{ml kg}^{-1} \text{min}^{-1}$) comparison between tests (n=16)



Development of the MS20MST Equation

In accordance with the second aim of the study, a regression to predict $\dot{V}O_2$ max for the MS20MST was developed, based on the final speed obtained in the MS20MST. $\dot{V}O_2$ max obtained by direct gas analysis whilst running on the treadmill is considered the “golden standard” by which the validity of MS20MST was established. Based on the analysis of 21 measurements of oxygen consumption ($\dot{V}O_2$ max), a multiple regression model analysis was run with laboratory $\dot{V}O_2$ max as the dependent variable and maximal speed (km h^{-1}), height (cm) and weight (kg) as the independent variables to determine the predictability and effectiveness of the $\dot{V}O_2$ max from selected variables, ultimately to assess the validity of the MS20MST as a significant predictor of aerobic capacity in ice-hockey players. The variables were selected by means of stepwise regression but only maximal speed was a significant predictor:

$$\dot{V}O_2 \text{ max} = -33.337 + 6.24(\text{speed}); [r=0.74, \text{SEE}=11.2 \%, n=21)$$

Where:

- a) $\dot{V}O_2 \text{ max}$ is expressed in $\text{ml kg}^{-1} \text{ min}^{-1}$,
- b) Speed is expressed in km h^{-1} .

The parameter estimates are shown in Table 4.3. With an r value of 0.74 and R^2 value of 0.523, we can see that 52.3 % of the variance in $\dot{V}O_2 \text{ max}$ is explained by the regression model. With a corresponding random error of 5.93 $\text{ml kg}^{-1} \text{ min}^{-1}$ (SEE) or 11.2%, the equation indicates good accuracy and the test is a good indicator of $\dot{V}O_2 \text{ max}$ but a large margin of error remains unexplained. A biomechanical efficiency index could possibly improve the equation, and should be tested in a future study.

Table 4.3: Regression Summary for Dependent Variable: $\dot{V}O_2 \text{ max}$ (n=21)

Variable	Beta	Standard Error of Beta	B	Standard Error of B	t(19)	p-level
Intercept			-33.3372	18.08071	-1.84380	0.080866
Final Speed	0.739828	0.154350	6.2402	1.30190	4.79318	0.000126
		Fit statistics				
		R		0.74		
		R-squared		0.547		
		Adjusted R-squared		0.523		
		Standard Error of Estimate (SEE)		5.93		
		F-Value		22.975		
		P value for F		0.00013		

4.3. Assessing and Comparing the Validity of Each Test

In accordance with the second aim of the study, 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 was assessed. First the correlations among the different variables in the different tests were established, and then the direct treadmill $\dot{V}O_2$ max ("gold standard") was used as the criterion variable (by comparing observed $\dot{V}O_2$ max to $\dot{V}O_2$ max predicted from original equations) to determine which test is better suited for the evaluation of the maximal aerobic power of ice-hockey players.

4.3.1 Correlations

Final Speed

There were a number of similarities between the final speed of the five tests (Table 4.4). MS20MST and SMAT correlate quite well with treadmill ($r=0.74$ and $r=0.78$, respectively) and very well with 20MST ($r=0.83$ and $r=0.87$, respectively) but much lower with FAST ($r=0.58$ and $r=0.61$, respectively). The 20 MST obtained the highest correlation with mean maximal treadmill running speed ($r=0.94$), and can be partly explained by the fact that the exercise modality is the same (running), as apposed to skating. This also demonstrates the validity of final speed of the 20 MST.

Table 4.4: Correlations of Maximum (Final) Speed Values

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.74*	0.78*	0.53*	0.94*
MS20MST		1	0.84*	0.58*	0.83*
SMAT			1	0.61*	0.87*
FAST				1	0.67*
20MST					1

* Correlation is significant at the 0.05 level

Duration

There were also a number of similarities between the tests (Table 4.5). The highest significant correlation with regard to test duration was between the treadmill and the 20 MST ($r=0.93$), even though the treadmill stage duration was two minutes as apposed to one minute in the 20 MST. Among the skating tests the MS20MST and the SMAT demonstrated the same correlation with treadmill test duration ($r=0.68$). Among the skating tests, the SMAT had the highest correlation with the 20 MST ($r=0.84$), followed by the MS20MST ($r=0.82$), and the FAST demonstrated the lowest but still significant correlation with 20 MST test duration ($r=0.59$). Furthermore, there was a good correlation between the MS20MST and SMAT ($r=0.89$).

Table 4.5: Correlations of Test Duration

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.68*	0.68*	0.50	0.93*
MS20MST		1	0.89*	0.55*	0.82*
SMAT			1	0.51*	0.84*
FAST				1	0.59*
20MST					1

* Correlation is significant at the 0.05 level

From the preceding results it is clear that the MS20MST has the shortest duration of all five tests, making it the most time efficient. Thus, when ice-time is limited and expensive, it is still possible to administer an on-ice test, if it is time efficient, and for this purpose, the MS20MST would be the best.

Rating of Perceived Exertion

Correlation coefficients are shown in Table 4.6. The only significant correlation between maximal RPE values obtained in the treadmill was with that obtained in the 20 MST ($r=0.59$).

Table 4.6: Correlations of RPE Values

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.25	0.43	0.28	0.59*
MS20MST		1	0.23	0.51	0.31
SMAT			1	-0.18	0.37
Fast				1	0.43
20MST					1

* Correlation is significant at the 0.05 level

The FAST seems to be perceived as being easier due to less muscular fatigue (continuous with no stop-and-go). This is supported by the lower maximal lactate obtained in the FAST. The physiological stress between tests is similar, as the mean $\dot{V}O_2$ max and the mean maximal HR, obtained during the FAST, are well correlated with the other tests, although FAST lactate was significantly correlated only with the MS20MST, treadmill and 20 MST. This perception of less physiological strain may be due to the fact that the FAST is curvilinear in nature, and allows subjects to build up speed gradually, and maintain that speed, before the skating speed becomes very fast. Subjects were more often withdrawn from the test (whereas subjects in the other skating tests stopped voluntarily) because they could not maintain the required speed of skating. Many of the subjects stated that they felt that the physiological strain was not as high as during the other skating tests, but that the skating speed required was too high to maintain, that being the reason for stopping or being with drawn from the test, thus, explaining the lower RPE ratings of the FAST. The lower lactate values in the FAST indicate that subjects could possibly continue physical exertion, but were unable to due to the high speed of skating and the difficulty and dangerous cornering at those high speeds.

In summary, from the above it is clear that the skating tests are perceived to be easier, but physiologically, they are as taxing as the running test. This perception may be due to the fact that ice-hockey players are more comfortable in and familiar with their training environment than with running, demonstrating the need for on-ice aerobic tests. Although the MS20MST has

the shortest distance, and has the lowest test duration, it is physiologically not dissimilar to the other tests. The MS20MST may thus be the preferable test because it is economic with regards to time and because of its sport-specific nature.

Lactate

Correlation coefficients are presented in Table 4.7. When each test was compared to the treadmill “gold standard”, there were correlations between the maximal lactate values for the treadmill and 20MST ($r=0.58$) and between treadmill and the FAST ($r=0.60$). Surprisingly, the MS20MST correlated with the FAST ($r=0.53$).

Table 4.7: Correlations of Lactate Values

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.28	-0.00	0.60*	0.58*
MS20MST		1	0.29	0.53*	0.28
SMAT			1	0.34	0.27
FAST				1	0.61*
20MST					1

*Correlation is significant at the 0.05 level

VO₂ max

Correlation coefficients are presented in Table 4.8. All the skating tests were significantly correlated with the treadmill and 20 MST, although the FAST correlations were much lower (0.41 and 0.69 respectively). The skating tests also significantly correlated with each other (the FAST again lower than the other tests).

Table 4.8: Correlations of $\dot{V}O_2$ max Values

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.74*	0.73*	0.41*	0.84*
MS20MST		1	0.86*	0.69*	0.83*
SMAT			1	0.66*	0.87*
FAST				1	0.69*
20MST					1

*Correlation is significant at the 0.05 level

4.3.2 Predictive Validity of Field Tests

$\dot{V}O_2$ max obtained by direct gas analysis whilst running on the treadmill is considered the "golden standard" by which validity of other tests measuring the same variable ($\dot{V}O_2$ max) can be established, because of its universal use and because similar $\dot{V}O_2$ are obtained on the treadmill and on the ice (Léger, Seliger & Bassard, 1980). Results of criterion treadmill test could be expressed in $\dot{V}O_2$ max ($\text{ml kg}^{-1} \text{min}^{-1}$) or in maximal speed units (km h^{-1}). In general, correlations between maximal speed attained in field tests with criterion treadmill tests are slightly better when the results of the treadmill tests are in speed units. For example, for the 20MST, correlation was 0.84 with $\dot{V}O_2$ max units and 0.94 with speed units. That being said, the extent to which each field test correlates with the criterion test is not the same but the same trend is observed whether $\dot{V}O_2$ max or maximal speed units are used. Thus using $\dot{V}O_2$ max units, the FAST test is much less correlated with the treadmill test ($r=0.41$ with a SEE or $7.53 \text{ ml O}_2 \text{ kg}^{-1} \text{min}^{-1}$ or 14.7% of treadmill $\dot{V}O_2$ max mean) than the two other skating tests, MS20MST and SMAT, which have similar accuracy ($r=0.74$ and 0.73 with $\text{SEE}=5.93$ and $5.65 \text{ ml kg}^{-1} \text{min}^{-1}$ or 11.2 and 11.0 %, respectively). With an r value of 0.84 and SEE of $4.69 \text{ ml kg}^{-1} \text{min}^{-1}$ or 9.02%, the 20MST, is the best field test, assuming treadmill $\dot{V}O_2$ max is a proper criterion. Finally, the maximal speed attained on the treadmill compared to $\dot{V}O_2$ max obtained during the same test yielded a correlation of 0.84 with a SEE of $4.72 \text{ ml kg}^{-1} \text{min}^{-1}$ or 8.95%. These

r and SEE values were obtained using the maximum number of subjects for each comparison (n=17 to 23) but almost the same r and SEE values were obtained using only data from the same 16 subjects that did all the tests. Refer to Table 4.9.

Table 4.9: Correlations and Standard Errors of Estimate Predicting Treadmill $\dot{V}O_2$ max and Maximal Speed from Field Test Maximal Speed

Treadmill (Y)	N	Predicted variable	r	SEE ml kg ⁻¹ min ⁻¹ or km h ⁻¹	SEE %
MS20MST (X)	21	$\dot{V}O_2$ max	0.74	5.93	11.2
		Max speed	0.75	1.23	8.07
SMAT (X)	20	$\dot{V}O_2$ max	0.73	5.65	11.0
		Max speed	0.79	1.16	7.73
FAST (X)	20	$\dot{V}O_2$ max	0.41	7.53	14.7
		Max speed	0.53	1.59	10.6
20MST (X)	17	$\dot{V}O_2$ max	0.84	4.69	9.02
		Max speed	0.94	0.70	4.59

Regression analyses (scatter plot, correlation and SEE; n=16-23) between direct $\dot{V}O_2$ max (treadmill) and the maximal speed in each test to establish predictive models was done to check external validity and to compare the validity of each test in a pair design. Exponential regressions were run, but the relationship between each test and the criterion $\dot{V}O_2$ max was no better than with simple (linear) regression. Generally, the exponential regression produced a better fit than the linear regressions. Linear regressions between treadmill $\dot{V}O_2$ max and final speed in each test are shown in Figure 4.8-4.12. These figures illustrate the random variation on each side of the regression for each test. These results demonstrate that to achieve the same aerobic fitness level on the treadmill, one has to skate at high speed in the FAST, medium speed in the SMAT, and low speed in the MS20MST. It is true to say that some tests are not only not equivalent in terms of positioning or discriminating between subjects, but it can also be said that some (MS20MST

and SMAT) are better than others (FAST) because the treadmill $\dot{V}O_2$ max is a valid criterion.

Figure 4.8: Treadmill $\dot{V}O_2$ max as a Function of Speed in the Treadmill Test

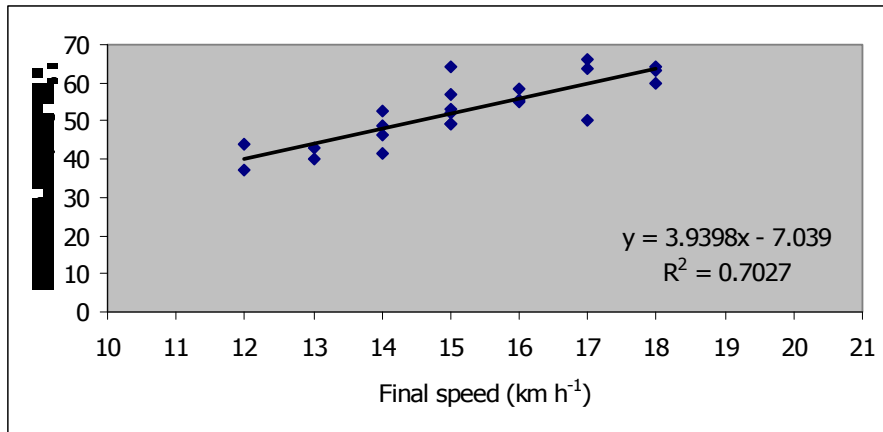


Figure 4.9: Treadmill $\dot{V}O_2$ max as a Function of Speed in the MS20MST

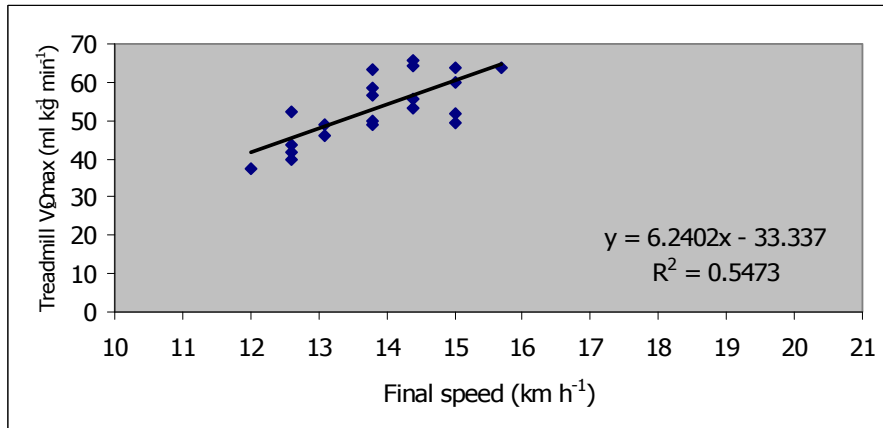


Figure 4.10: Treadmill VO₂ max as a Function of Speed in the SMAT

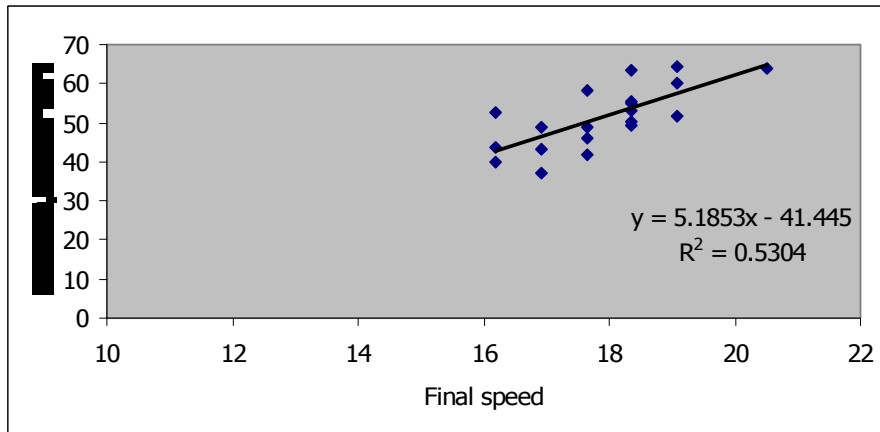


Figure 4.11 Treadmill VO₂ max as a Function of Speed in the FAST

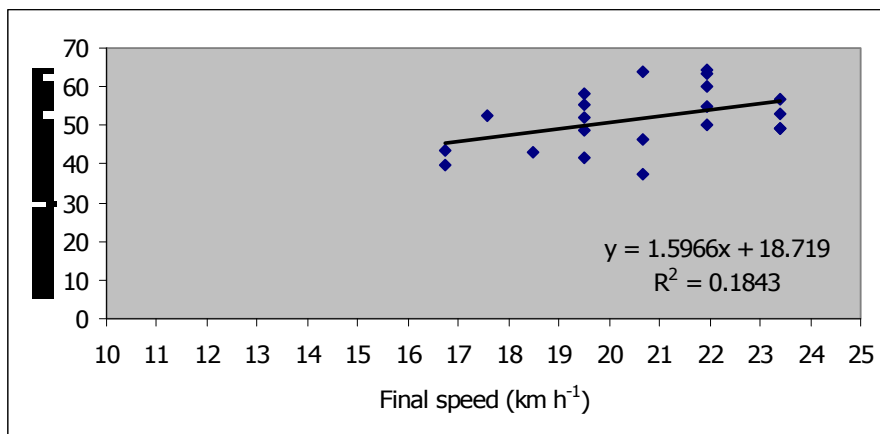
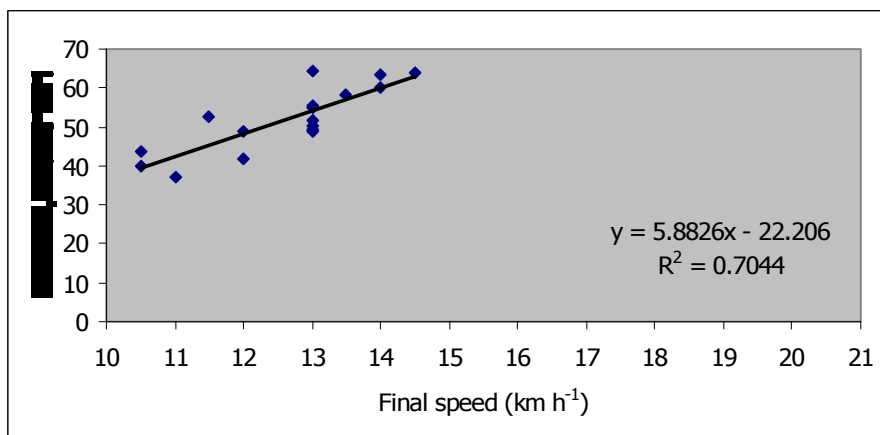


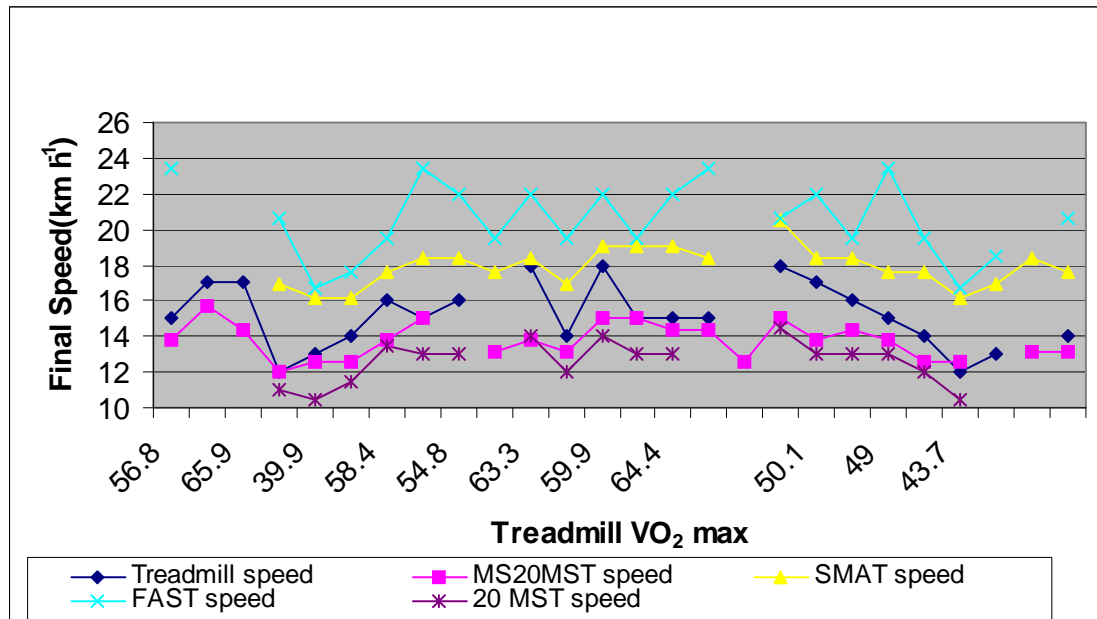
Figure 4.12 Treadmill VO₂ max as a Function of Speed in the 20 MST



From the above figures, the treadmill and the 20 MST have similar R^2 ($R^2=0.7027$ and $R^2= 0.7044$ respectively) indicating that 70.44 % and 70.27 % of the variance can be explained, again demonstrating the validity of the prediction equation of the 20 MST. Among the field ice-skating tests MS20MST and the SMAT ($R^2=0.5473$ and $R^2=0.5304$ respectively) showed similar validity where 54.73 % and 53.04 % of the variance can be explained by the respective regression equations. Regarding the validity of the FAST, the FAST showed a lower $R^2=0.1843$, where only 18.43 % of the variance can be explained by the regression equation. The FAST may thus be less valid because, subjects have less control on how the subjects negotiate the change of direction at each end of the course (this is also not well standardized and specified in the protocol) and also because, the terminal point is less reliable in a test where the speed increases exponentially with time (as apposed to a linear increase) and a small difference in motivation could make a large difference in the final results of FAST which in turn negatively affects the correlation with treadmill $\dot{V}O_2$ max. Furthermore, the 20 MST is better correlated to the two other skating tests than to the FAST. These are interesting because they may indicate that anaerobic fitness also has an effect on the results of an aerobic test i.e. correlation is not perfect between $\dot{V}O_2$ max test results because other factors are also involved.

Finally, the treadmill $\dot{V}O_2$ max were regressed against the mean maximal speed in each test and are plotted on a single graph to compare the different tests. Refer to Figure 4.13.

Figure 4.13: Comparison of Treadmill Speed as a Function of $\dot{V}O_2$ max in All Tests

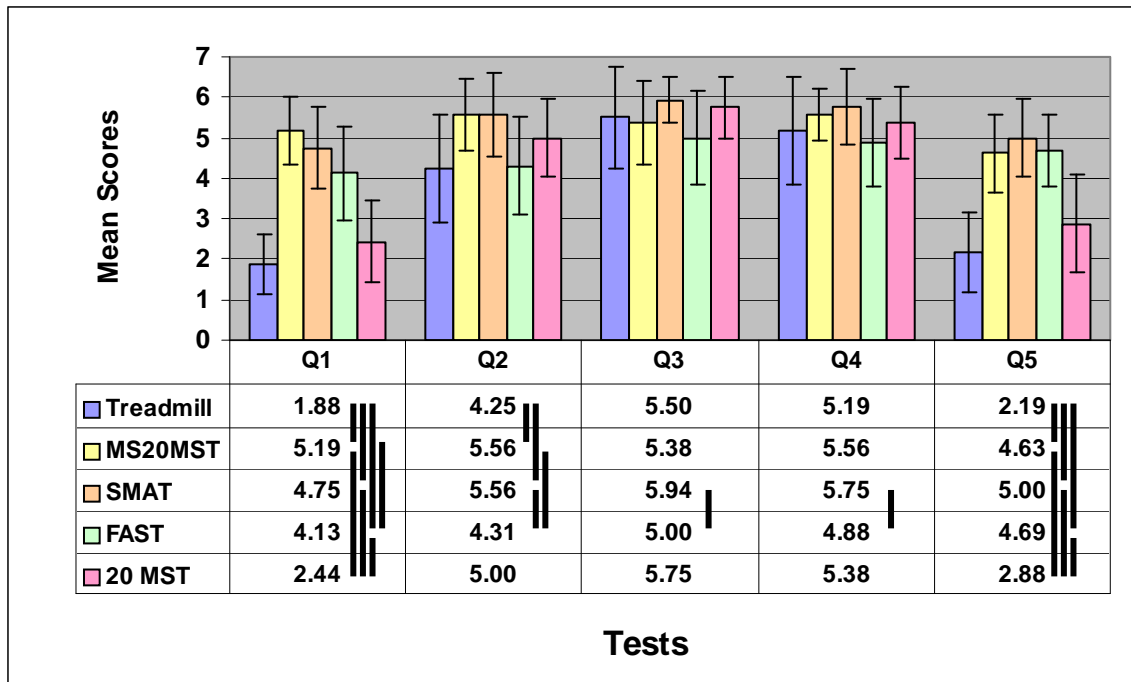


In summary, the administration of both the MS20MST and SMAT is inexpensive and does not require sophisticated equipment, only an audio recording of the test, compact disc player, measuring tape and a few cones, and many players can be tested simultaneously, in their practice/competition dress, without requiring players to change into other clothes or remove part of the kit (as in the FAST). Because of these abovementioned advantages and because of the higher correlations of the MS20MST and the SMAT, they are the preferable tests to use when assessing the aerobic fitness of adult male ice-hockey players. In concordance with the fourth aim of the study [to determine if these on ice skating tests are in effect better than the over-ground 20 m shuttle running test (Léger *et al.*, 1988)] it can be said that the 20 MST has once again proven to be a valid test of aerobic fitness can be used with confidence to predict the aerobic capacity of ice-hockey players, and is preferable over other running tests, and is the test of choice if ice testing cannot be conducted.

4.4. Qualitative analysis: Determining which test is rated by ice-hockey players as being best suited and the most functional using the Likert scale

The third aim of the study was to determine which test is rated by the players as being the best suited and most functional test. For this purpose a seven-point Likert scale was used to evaluate five different aspects of each test. Players answered each question by giving a rating of between one and seven, one being the lowest possible score and seven being the highest possible score (refer to Appendix K). For all questions, the higher the score, the better the result, indicating greater similarity between the test and an ice-hockey game, and greater suitability of the tests to assess aerobic fitness in adult ice-hockey players. An overview comparison of the five questions, in the five tests is shown in Figure 4.14. There appears to be a trend where the running tests generally score lower than the skating tests, indicating a subjective need for skating tests to assess aerobic fitness in adult ice-hockey players.

Figure 4.14: Comparison of Scores Obtained on the Likert Resemblance Scale (1-7) During Different Tests



- Q1 Similarity of basic skating skills (not puck handling) of the test compared to those of a hockey game
- Q2 Resemblance between maximal intensity of the test & maximal intensity of a hockey game
- Q3 How is the test suited to evaluate aerobic fitness of hockey players?
- Q4 How is the test suited to evaluate overall fitness (including muscular & cardiovascular fitness) of hockey players?
- Q5 How is the test suited to evaluate overall hockey ability (fitness & skating skills) of hockey players?

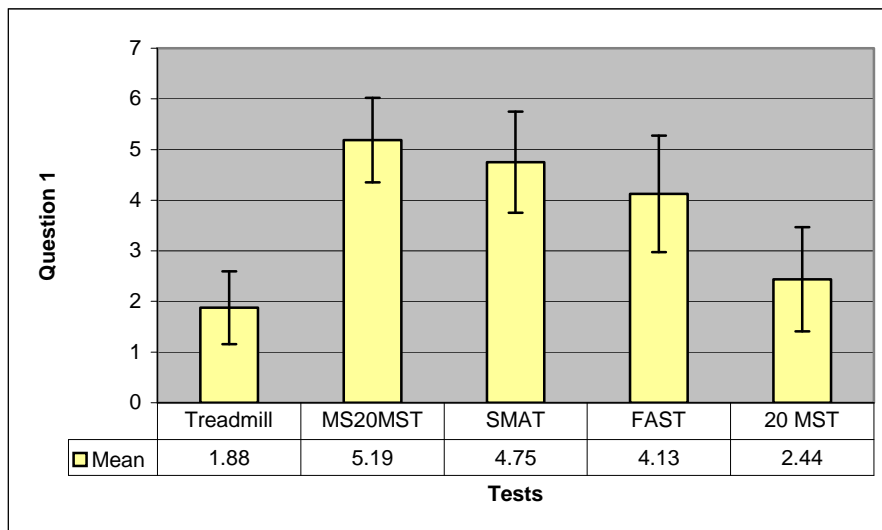
Note: Pairs of values joined by a vertical bar are different ($p < 0.05$)

Question 1: Similarity of basic skating skills (not puck handling) of the test compared to those of a hockey game

The mean score obtained for question one in all five tests as well as the significant differences are represented in Figure 4.15. Both running tests yielded lower ratings than the three skating tests. Logically the laboratory treadmill test was rated as being the least specific of all the tests because it was conducted in a laboratory environment and the modality was running and not skating. Any type of skating would be more specific to the hockey player

than any running protocol. Within the skating tests, FAST scores were lower than the MS20MST and SMAT scores. The MS20MST and SMAT obtained the highest subjective rating of test similarity with regard to basic skating skill as compared to the game of ice-hockey, and are the best tests to mimic skating skill. The 20 MST is however more specific for ice-hockey than treadmill running as it is a field test and the nature of the test is stop-and-go, which is similar to hockey, even though it is not skating. The higher rating of the MS20MST and SMAT tests is due to the fact that they are skating tests, and have stop-and-go nature (which is similar to the game of ice-hockey). The FAST was rated more specific than the two running tests (because it is skating), but not as specific as the two skating tests (because it is continuous and curvilinear), which may in fact be more appropriate for speed skating and figure skating than ice-hockey.

Figure 4.15: Mean Rating For Similarity of Basic Skating Skills of the Different Tests as Compared to the Game of Ice-Hockey (n=16)



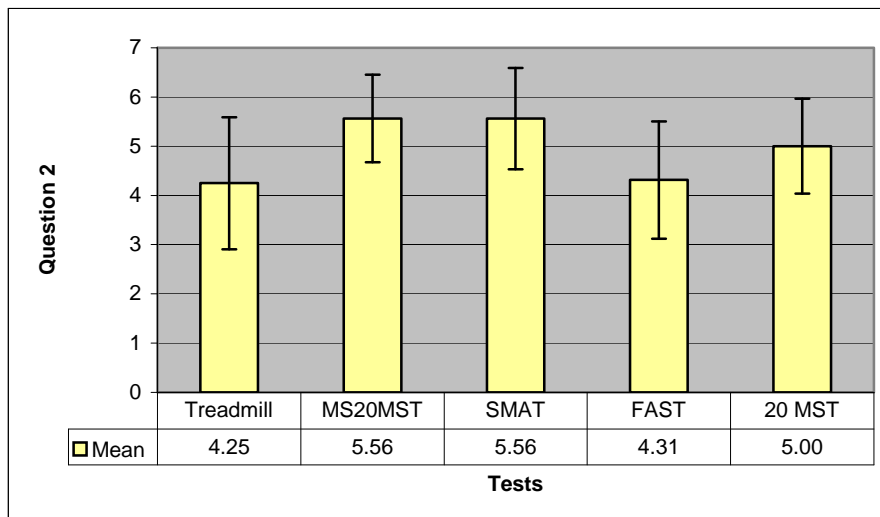
When subjects rated the similarity of the skating skills required by the test as compared to those required during a hockey game (excluding puck handling), there were statistically significant differences between the scores obtained

between the treadmill and the MS20MST ($p \leq 0.0001$), treadmill and the SMAT ($p \leq 0.0001$), and the treadmill and the FAST ($p \leq 0.0001$). Similarly, the 20 MST had highly significant differences with all three skating tests (MS20MST, SMAT, and FAST) ($p \leq 0.0001$). The MS20MST also differed significantly with the FAST ($p \leq 0.05$).

Question 2: Resemblance between maximal intensity of the test & maximal intensity of a hockey game

Mean responses to question two are presented in Figure 4.16. SMAT and MS20MST again obtained the highest subjective rating with regard to the similarity of the intensity of test to the intensity of the ice-hockey game followed by the 20 MST, and then FAST and the treadmill.

Figure 4.16 Mean Rating of Similarity of Intensity of the Different Tests as Compared to the Game of Ice-Hockey (n=16)



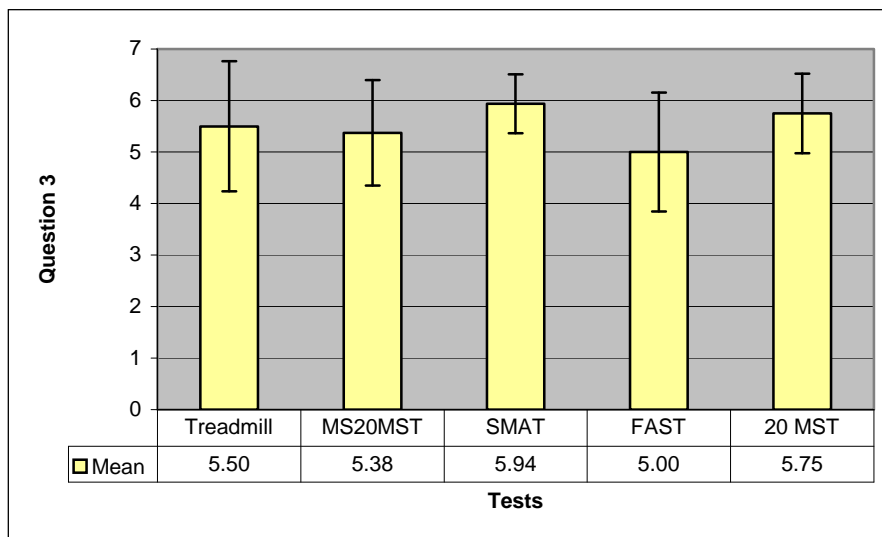
There were significant differences between the treadmill and the MS20MST ($p \leq 0.01$) and between the treadmill and the SMAT ($p \leq 0.01$). There were also significant differences between the FAST and MS20MST ($p \leq 0.01$), as well as

between the FAST and SMAT ($p \leq 0.01$). This is to be expected as the MS20MST and SMAT are similar in nature.

Question 3: How is the test suited to evaluate aerobic fitness of hockey players?

The mean responses to question three in all tests is shown in Figure 4.17. Three out of five tests (MS20MST, FAST, and treadmill) had very similar scores with regard to subjective suitability of the tests to evaluate aerobic fitness in ice-hockey players. The FAST obtained the lowest suitability rating, indicating that subjects felt that the FAST was not as suited to assessing aerobic fitness as the other tests. The only statistically significant difference between the rating of suitability for assessing aerobic fitness occurred between the SMAT and FAST ($p \leq 0.05$).

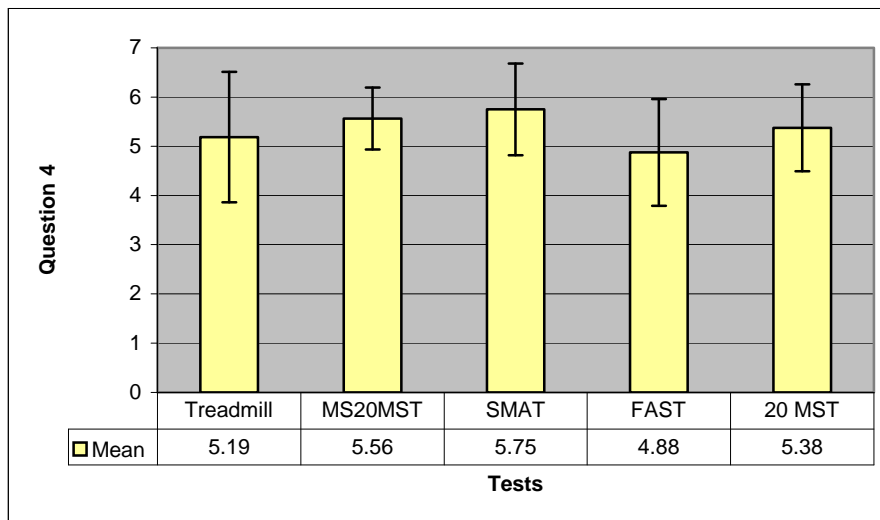
Figure 4.17: Mean Rating of Suitability of the Different Tests to Evaluate Aerobic Fitness of Hockey Players (n=16)



Question 4: How is the test suited to evaluate overall fitness (including muscular & cardiovascular fitness) of hockey players?

The mean responses to question four in all tests are shown in Figure 4.18. The SMAT and MS20MST obtained similar scores with regard to suitability to evaluate overall fitness in ice-hockey players, followed by a lower rating of the 20 MST, treadmill and FAST. The only statistically significant difference occurred between the SMAT and FAST ($p \leq 0.05$).

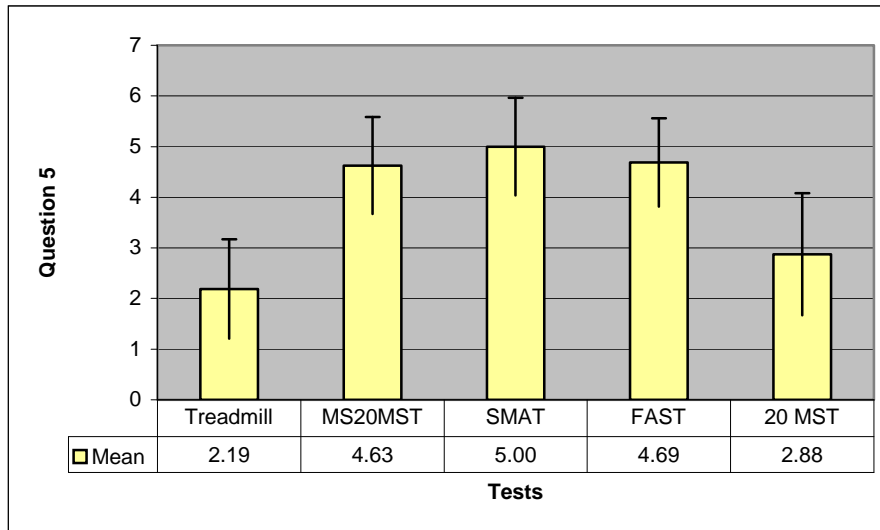
Figure 4.18: Mean Ratings With Regard to Suitability of Each Test to Evaluate Overall Fitness (Including Muscular & Cardiovascular Fitness) of Hockey Players (n=16)



Question 5: How is the test suited to evaluate overall hockey ability (fitness & skating skills) of hockey players?

Mean responses to question five in all tests is represented in Figure 4.19. The treadmill and the 20 MST yield lower ($p \leq 0.0001$) scores than the three skating tests while the skating tests were not significantly different from each other.

Figure 4.19: Mean Rating of Suitability of Tests to Evaluate Overall Fitness in Ice-Hockey Players (n=16)



In summary, the qualitative analysis reveals that the skating tests (MS20MST and SMAT) generally scored higher with regards to similarity to the game of ice-hockey, as well as suitability to assess aerobic and overall fitness in ice-hockey players. This clearly demonstrates the need for on-ice skating tests for the assessment of aerobic fitness in ice-hockey. The FAST however, seems to be the least preferable of the skating tests, and sometimes even less preferable than the 20 MST.

Correlations among Q1-5

Q1

Correlation coefficients are presented in Table 4.10. There was a significant correlation between the mean score for question one between the treadmill and the 20 MST ($r=0.53$), which is to be expected since they are both running tests, and between the treadmill and the FAST ($r=0.59$) (they also had similar RPE values). There was also a significant correlation between FAST and the 20 MST ($r=0.68$), which is unexpected.

Table 4.10: Correlations of Question 1 Values

Correlation Matrix					
	Treadmill	MS20MST	SMAT	Fast	20MST
Treadmill	1	-0.07	0.05	0.59*	0.53*
MS20MST		1	0.46	0.11	0.13
SMAT			1	0.26	0.31
FAST				1	0.68*
20MST					1

* Correlation is significant at the 0.05 level

Q2

Correlation coefficients are presented in Table 4.11. The only significant correlation with regard to similarity of intensity among the test was between the treadmill and 20 MST ($r=0.57$), this is to be expected since the modality of the tests are the same (both running), and probably equally unfamiliar to the subjects as apposed to skating.

Table 4.11: Correlations of Question 2 Values

Correlation Matrix					
	Treadmill	MS20MST	SMAT	Fast	20MST
Treadmill	1	0.26	0.47	-0.01	0.57*
MS20MST		1	0.21	-0.18	0.46
SMAT			1	-0.04	0.47
FAST				1	-0.23
20MST					1

* Correlation is significant at the 0.05 level

Q3

There were no significant correlations among the five tests with regard to suitability for assessing aerobic fitness.

Q4

Correlation coefficients are presented in Table 4.12. The only correlations were between the treadmill and the 20 MST ($r=0.50$), and between the MS20MST and the 20 MST ($r=0.55$).

Table 4.12: Correlations of Question 4 Values

Correlation Matrix					
	Treadmill	MS20MST	SMAT	Fast	20MST
Treadmill	1	0.26	0.36	0.34	0.50*
MS20MST		1	0.37	0.21	0.55*
SMAT			1	0.30	0.45
FAST				1	0.19
20MST					1

* Correlation is significant at the 0.05 level

Q5

Correlation coefficients are presented in Table 4.13. The only significant correlation was a significant correlation between the treadmill and 20MST ($r=0.75$) (again probably because they are both running tests).

Table 4.13: Correlations of Question 5 Values

Correlation Matrix					
	Treadmill	MS20MST	SMAT	Fast	20MST
Treadmill	1	0.15	0.49	0.38	0.75*
MS20MST		1	0.36	0.25	0.01
SMAT			1	0.47	0.47
FAST				1	0.09
20MST					1

* Correlation is significant at the 0.05 level

In summary, the qualitative analysis reveals that the skating tests consistently scored higher with regards to similarity to the game of ice-hockey, as well as suitability to assess aerobic and overall fitness in ice-hockey players. This clearly demonstrates the need for on-ice skating tests for the assessment of aerobic fitness in ice-hockey.

4.5. General Discussion

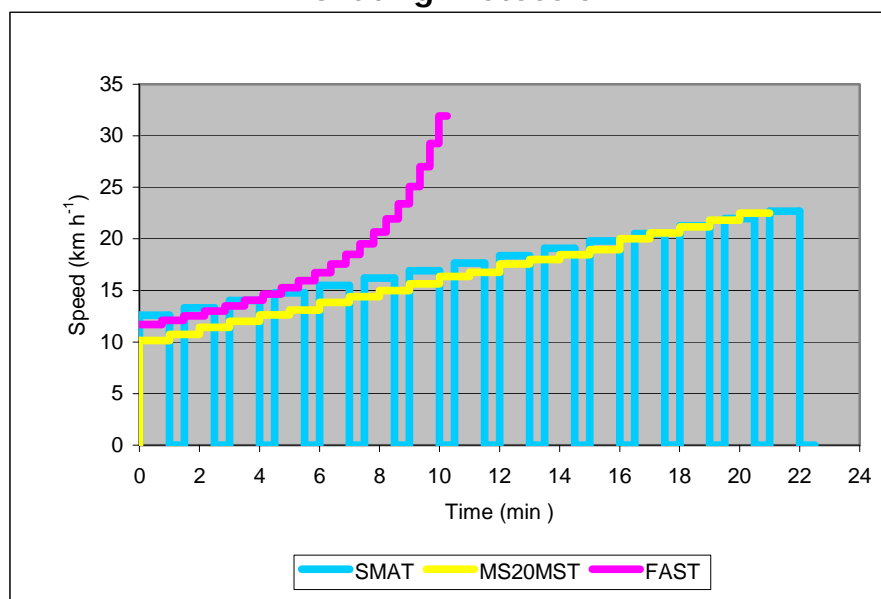
The validation of the three new ice-skating field tests has been done as follows:

1. with medium to large groups of subjects, with a wide range in maximal speed and/or $\dot{V}O_2$ max values (fitness levels),
2. with homogeneous skating ability (stop, start, turning, and cross-over skating)
3. with subjects of the same gender (males), age (adults), and specialty category (hockey), and
4. with equipment specific to the specialty and test (full equipment for MS20MST and SMAT, and only helmet, stick and gloves for the FAST).

Final Speed

The progression of speed in the three skating protocols is presented in Figure 4.20.

Figure 4.20: Progression of Speed in the Three ice-Skating Protocols



Skating velocity can be termed maximal aerobic skating velocity (MASV) or the functional maximal aerobic power (FMAP), and along with $\dot{V}O_2$ max, can be considered the “performance score” that can serve as a guideline for monitoring individual training intensity and a means to evaluate the aerobic effect of a particular program (Leone *et al.*, 2007). However, this is true only if subjects reach steady state $\dot{V}O_2$ at each stage which is probably not the case in all the protocols used in this study, due to the differences in maximal speed obtained in the MS20MST and SMAT). Léger, Seliger & Bassard (1979) reported that hockey players had lower coefficients of variation for the maximal skating speeds (3.4-4.8%) than for their $\dot{V}O_2$ max (11.0-15.1%). The MS20MST had the lowest maximal skating speed, and although this correlated with the treadmill speed, it is questionable whether this is favourable. Although the MS20MST is specific for ice-hockey, with its frequent stop and go, the distance of the test (shorter distance than SMAT, therefore requiring more stop-and-go), causes rapid muscular fatigue, and limits subjects from attaining higher maximal speed. 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). Thus, with regards to maximal speed, the SMAT allows higher maximal speed, while maintaining a ice-hockey specific nature.

Heart rate

Heart rate has been shown to be a good indicator of estimating energy expenditure in hockey (Boyle, Mahone & Wallace, 1994). Petrella, *et al.* (2005) however, state that FAST-HR was less important in the estimation of aerobic capacity with the FAST; in fact, they showed it to be unreliable. In the development of the equation for the MS20MST in this study, height, weight, and duration were less important than final speed of the test. In fact final speed was the only significant predictor.

Léger, Seliger & Bassard (1979) demonstrated lower maximal heart rates on-ice for both hockey players and runners ($10 \text{ beats min}^{-1}$), compared to the treadmill test. Vergès, Flore & Favre-Juvin (2003) also found a significant difference in heart rate during laboratory treadmill running ($195.3 \pm 6.8 \text{ beats min}^{-1}$) and field roller skiing ($190.4 \pm 5.6 \text{ beats min}^{-1}$), but not blood lactate concentration. In the present study, the same trend but with smaller magnitude was observed, where all four field tests demonstrated lower HR_{max} values than the laboratory treadmill running test. Petrella (2006) found similar maximum HR during the FAST and treadmill test ($190 \text{ beats min}^{-1}$ in both tests). Since maximal lactate was lower during FAST and the treadmill test (see next section), we cannot exclude the possibility that hockey players of this study did not push themselves to the same extent during those tests explaining why HR was not higher during the treadmill test in this study compared to other ones. Similarly, Petrella (2006) found lactate values after their test (next section) to be higher than those reported in this study, indicating that they may have been able to push their subjects more than the subjects in this study (or the subjects were more motivated in that study) and explaining their similar maximal HR for the treadmill test and the FAST.

Lactate

During heavy dynamic exercise extracellular lactate can increase from 1.3 mmol L^{-1} to more than 13 mmol L^{-1} (ACSM, 2006b). The mean maximal lactate among the five tests in this study was 10.4 mmol L^{-1} , and is considered to be high, indicating maximal effort. 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^{-1} , respectively) then declined during the third period (mean 4.9 mmol L^{-1}). The blood lactate in this study, is higher (10.4 mmol L^{-1}) than the lactate measured at the end of each period of the hockey game, as reported by Houston & Green (1976), to be in excess of 5 mmol L^{-1} and similar to the $\sim 12 \text{ mmol L}^{-1}$ that has been observed after one period of play reported by Snyder & Foster (1994). With time

particularly with active recovery on ice and passive recovery on the bench, oxidative metabolism gets rid of lactate as is the common case during prolonged continuous exercise. Values reported by Snyder and Foster are however puzzling. On the other hand, with 14 males aged 21.73 ± 0.88 years, accumulated blood lactate concentration was 12.1 ± 2.91 mmol L⁻¹ after the FAST (Petrella, 2006). This is higher than the maximum lactate measured five minutes after completing the FAST in this study ($n=16$, 9.19 ± 2.97 mmol L⁻¹). Maybe they were able to motivate their players more than subjects in this study. Green (1978) measured blood lactate levels of 10.9 ± 1.2 mmol L⁻¹ following 30 minutes and 13.3 ± 0.6 mmol L⁻¹ following 60 minutes of intermittent exercise. The blood lactate measured following the only intermittent test in this study (SMAT) was similar (12.1 mmol L⁻¹) than that reported by Green (1978).

The MS20MST and the SMAT both resulted in higher lactate values than both the treadmill and the 20 MST, indicating a higher anaerobic contribution in both the MS20MST and the SMAT, as compared to the FAST and the running tests. This indicates that the nature of the MS20MST and the SMAT are more hockey specific than the other tests. Although the subjects in this study were ice-hockey players, the nature of the FAST may make the test more suitable to speed skating or figure skating, rather than ice-hockey. This supports the notion of testing players in their training environment in a “competition simulated” manner.

$\dot{V}O_2 \max$

The assessment of aerobic capacity is a fundamental measurement in the field of exercise physiology and provides useful information for exercise prescription, disease risk assessment, and monitoring the effectiveness of training programs (ACSM, 2006). Having a well trained aerobic system in ice-hockey will be beneficial for numerous reasons. Although high intensity is required during a game, the aerobic system plays an important role, simply

due to the total duration of a game (Green, 1987). 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, 1976). Recovery is also positively influenced by a well trained aerobic system, not only between the bursts of high intensity during a game, but also between subsequent games (Twist & Rhodes, 1993a; Bracko, 2001). Arnett (1996) states that the critical measure specific to ice-hockey is the ability of the oxidative energy system to replenish phosphocreatine and ATP concentrations, in turn allowing high intensity performance to be repeated. Therefore, the effectiveness of the oxidative energy system to replenish energy stores during the rest phase is vital for success in ice-hockey.

Furthermore, by having a well trained aerobic system, the fatigue experienced during a game is reduced, allowing the player to execute skills more accurately (technical component), since hockey demands precise coordination of many muscle groups, excessive increases in lactate would interfere with the execution of hockey skills (Montgomery, 1988). With less perceived fatigue, players are able to make decisions more quickly, with improved reaction time (tactical component). From a psychological point of view, perceived exertion will be reduced, thereby improving motivation and concentration. Physically, there is reduced injury risk, and overall improved performance.

$\dot{V}O_2$ max is important in hockey, as when two players have the same efficiency, the one who has the greatest $\dot{V}O_2$ max will be the best one to perform aerobic skating (Léger, Seliger & Bassard, 1979). The mean $\dot{V}O_2$ max score across tests was 51.28 ml kg⁻¹ min⁻¹. This value is comparable to that reported in the literature (44.4-66.5 ml kg⁻¹ min⁻¹, refer to Appendix D).

According to Snyder & Foster (1994) ice-hockey players, even more so than speed skaters, tend to have relatively ordinary aerobic abilities. Values for $\dot{V}O_2$ max ranging from 53-57 ml kg⁻¹ min⁻¹ have been reported for ice-hockey players who completed treadmill running tests, which is comparable to the mean $\dot{V}O_2$ max reported for treadmill running during this study (52.74 ml kg⁻¹ min⁻¹). It has been reported that ice-hockey players had a mean $\dot{V}O_2$ max of 57.2 ml kg⁻¹ min⁻¹ during running tests, 53.4 ml kg⁻¹ min⁻¹ during cycling tests, and 55.5 ml kg⁻¹ min⁻¹ ml kg⁻¹ min⁻¹ during skating tests (Snyder & Foster, 1994).

In 1976 Simard demonstrated that the best skaters had lower $\dot{V}O_2$ max in the laboratory, showing that they were much more efficient on the ice and demonstrating that laboratory testing can yield inaccurate results. This further illustrates the advantage of testing players in their training environment to obtain accurate results. Even with similar $\dot{V}O_2$ max and lactate values on the treadmill and on the ice, a skating test is still preferable for hockey players, and treadmill testing of a hockey player who is a poor skater, but a good runner might give imprecise information as to his ability to perform aerobic skating (Léger, Seliger & Bassard, 1979). Leone *et al.* (2007) state that sport specific training and testing is recognized as essential to maximize the performance in elite athletes. Skating movements are not mirrored by either bicycle or treadmill tests and therefore may not adequately reflect the specific aerobic power developed by ice-hockey players (Nobes *et al.*, 2003).

In an attempt to make the measurement of $\dot{V}O_2$ max more sport specific for ice-hockey, Dreger & Quinney (1999) used a skating treadmill protocol where subjects skated in their own hockey skates. The protocol was intermittent using 2 minutes of skating, followed by 2 minutes of rest. This, to some extent mirrors the intermittent nature of ice-hockey. This protocol can be criticized, because subjects were only wearing hockey skates, shorts and a t-shirt, thus eliminating the effect of added mass from wearing a full kit (as in practice and competition), and not carrying a stick. Secondly, Dreger &

Quinney (1999) used a protocol where the speed was self selected (14.4 to 16.0 km/h) and the elevation was increased by 2% at every stage. This might defeat the purpose of trying to develop a test and protocol that is sport specific, because hockey players never skate uphill, and this protocol alters the movement mechanics of skating and results may be negatively affected by muscular fatigue rather than cardiorespiratory fatigue. This increase in grade may be necessary due to the limited speed of the treadmill. Furthermore, the direction of skating on the skating treadmill cannot change, as in a game situation. Although the skating treadmill has advantages such as representing the skating movement, the increased resistance, however, may make it more appropriate for training than testing. When using the skating treadmill, it is also easier to control the speed and distance, which is more difficult to do during ice testing. Disadvantages however, include the high cost of such a piece of equipment, it is time consuming, and only one subject can be tested at a time. In the laboratory, there is also a lack of wind resistance, and a competitive environment, as well as a difference in temperature in the laboratory as compared to the ice arena.

Cycle ergometry, treadmill running and treadmill skating offer some variation of metabolically demanding exercise, but do not allow the participant to perform the same mechanics of skating on-ice (Petrella, 2006; Leone *et al.*, 2007). There are biomechanical complexities and increased energy demands during shuttle running compared to treadmill running, which may be attributed to differences in factors such as intensity, exercise mode, technique, and musculature employed between the two conditions (Flouris, Metsios & Koutedakis, 2005). If ice testing cannot be done, the 20 MST is preferable to laboratory testing, for reasons stated above.

In a previous attempt to measure the $\dot{V}O_2$ max values of ice-hockey players while subjects performed the on-ice skating 20 MST (original version, Léger *et al.*, 1988), as directly determined by the Aerosport™ portable gas analyser, Kuisis & van Heerden (1999) reported lower $\dot{V}O_2$ max values

($43.7 \pm 6.6 \text{ ml kg}^{-1} \text{ min}^{-1}$) than reported during this study (using the presently developed prediction equation) when subjects performed the MS20MST ($52.27 \text{ ml kg}^{-1} \text{ min}^{-1}$). Petrella (2006) determined the $\dot{V}O_2$ max of adult male ice-hockey players performing the FAST to be $53.97 \text{ ml kg}^{-1} \text{ min}^{-1}$, subjects performing the FAST in this study obtained a mean $\dot{V}O_2$ max of $52.12 \text{ ml kg}^{-1} \text{ min}^{-1}$.

Léger, Seliger & Bassard (1979) found no difference between the $\dot{V}O_2$ max of ice-hockey players in three ice skating tests (20 m on-ice course with and without equipment, and 140 m oval on-ice course) and an incremental treadmill test. A study on speed skaters by Quirion *et al.* (1988) states that the effect of cold exposure above anaerobic threshold decreases the blood lactate concentration, increases the $\dot{V}O_2$ max, with no change in exercise time and power output. The influence of cold on muscular exercise varies according to many factors among which the most important are: the type of exercise, the intensity and duration of exercise, fatty tissue, presence or absence of cold wind, clothing, severity of cold, fluctuations in body temperature, and energy reserves. Maximal cardiorespiratory capacity is lower and submaximal strain increases when ambient working temperature decreases. This means that individual strain caused by a given submaximal workload may be significantly higher in cold as compared to thermo neutral environment due to cooling (Oksa *et al.*, 2004).

Full hockey equipment (kit) includes shoulder, elbow, and shin pads, hockey jersey, gloves, socks, pants, helmet, and stick. Subjects in this study were weighed in the laboratory wearing only running shorts, and then again in the ice arena wearing full kit, with skates and hockey stick, before the SMAT or MS20MST. A small sub sample of four subjects were also weighed wearing a tracksuit, helmet, stick, and gloves, as required for the FAST. The mean added mass when dressed in full kit was $9.9 \pm 2.2 \text{ kg}$, and the added mass for the FAST ranged between 3.2 and 7.3 kg ($n=4$). Although Léger, Seliger & Bassard (1979) state that equipment weight and design increase the cost of

skating by 4.8 % and reduces the endurance time by 20.3 %, Leone *et al.* (2007) are of the opinion that hockey equipment has changed dramatically since then and that the effect of equipment, if any, today, is probable marginal, although tightness of some cloths may still impede the motion of skating. From the previously mentioned added mass in this study, one would surmise that $\dot{V}O_2$ was higher in the tests where subjects were dressed in full kit (MS20MST and SMAT), but according to the results, there was no significant difference among the $\dot{V}O_2$ max obtained in the five tests, despite differences in dress. In this study, there were however, significant differences among the five tests with regard to test duration, but other factors may explain this difference and it is unlikely that the test duration was affected by the added mass of partial- or full-kit.

Moreover, Léger, Seliger & Bassard (1979) state that the skated 20 MST with equipment more closely approximates the nature of skating seen in a game. Thus, an added advantage of both the MS20MST and the SMAT can both be performed on a regular arena ice surface with players wearing full hockey equipment, as in a game situation, thus proving to be very specific. The administration of both these tests is inexpensive and does not require sophisticated equipment, only an audio recording of the test, compact disc player, measuring tape and a few cones, and may players can be tested simultaneously, in their practice/competition dress, without requiring players to change into other clothes or remove part of the kit (as in the FAST).

The SMAT has one specific advantage over the other two skating tests, because it is intermittent. The SMAT has 30 second rest periods after each one minute stage, thus avoiding undue muscular fatigue or injury to the lower back as ice-hockey players rarely skate in forward flexion for longer than 30 seconds. This also ensures that the end of the test for each subject is principally related to cardiorespiratory energy system fatigue and not muscular fatigue (Leone *et al.*, 2007). The ability to repeatedly perform very

high intensity exercise seems to be more sport specific rather than the ability to produce a single effort or prolonged exercise (Psotta *et al.*, 2005).

Leone *et al.* (2007) found the correlation coefficient between the SMAT and the 20 MST to be rather modest ($r=0.69$ for boys and $r=0.47$ for girls), indicating that the 20 MST shared only 48.2% and 21.9% of the variance with the SMAT respectively. In this study, the SMAT was the skating test with the highest correlation with the 20 MST ($r=0.87$), followed by the MS20MST ($r=0.83$). The FAST was not significantly correlated with the 20 MST ($r=0.46$).

Arnet (1996) states that the results of aerobic power tests should be interpreted with caution if the objective is to evaluate the energy systems needed to succeed in ice-hockey, and suggested that the Reed Repeat Sprint Skate Test is more useful in identifying whether training has resulted in specific metabolic adaptations. From the results obtained in this study, it can be said that all of the field tests used were able to discriminate between players of different fitness levels, and accurately predict treadmill $\dot{V}O_2$ max, some more accurately (MS20MST, SMAT, 20 MST), than others (FAST), and ice-tests being preferable to running tests.

In conclusion it is emphasised that any of the three of the skating tests can be used to evaluate the aerobic capacity of experienced hockey players who have mastered their skating skills (and who can perform rapid deceleration and abrupt stops, especially for the MS20MST and SMAT; cornering and cross-overs for the FAST). These tests should, however, be used with caution in beginners as the lower mechanical efficiency of beginners or unskilled players may affect the precision of the estimation of the oxygen uptake.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

Recently three new skating tests to assess aerobic fitness have emerged (SMAT, Leone, Léger, & Comtois, 2002, unpublished; MS20MST, Kuisis, 2003; and FAST, Petrella, 2006). However the validity of the three new ice-skating field tests was not always obvious since the reported statistical indices (r and SEE) were quite different. This can be ascribed to them being developed using different age and gender groups, sometimes with small groups of subjects, wearing different equipment, and using different types of protocols, thus making comparisons between the tests difficult. Consequently it was deemed necessary to revalidate all three of the new tests using a homogenous group of subjects (who had the same skating ability for all tests), with standardised procedures for all tests.

The aim of this study was thus to:

1. compare the MS20MST, SMAT, and FAST ice-skating tests to determine how they relate to each other or to determine their common variance,
2. 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. To assess the external validity by comparing observed $\dot{V}O_2$ max to $\dot{V}O_2$ max predicted from original equations of the SMAT and FAST,

3. determine which test is rated by the players as being the best suited and most functional test, and
4. determine if these on-ice skating tests are in effect better than the over-ground 20 MST.

Summary

Testing players in their training environment more accurately reflects the muscular and metabolic demands of the sport, as well as specific adaptations from training (Daub *et al.*, 1983). Of the three new tests, two of them, more accurately reproduce the “mechanics” or movement patterns (stop-and-go) of ice-hockey as seen in a game situation (MS20MST and SMAT) and duration of exertion (SMAT, one minute stages, followed by 30 seconds of rest) than others (FAST, continuous and curvilinear). Due to the differences in efficiency between running and skating (Léger, Seliger & Bassaerd, 1979), it is preferable to test ice-hockey players on-ice. Furthermore, these new tests allow testing many players simultaneously, in fact Petrella (2006) states that the FAST can comfortably test up to eight ice-hockey players simultaneously, and that a full roster hockey team can be completely evaluated within a typical one hour practice session. When using the SMAT, between 10 and 15 players can be tested on-ice at the same time, depending on their body size (Leone *et al.*, 2007); the same applies for the MS20MST. These tests also require less time than laboratory treadmill testing, less equipment, and are less expensive, as they can be easily administered during a training session, wearing either complete (SMAT and MS20MST) or partial ice-hockey equipment (FAST). Field tests such as the ones used in this study are valid and reliable [MS20MST $r=0.87$ (Kuisis, 2003); SMAT $r= 0.92$ (Leone *et al.*, 2007); FAST $r=0.76$ (Faught, Nystrom & Montelpare, 2003)].

The availability of the three new skating field tests of aerobic fitness provides the coach and sport scientist with the option of more specific on-ice field tests that are sometimes more time efficient. With regard to the three new on-ice aerobic tests, the MS20MST and the SMAT are very similar with regard to physiological demand (HR_{max} and $Lactate_{max}$), RPE, and subjective suitability ratings (Likert scale). The SMAT, however, might be more specific due to its intermittent nature, but that the MS20MST may be more specific with regards to distance, and more economical with regards to time (MS20MST test duration is approximately less than half of that of treadmill test duration, and approximately half of the SMAT duration). The FAST is not as specific to ice-hockey, because of its nature (continuous and curvilinear, with no stop-and-go), but because the modality is skating, it is more specific than running tests of aerobic fitness. In conclusion, the MS20MST or the SMAT should be the first option in assessing the aerobic fitness of adult male ice-hockey players, but if ice-time is a problem, the 20 MST can be used with confidence.

Conclusion and Recommendations for Practice

1. When assessing the aerobic fitness of ice-hockey players, skating tests are better than running tests, simply because they are skating tests, and the modality is skating, which is more sport specific than any kind of running test (laboratory treadmill running, or running field tests),
2. The MS20MST and the SMAT are very similar with regard to physiological demand ($\dot{V}O_2$ max, HR, and lactate), RPE and subjective suitability ratings (Likert resemblance scale), are seen to more ice-hockey specific, and are preferable over the FAST,
3. FAST may be as specific to ice-hockey (because it is skating), but is less valid than the MS20MST and SMAT (obtaining the lowest correlations with the treadmill $\dot{V}O_2$ max, maximal lactate, maximal HR, PRE and lowest

Likert resemblance scores), and with its oval course is probably better suited to figure- and/ or speed skating. To date however, no research has examined that possibility,

4. MS20MST is the best test of overall fitness (aerobic and anaerobic, muscular and cardiovascular fatigue), and is the most time efficient, requiring approximately half of the time required by the SMAT or treadmill test. It also uses a hockey-specific, shorter distance, which may be more appropriate for players in certain positions than the SMAT,
5. SMAT is the most specific for testing aerobic fitness in adult ice-hockey players, due to its stop-and-go, intermittent nature, and due to the fact that the distance skated is 45 m (as apposed to 20 m), there is less frequent stop-and-go, and along with the rest intervals, reduces the muscular fatigue in the legs and subjects stop the test prematurely; and
6. 20 MST has again been proven to be valid, and even suitable for aerobic assessment in adult ice-hockey players and is the best test to do if there is a lack of ice-time or financial restraint. Although the modality of the 20 MST (running) is not ideal for ice-hockey (running is not skating), the 20 MST is more specific than the treadmill or other field tests [due to the fact that its distance is short (20 m), and it has frequent stop-and-go, as in ice-hockey]. Furthermore, the 20 MST might, in certain circumstances still be more economical than the on-ice field tests of aerobic fitness, because ice time is expensive and the availability thereof is often limited. Interestingly, the 20 MST was better related to the SMAT or the MS20MST.

A possible modification to the MS20MST test would be to erase the audio voice indicating the beginning of a new level. It is speculated that many subjects stop the test the end of a stage, but the reasons for this are unclear, and it might be because they do not want to continue or because they push

themselves to try to complete the level. Furthermore, the counting of the shuttles could be consecutive starting at one and continuing to increase throughout the test (as in the FAST), and not restart at the beginning of each stage. The FAST test however, has different stages, but only counts the length numbers, so the researcher can see what stage the subject is on, but the subject only knows how many lengths they have done, and continues to aim for the next length, and is not tempted to aim for the end of a particular stage at which they think they will stop (as in MS20MST and SMAT). Doing the test with both of these “versions” might give some clarity as to which is better. Alternatively, the MS20MST test may further be modified to include rest intervals after each stage or shuttle (30 s after each stage as in the SMAT, or 10 s after each shuttle, as in the Yo-Yo test) making it intermittent, but very specific to ice-hockey because of the distance.

The SMAT seems to have an advantage over the other skating tests in that it includes rest periods after each stage, making it intermittent, much like ice-hockey. The distance however, may be too long, and subjects skate 45 m before they stop and turn, thus, a distance of 30 m might be more appropriate.

It is emphasised that any of the three of the skating tests can be used to evaluate the aerobic capacity of experienced hockey players who have mastered their skating skills (and who can perform rapid deceleration and abrupt stops, especially for the MS20MST and SMAT; cornering and cross-overs for the FAST). These tests should, however, be used with caution in beginners as the lower mechanical efficiency of beginners or unskilled players may affect the precision of the estimation of the oxygen uptake.

Future Research

The application of FAST to figure skating and speed skating needs to be researched, as it may be more appropriate for those disciplines, than for ice-hockey. It may also be interesting to study a more specific path for short track speed skating (using a standardized competitive course versus the symmetrical oval course). Also, an oval protocol with a linear increase in speed needs to be compared to the current FAST, in which speed increases exponentially. However the next most logical research step in determining the best and most valid skating test of aerobic capacity in ice-hockey players is to perform all three field tests with portable gas analysis throughout each test. Alternatively $\dot{V}O_2$ max can be obtained with the backward extrapolation of $\dot{V}O_2$ max at time zero of recovery using the exponential least squares regression (Di Pampero *et al.*, 1976; Léger, Seliger & Bassard, 1979), and to compare the results to those obtained from a skating treadmill protocol and/or a traditional running treadmill.

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APPENDIX A

Time Motion Analysis of Game Play

Time Period	Players						
	5 University (Forwards) ^a	3 University (Defensemen) ^a	10 University ^b	80 Junior ^c	170 Midget ^c	12 Old Timers ^d	89 Minor League ^e
Bench time between shifts (s)	293±16	189±18	225±25	329	147.5	276.3±14.0	228
Ice/shift time (s)				146.3	91.2	233.1	160
Bench/on-ice ratio	2.52	1.24	2.66	2.25	1.61	1.20	1.43
Playing time/game (s)	1152±54	1723±97	1471±84	1884	1032	1134	828
Shifts	20.2±0.6	24.3±0.7	17.4±1.0	12.8	11.3	7.8±0.6	9.0
Playing time/shift (s)	57.9±2.5	73.1±4.7	85.4±3.1	86.9		139.1±10.5	94.9
Total stoppage time/shift (s)	58.2	79.3	62.3	59.4		75.3±8.8	
Play stops/shift (s)	2.0±0.1	2.6±0.2	2.3±1.0			3.5±0.3	2.3
Time/play stoppage (s)	29.1±3.3	30.5±4.1	27.1±1.4			21.5	
Playing time between stoppage (s)	29.5±0.8	28.5±0.3	39.7±2.6			20.6±1.3	

^a Data from Green *et al.* (1987a)

^b Data from Green *et al.* (1976)

^c Data from Léger (1980)

^d Data from Montgomery & Vatzbedian (1979)

^e Data from Paterson (1979)

(Montgomery, 1988)

APPENDIX B

Physical Characteristics of Ice- Hockey Players

Reference	Level of Play	Years of Experience	Age (yrs)	Stature (cm)	Mass (kg)	Body fat %
Houston & Green (1976)	Major Junior A & University League (ice-hockey)	Minimum of 8				
Forwards			19.1±2.2	176.2±5.0	77.9±6.2	10.2±2.9
Defense			18.7±1.8	180.8±5.3	82.2±7.3	10.1±2.4
Goalie			19.5±2.7	176.5±4.6	72.9±7.9	9.6±4.2
Smith <i>et al.</i> (1982)	Canadian Olympic Ice-Hockey Team (n=23)		19-29	179.8±1.1	81.1±1.3	10.6±0.1
Agre <i>et al.</i> (1988)	NHL (n=27)					
Goalies			25.0±3.0	177.2±2.8	77.7±3.2	8.7±2.4
Forwards			24.8±0.9	183.5±1.4	86.1±1.9	7.7±1.3
Defensemen			24.9±1.3	184.7±2.1	88.5±1.9	12.2±1.1
Twist & Rhodes (1993b)	NHL (n=31)					
Forwards			24.4±4.6	186.9±4.3	92.7±3.8	10.8±2.4
Defensemen			24.7±2.6	187.7±4.8	93.9±4.2	12.1±2.5
Goal tenders			27.3±4.5	184.2±3.1	84.1±4.6	13.5±3.1
Boyle <i>et al.</i> (1994)	Competitive Field Hockey Players (n=9)		26±4.5	177.3±3	75±5.4	12.4±2.4
Dreger & Quinney (1999)	Elite Ice-Hockey Players (n=6)		15.8±0.41	176.4±3.90	74.4±6.51	
Bracko (2001)	Elite Women's Ice-Hockey Players (n=8)	17±6	25±5	176.2±2.3	68.9±6.4	
	Non-elite Women's Ice-Hockey Players (n=15)	8±3	19±2	168.2±7.6	65.3±6.6	
Bracko & George (2001)	Women's Ice-Hockey Players (n=61)	4.68±2.69	12.18±2.05	153.05±14.38	44.41±12.30	18.37±5.5
Bracko & Fellingham (2001)	Calgary Hockey Players & American Hearing Impaired Hockey Association (n=19 female)	3.80±1.74	10.95±0.55	143.43±8.3	36.44±7.13	19±7.41
	Calgary Hockey Players & American Hearing Impaired Hockey Association (n=21 male)	5.0±0.89	10.75±0.65	140.92±4.11	35.66±4.32	7.58±2.24
	Calgary Hockey Players & American Hearing Impaired Hockey Association (n=20 female)	4.25±2.27	12.75±0.54	158.6±1.07	46.97±7.95	17.43±3.71
	Calgary Hockey Players & American Hearing Impaired Hockey Association (n=31 male)	6.68±1.06	12.25±0.52	159.17±8.68	48.28±8.54	6.80±3.41
	Calgary Hockey Players & American Hearing Impaired Hockey Association (n=15 female)	5.96±3.03	14.55±0.46	164.85±5.94	58.83±5.92	19.88±4.85
	Calgary Hockey Players & American Hearing Impaired Hockey Association (n=25 male)	9.0±1.63	14.65±0.26	166.69±9.99	56.92±9.61	13.8±2.96
Hoff <i>et al.</i> (2005)	Elite	10+	24.2±4.7	179.9±6.1	84.2±8.1	16.6±4.0
	Junior Elite	7	17.6±0.9	179±7	72.3±6.0	15.7±4.4
Behm <i>et al.</i> (2005)	Junior (n=30)	5-13	19.8±3.5	178.6±6.5	78.9±10.1	
Green <i>et al.</i> (2006)	National Collegiate (n=29)			182±5	84.9±6.4	12±3
Vescovi <i>et al.</i> (2006)	NHL Combines 2001 (n=74)		17.9±0.5	185.5±4.3	88.8±6.3	10.2±1.6
	NHL Combines 2002 (n=84)		18.0±0.6	185.3±4.5	87.5±6.1	10.0±1.5
	NHL Combines 2003 (n=92)		18.0±0.6	186.1±4.4	87.5±7.6	9.5±1.6

APPENDIX C

Muscular Endurance, Flexibility & Speed Characteristics of Ice- Hockey Players

Author	Level of Play	Yrs of Experience	Age (yrs)	Vertical Jump (cm)	Push-Ups (1 min)	Sit-Ups (1 min)	Sit & Reach (cm)	40 Yard Dash (s)
Bracko & Fellingham (2001)	Calgary hockey players & American Hearing Impaired Hockey Association (n=19 female)	3.80±1.74	10.95±0.55	29.76±6.63	28.94±12.62	32.5±8.0	39.6±7.82	7.45±0.61
	Calgary hockey players & American Hearing Impaired Hockey Association (n=21 male)	5.0±0.89	10.75±0.65	33.46±7.48	22.21±10.96	30.78±11.94	33.77±7.56	9.44±0.52
	Calgary hockey players & American Hearing Impaired Hockey Association (n=20 female)	4.25±2.27	12.75±0.54	31.0±7.2	31.95±10.65	35.15±7.5	37.39±9.99	7.01±0.5
	Calgary hockey players & American Hearing Impaired Hockey Association (n=31 male)	6.68±1.06	12.25±0.52	37.93±7.5	29.60±10.13	38.23±8.41	36.24±7.71	6.58±0.49
	Calgary hockey players & American Hearing Impaired Hockey Association (n=25 male)	9.0±1.63	14.65±0.26	44.43±8.14	37.44±11.55	42.72±7.11	39.28±8.75	6.40±0.42
Bracko (2001)	Elite Females (n=8)	7	25±5					
	Non-Elite Females (n=15)	3	19±2					
Bracko & George (2001)	Women's Ice-Hockey Players (n=61)	4.68±2.60	12.18±2.05	31.29±8.15	29.16±11.10	33.17±8.75	38.83±9.04	7.19±0.7
Hoff <i>et al.</i> (2005)	Elite	10+	24.2±4.7	48.2±4.6				
	Junior elite	7	17.6±0.9	43.6±3.6				
Vescovi <i>et al.</i> (2006)	NHL Combines 2001 (n=74)		17.9±0.5	67.2±8.3	Max 23.1±3.8	Max 39.6±22.8		
	NHL Combines 2002 (n=84)		18.0±0.6	58.8±6.1	Max 27.1±5.9	Max 23.5±12.9		
	NHL Combines 2003 (n=92)		18.0±0.6	56.1±9	Max 22.5±6.0	Max 16.5±10.5		

APPENDIX D

Aerobic & Anaerobic Capacity of Ice-Hockey Players

Reference	Level of Play	Age (yrs)	VO ₂ max (ml kg ⁻¹ min ⁻¹)	VO ₂ max Protocol	HR max	Anaerobic Lactate Capacity (mmol L ⁻¹)	Anaerobic Lactate Capacity Protocol	On-Ice Anaerobic Power (w kg ⁻¹)
Cunningham <i>et al.</i> (1976)	Highly Successful Competitive Players (n=15)	10.6±0.3	56.6±7.7	PWC ₁₇₀ (50 rpm, 5 min loads, 150 kpm for supramaximal)	197±8			
Houston & Green (1976)	Major Junior A & University League (n=48)	16-20 18-23	44.4-66.5	12.9 km h ⁻¹ 1% increase in grade every minute		7.2-21.7	12.9 km h ⁻¹ at 20% grade, La 5 & 12 min post test	
Smith <i>et al.</i> (1982)	Canadian Olympic Team (n=23)	19-29	54.0±1.2	Continuous Monark cycle protocol starting at 150 watts, increased by 0.5 Kp every 2 minutes				
Agre <i>et al.</i> (1988)	NHL (n=27)			Treadmill Bruce Protocol				
Goalies		25.0±3.0	53.1±1.2		192±3.7			
Forwards		24.8±0.9	54.2±1.3		186±2.1			
Defensemen		24.9±1.3	52.2±1.0		183±3.5			
Twist & Rhodes (1993b)	NHL (n=31)							
Forwards		24.4±4.6	57.4±3.1			15.1±2.1	Modified 30 s Wingate Cycle ergometre protocol	
Defensemen		24.7±2.6	54.8±3.9			14.9±1.8		
Goal tenders		27.3±4.5	49.1±2.5			14.9±2.2		
Dreger & Quinney (1999)		15.8±0.41	60.4±5.1	Skating treadmill (intermittent protocol, constant speed 14.4 -16.0 km h ⁻¹ ; initial grade 0%, increasing by 2% every 2 min)	202.3±4.27			
			59.0±8.31	Cycle ergometre (5 min at 100-150 watt, increased by 25 watt every 2 min, 60 rpm)	200.7±4.55			
Bracko (2001)	Elite females (n=8)	25±5						6.63±0.42
Hoff <i>et al.</i> (2005)	Elite	24.2±4.7	57.4±4.7	Treadmill (inclination 6°), speed 6 km h ⁻¹ increased by 1 km h ⁻¹ every minute	191.1±4.3			5.5±0.27 (40 m)
	Junior Elite	17.6±0.9	58.5±4.4		203±9			
Green <i>et al.</i> (2006)	National Collegiate (n=29)		59±4	Discontinuous incremental treadmill (3 min stages, 90 s rest between stages; 9.7 km h ⁻¹ with 0% grade, 9.7 km h ⁻¹ , 5%, increasing by 1.6 km h ⁻¹ & 1%				
Vescovi <i>et al.</i> (2006)	NHL Combines 2001 (n=74)	17.9±0.5	58.9±3.5	Cycle ergometre (70 rpm, starting at 2.0 kp, increasing by 1 kp every 2 min for first 3 levels, there after by 0.5 kp every 1 min at 80 rpm)				
	NHL Combines 2002 (n=84)	18.0±0.6	55.9±5.7					
	NHL Combines 2003 (n=92)	18.0±0.6	57.7±5.2					

Reference	Group	n	Peak Power (W kg ⁻¹)	30-second Anaerobic Endurance (W kg ⁻¹)
Smith <i>et al.</i> (1982)	Canadian Olympic Forwards 1980	15	11.7±1.0	9.6±0.6
	Canadian Olympic Defense 1980	6	11.5±0.4	9.6±0.9
Rhodes <i>et al.</i> (1986)	NHL Defense	27	12.0±1.5	9.5±1.0
	NHL Forwards	40	12.0±1.2	9.1±5.5
	NHL Goal Tenders	8	11.4±1.1	8.6±5.2
Montgomery & Dallaire (1986)	Montreal Canadians- Defensemen	12	9.8±1.1	8.2±0.3
	Montreal Canadians- Forwards	6	10.3±0.4	8.7±0.7
	Montreal Canadians- Goaltenders	3	10.6±1.0	8.3±0.1
	Montreal Canadians 1981-82	27	9.9±0.7	8.3±0.3
	Montreal Canadians 1982-83	30	10.4±1.1	8.7±0.8
Watson & Sargeant (1986)	University and Junior	24	10.1±1.0	7.7±1.0
Gamble (1986)	University	17	11.5±0.6	9.2±0.5
Brayne (1985)	University	17	11.5±0.8	9.0±0.7

Montgomery (1988)

APPENDIX E

Physical Activity Readiness Questionnaire (PAR-Q)

**(Canadian Society for Exercise
Physiology)**

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of <u>any other reason</u> why you should not do physical activity?

If
you
answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____

DATE _____

SIGNATURE OF PARENT _____

WITNESS _____

or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.



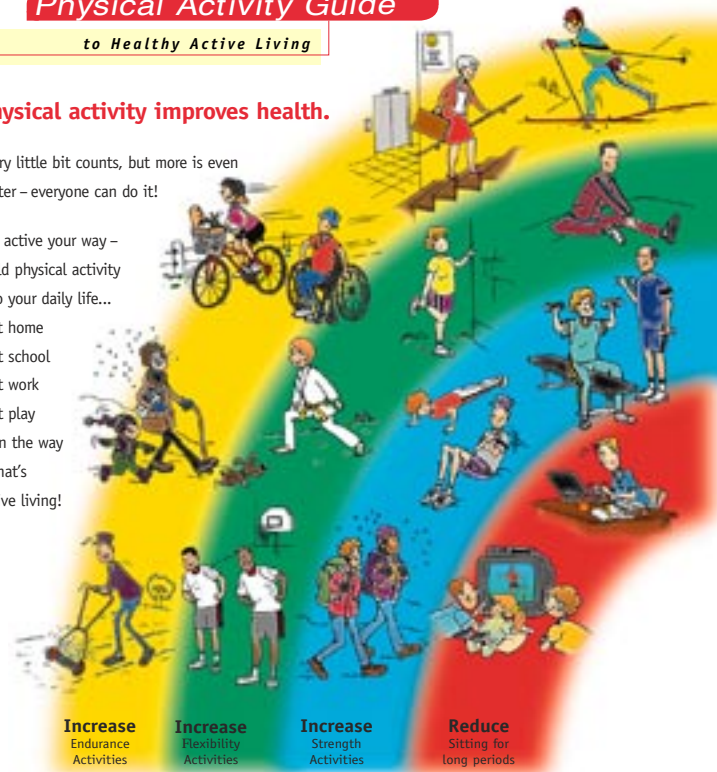
CANADA'S
Physical Activity Guide
to Healthy Active Living

Physical activity improves health.

Every little bit counts, but more is even better – everyone can do it!

Get active your way – build physical activity into your daily life...

- at home
 - at school
 - at work
 - at play
 - on the way
- ...that's active living!



Choose a variety of activities from these three groups:

Endurance
4-7 days a week
Continuous activities for your heart, lungs and circulatory system.

Flexibility
4-7 days a week
Gentle reaching, bending and stretching activities to keep your muscles relaxed and joints mobile.

Strength
2-4 days a week
Activities against resistance to strengthen muscles and bones and improve posture.

Starting slowly is very safe for most people. Not sure? Consult your health professional.

For a copy of the *Guide Handbook* and more information: **1-888-334-9769**, or www.paguide.com

Eating well is also important. Follow *Canada's Food Guide to Healthy Eating* to make wise food choices.

Get Active Your Way, Every Day – For Life!

Scientists say accumulate 60 minutes of physical activity every day to stay healthy or improve your health. As you progress to moderate activities you can cut down to 30 minutes, 4 days a week. Add-up your activities in periods of at least 10 minutes each. Start slowly... and build up.

Time needed depends on effort				
Very Light Effort	Light Effort	Moderate Effort	Vigorous Effort	Maximum Effort
60 minutes	30-60 minutes	20-30 minutes		
<ul style="list-style-type: none"> • Strolling • Dusting 	<ul style="list-style-type: none"> • Light walking • Volleyball • Easy gardening • Stretching 	<ul style="list-style-type: none"> • Brisk walking • Biking • Raking leaves • Swimming • Dancing • Water aerobics 	<ul style="list-style-type: none"> • Aerobics • Jogging • Hockey • Basketball • Fast swimming • Fast dancing 	<ul style="list-style-type: none"> • Sprinting • Racing
Range needed to stay healthy				

You Can Do It – Getting started is easier than you think

Physical activity doesn't have to be very hard. Build physical activities into your daily routine.

- Walk whenever you can – get off the bus early, use the stairs instead of the elevator.
- Reduce inactivity for long periods, like watching TV.
- Get up from the couch and stretch and bend for a few minutes every hour.
- Play actively with your kids.
- Choose to walk, wheel or cycle for short trips.
- Start with a 10 minute walk – gradually increase the time.
- Find out about walking and cycling paths nearby and use them.
- Observe a physical activity class to see if you want to try it.
- Try one class to start – you don't have to make a long-term commitment.
- Do the activities you are doing now, more often.

Benefits of regular activity:

- better health
- improved fitness
- better posture and balance
- better self-esteem
- weight control
- stronger muscles and bones
- feeling more energetic
- relaxation and reduced stress
- continued independent living in later life

Health risks of inactivity:

- premature death
- heart disease
- obesity
- high blood pressure
- adult-onset diabetes
- osteoporosis
- stroke
- depression
- colon cancer

Source: Canada's Physical Activity Guide to Healthy Active Living, Health Canada, 1998 <http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf>

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FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed-X)** – to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for Pregnancy)** – to be used by doctors with pregnant patients who wish to become more active.

References:

Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. *J. Clin. Epidemiol.* 45:4 419-428.

Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy. In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health**. Champaign, IL: Human Kinetics.

PAR-Q Validation Report, British Columbia Ministry of Health, 1978.

Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Can. J. Spt. Sci.* 17:4 338-345.

For more information, please contact the:

Canadian Society for Exercise Physiology
202-185 Somerset Street West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565
Online: www.csep.ca

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (révisé 2002)».

APPENDIX F

**Letters of Approval From
University of Pretoria &
University of Montréal Ethics
Committees**

Montréal, le 26 septembre 2006

Monsieur Luc Léger
Professeur titulaire
Département de kinésiologie
CEPSUM, 2100 boul. Édouard-Montpetit
Bureau 7203

OBJET : Certificat d'éthique

Monsieur Léger,

Vous avez soumis le projet intitulé « Validité comparative de trois tests en patin à glace pour évaluer l'aptitude aérobie de hockeyeurs adultes » pour évaluation par le Comité d'éthique de la recherche des sciences de la santé (CÉRSS).

Je suis heureuse de vous informer que le Comité a jugé le projet conforme aux normes déontologiques. Un certificat d'éthique a donc été émis et vous est envoyé.

Le certificat d'éthique est émis pour une durée d'un an. À l'échéance, un suivi déontologique sera effectué, conformément aux normes de fonctionnement du Plan d'action ministériel en éthique de la recherche et en intégrité scientifique.

Il est aussi à souligner que vous devrez faire part au CÉRSS de toute nouvelle information (changement dans les connaissances scientifiques...) ou observation (événement négatif...) ou de tout changement au protocole expérimental, qui pourrait modifier le fondement éthique sur lequel repose votre projet de recherche.

Je vous prie de recevoir, Monsieur, l'expression de mes salutations distinguées.



Marie-France Daniel
Présidente
Comité d'éthique de la recherche des sciences de la santé
CEPSUM, 2100 Edouard-Montpetit, bureau 7211
Téléphone : (514) 343-5624
Télécopieur : (514) 343-2181
Courriel : marie-france.daniel@umontreal.ca

p.j.

**COMITÉ D'ÉTHIQUE DE LA RECHERCHE DES SCIENCES DE LA SANTÉ
(CÉRSS)**

CERTIFICAT D'ÉTHIQUE

Titre du projet : Validité comparative de trois tests en patin à glace pour évaluer l'aptitude
aérobie de hockeyeurs adultes

Sous la direction de : Monsieur Luc Léger

Nom de l'étudiant : Madame Suzanne Kuisis

À la réunion du 28 août 2006, 11 membres du CÉRSS étaient présents : la présidente, la vice-présidente, l'experte en éthique, l'experte en droit, un représentant du public, la représentante des étudiants, le représentant de la Faculté de pharmacie, la représentante de la Faculté de médecine dentaire, la représentante de l'École d'optométrie, la représentante de la Faculté des sciences infirmières, le représentant du Département de kinésiologie.

Le Comité a jugé le projet mentionné ci-haut conforme aux règles d'éthique de la recherche sur les êtres humains.

Le certificat est émis pour la période du 26 septembre 2006 au 25 septembre 2007.

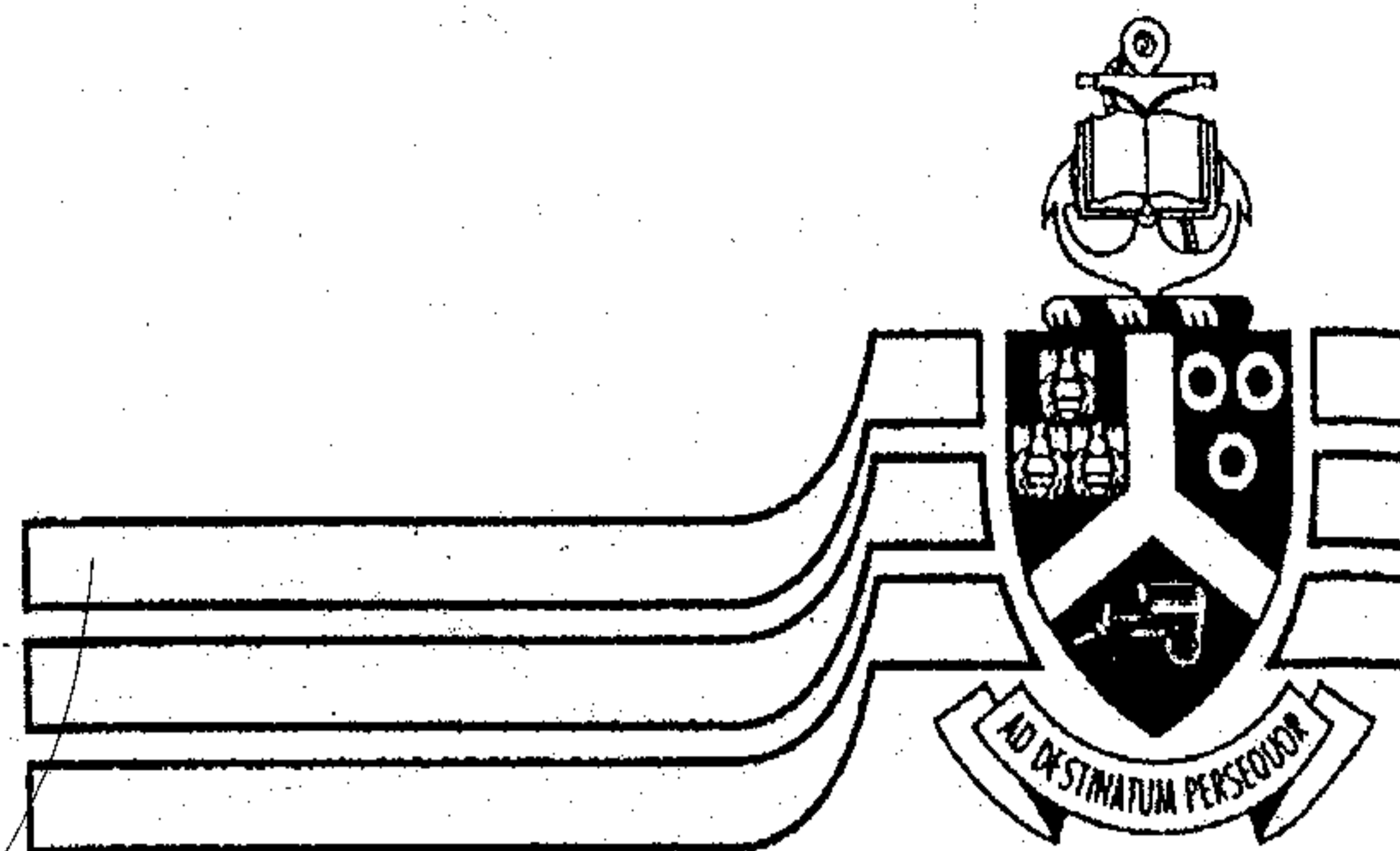
Le 26 septembre 2006.

Marie-France Daniel
Présidente
Comité d'éthique de la recherche des sciences de la santé
CEPSUM, 2100, Edouard-Montpetit, bureau 7211
Téléphone : (514) 343-5624
Télécopieur : (514) 343-2181
Courriel : marie-france.daniel@umontreal.ca

Members:

Research Proposal and Ethics Committee

Dr P Chiroro; Dr M-H Coetzee; Prof C Delpont;
Dr JEH Grobler; Prof KL Harris; Ms H Klopper;
Prof E Krüger; Prof B Louw (Chair); Prof A Mlambo;
Prof D Prinsloo; Prof G Prinsloo; Dr E Taljard;
Prof A Wessels; Mr FG Wolmarans



University of Pretoria

**Research Proposal and Ethics Committee
Faculty of Humanities**



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

31 January 2006

Dear Doctor van Heerden

Project: *Validation and normative establishment of the modified (skating) 20 Metre Multi-stage Shuttle-run Test*
Researcher: SM Kuisis
Supervisor: Dr HJ van Heerden
Department: Biokinetics, Sport & Leisure Science
Reference number: 25519833

Thank you for your correspondence of 7 December 2005 regarding the above application for ethical clearance.

I have pleasure in informing you that the Research Proposal and Ethics Committee formally approved the above study at an *ad hoc* meeting held on 26 January 2006. The approval is subject to the candidate abiding by the principles and parameters set out in her application and research proposal in the actual execution of the research.

The Committee requests you to convey this approval to Ms Kuisis.

We wish you success with the project.

Sincerely

Prof Brenda Louw
Chair: Research Proposal and Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA

University of Montreal

Department of Kinesiology

Dossier No 735

Montreal, 26 September 2006

Mr Luc Léger
Tenured Professor
Department of kinesiology
CEPSUM, 2100 boul. Edouard-Montpetit
Office 7203

RE: Ethics Certificate

Sir,

You submitted the project entitled “Comparative validity of three ice skating tests to evaluate the aerobic aptitude of adult hockey players” for assessment by the Ethics Committee of the Health Science Research Institute (CERSS).

I am glad to inform you that the committee considered that the project complied with deontological standards. Therefore, an ethics certificate has been issued and is being sent to you.

The ethics certificate is issued for a period of one year. At the end of the period, a deontological follow-up will be carried out, in accordance with the operating standards of the ministerial plan of action for research ethics and scientific integrity.

We wish also to emphasise that you will have to inform the CERSS of any new information (change in scientific knowledge...) or observation (negative event) or any change in the experimental procedure, which could modify the ethical basis on which your research project rests.

Yours faithfully

Marie-France Daniel
Chairlady
CERSS
CEPSUM, 2100 Edouard-Montpetit, office 7211
Tel. (514) 343-5624
Fax: (514) 343-2181
e-mail: marie-france.daniel@umontreal.ca

University of Montreal

Department of Kinesiology

Dossier No 735

**ETHICS COMMITTEE OF HEALTH SCIENCE RESEARCH
(CERSS)**

ETHICS CERTIFICATE

Title of the Project: Comparative validity of three ice skating tests to evaluate the aerobic aptitude of adult hockey players.

Under the direction of: Mr. Luc Léger

Name of student: Mrs Suzanne Kuisis

At the meeting of 28 August 2006, 11 members of the CERSS were present: the chairlady, the vice-chairlady, the ethics expert, the law expert, a representative of the public, a student representative, representatives of the faculty of pharmacy, a representative of the faculty of dental medicine, a representative of the optometry School, a representative of the faculty of nursing, a representative of the Department of kinesiology.

The committee considered that the above-mentioned project complied with the ethics rules of research on human beings.

The certificate is issued for the period from 26 September 2006 to 25th September 2007

26 of september 2006

Marie-France Daniel

APPENDIX G

Informed Consent

Please note that this document was originally in French (as all the subjects were French) and has been translated for examination purposes.

Voluntary consent Form

To take part in the study described below

TITLE OF STUDY:

COMPARATIVE VALIDITY OF THREE ICE SKATING TESTS TO EVALUATE THE AEROBIC APTITUDE OF ADULT HOCKEY PLAYERS

STUDENT RESEARCHER: Suzan KUISIS

Institution/Department: University of Montréal, Department of Kinesiology
Address: CP 6128, succ. Centre ville. MONTREAL H3C 3J7, Canada
Telephone: +1 (514)343 6111 Extension 3125
E-mail: suzan.kuisis@up.ac.za

MAIN RESEARCHER: Luc LEGER.....

Institution/Department: University of Montréal, Department of Kinesiology
Address: CP 6128, succ. Centre ville. MONTREAL H3C 3J7, Canada
Telephone: +1 (514)343 7792
E-mail: luc.leger@umontreal.ca

INTRODUCTION

Maximum oxygen consumption (VO_2 max) is a key parameter for performance in ice hockey. This is usually measured directly, in a laboratory where the subject is connected to a gas analyzer. Three new ice-skating tests to measure VO_2 max have recently been developed to make testing more specific to the sport, and that predict VO_2 max from the maximum speed reached during those tests that have progressively increasing speed. These new tests have been researched by different researchers on different groups of subjects. It is necessary to validate the new tests and to compare these new tests to determine the advantages and disadvantages of each test.

AIMS AND OBJECTIVES OF THE STUDY

The aims of this study are to:

1. assess the validity and suitability of three ice-skating tests and compare the three ice-hockey tests to determine their degree of concordance,
2. to compare these tests to the measurement of VO_2 max obtained on the treadmill in the laboratory, and
3. compare a conventional 20-m shuttle running test in a gymnasium with the hypothesis that such a simple test would be as valid as more specific ice skating tests that require costly ice time.

TERMS FOR PARTICIPATION IN THE STUDY

Each subject must therefore be available for 5 tests within a 2 to 3 week period. The tests take place in a mixed order according to the first test the subject takes, in order to avoid any bias. No more than one test per day and no more than 3 tests on consecutive days will be performed as this will affect the results. The tests will consume approximately 2 hours of your time. The tests will take place at the Human Performance laboratory, gymnasium, and the ice arena at CEPSUM (university of Montreal). Tests will be conducted by the student researcher, Suzan Kuisis, who will be assisted by students.

DESCRIPTION OF THE TESTS

STANDARD TEST ON TREADMILL

The treadmill test will be done in the Human Performance Laboratory of the Department of Kinesiology, at the University of Montréal also located in the CEPSUM. The maximum standard treadmill test with multiple stages will be approximately 10 to 20 minutes in duration according to each subject's physical aptitude. This test begins at 10 km h^{-1} (slow speed, easy for everyone); the speed increases with 1 km h^{-1} after each 2 min stage. A nose clip will be worn and a mouthpiece is held in the mouth. During this test, the subject will be connected to a gas analyzer, the subject breathes through the mouthpiece, which containing a valve which directs the ambient air into the mouth at the time of the inspiration and the air expired into the system for means of analysis and calculation of the oxygen uptake (VO_2), a measure of the expenditure of energy. The mouthpiece and the valve are maintained in place by means of an adjustable headset. The subject also wears a nose-clip. Besides the slight discomfort, this system does not present any risk for the subject. The VO_2 measured within the last stage represents the maximum oxygen consumption of the subject (VO_2 max). This measurement of the aerobic aptitude is used as standard measurement to validate the field tests, in gymnasium and on ice.

FIELD TESTS IN THE GYMNASIUM AND ON ICE

Each subject must also do 4 other field tests, in a gymnasium (1x) or on ice with skates (3x). These tests are carried out in groups of 3 to 6 subjects. The duration of these tests is 10 to 20 minutes, but will depend on the physical aptitude of each subject. Each test is maximal and progressive, and is easier at the start and becomes more difficult. Subjects are required to give a maximal effort. Subjects will need to allow time for changing into fill hockey kit and for a 5 minute explanation of each test.

The principle characteristics of each of the field tests are described in Table 1 below and shown in Figure 1.

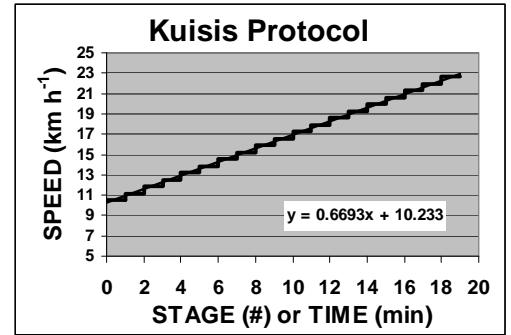
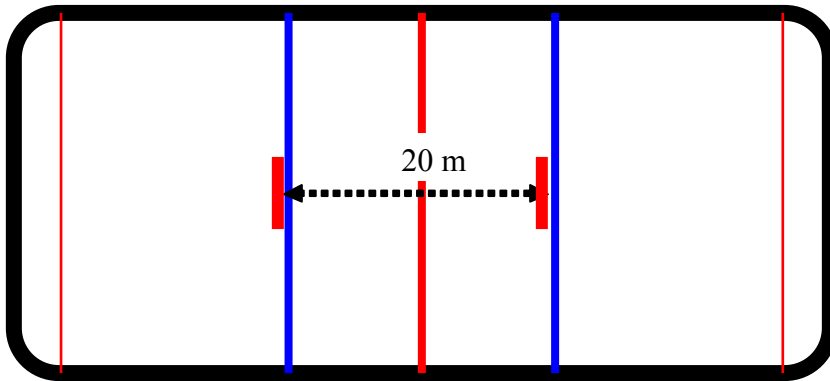
Table 1. Characteristics of the maximal multistage running and ice skating tests.

	20-m shuttle run	20-m shuttle skate	45-m shuttle skate	48.8 m shuttle skate
Source	Léger al 1988	Kuisis 2001	Leone al 2006	Petrella 2006
Displacement technique	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
Protocol Type	Max Multistage Continuous	Max Multistage Continuous	Max Multistage Intermittent	Max Multistage Continuous
Speed vs Stage	Linear	Linear	Linear	Curvilinear
Stage duration	1 min	1 min	1 min	45 s → 19.5 s*
Rest interval	0 s	0 s	30 s	0 s
Initial speed	8.5 km h ⁻¹	10.0 km h ⁻¹	12.6 km h ⁻¹	15 s (11.7 km h ⁻¹)
Speed increase	0.5 km h ⁻¹	0.5 km h ⁻¹	0.72 km h ⁻¹	-5 s (0.4→2.0 km h ⁻¹)
Equipment	Running shoes	Full hockey gear (+ portable VO ₂ system**)	Full hockey gear	Skates, Stick, helmet, gloves

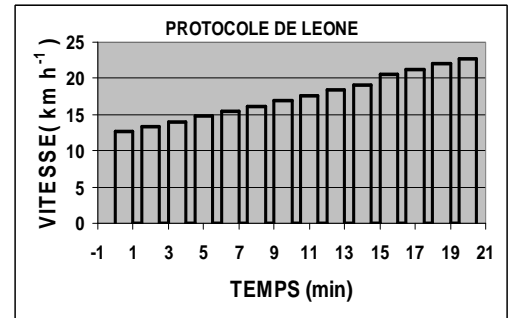
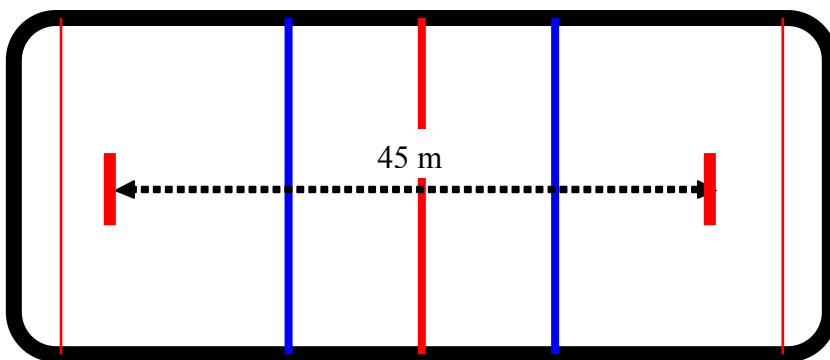
* For the best results so far

Figure 1. Ice-skating tests

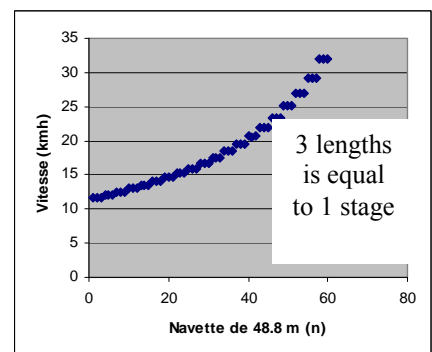
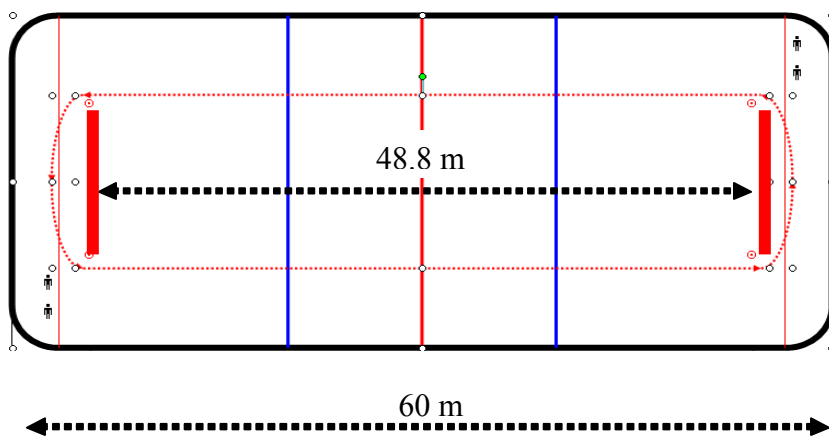
1. Kuisis 2001 Test



2. Leone Test



3. Faught Test



MEASUREMENTS TAKEN DURING THE TESTS

1. The performance score of the test is the number of completed stages
2. VO_2 will be measured continuously during the standard treadmill test. The maximum value reached at the end of the test (VO_2 max) is used as the standard to validate the maximum speed reached at the end of the field tests. The VO_2 is measured by the collection of gases expired during the treadmill test, as described in the preceding section
3. Measurement of blood lactate will be used as an indication of the overall intensity of the tests, indicating the gross anaerobic contribution of the test. Lactate will be measured by pricking the finger and collecting a drop of blood, between 5 and 8 minutes of completion of each test. This procedure is similar to that used by people who monitor their blood glucose by means of a domestic glucose meter. The prick is a little painful, but it is without danger if one takes the precautions (sterilization)
4. Measurement of maximal HR at the end of each test to determine the respective intensity or difficulty of each test
5. The Borg Rated Perceived Exertion (RPE) is also used to establish the degree of difficulty of each test, and is subjectively established on a 6 to 20 point scale from "very very easy" to "very very difficult" and constitutes another classical indication of the overall difficulty of each test. This only takes a few seconds
6. Likert resemblance score is obtained on a subjective scale. Each test will be evaluated at 5 levels (questions), on a scale of 1 to 7 where subjects rate the similarity of the test to ice-hockey and the suitability of the test to evaluate aerobic fitness in ice-hockey players. This takes less than one minute to answer
7. During the tests on ice, the subjects will be filmed in order to try to develop indices of the level of skill and technique of stopping, starting, the skating of crossovers and turns. The technical level could then be used, with maximum speed, as a determinant in the prediction of VO_2 max.

CONDITIONS OF PARTICIPATION

Inclusion criteria

1. healthy males aged between 18 and 50 years of age,
2. hockey players who have mastered their skating skills (start, stop, forward acceleration, skating turns and cross-overs)
3. be available for the duration of the study and to come to the University for all 5 testing sessions
4. read, understand and voluntarily sign an informed consent form describing the tests to be done

Exclusion criteria

1. failure to meet inclusion criteria just described
2. having a medical contraindication to exercise from his medical doctor or answer yes to any of the questions in the PAR-Q physical readiness questionnaire of the Canadian Society for Exercise Physiology
3. injury during the testing period

ADVANTAGES IN PARTICIPATING

The evaluation of an athlete's physical aptitude, whatever his speciality, forms part of the planning process of sport training. The evaluation of physical aptitude in athletes is a specialized process. By participating in this project you will obtain results regarding your aerobic capacity, which constitutes an important aspect of performance. We will also be able to discuss with you the strategies which are available to you to improve this parameter.

RISKS AND DISCOMFORT

In the course of those physical tests, you may experience great fatigue. All precautions are taken to ensure that the tests take place in the safest manner possible. The laboratory is equipped with an automated external defibrillator and researchers have obtained cardiopulmonary resuscitation certificates (the Head of the laboratory is also a certified CPR instructor, Arthur Long, 343 6111, extension 4238).

The PAR-Q questionnaire helps to minimize the risk of your participation, and eliminate subjects who are potentially at risk. The PAR-Q comprises a margin of error and the risks detected by the PAR-Q require confirmation by a doctor.

VOLUNTARY PARTICIPATION AND WITHDRAWAL OR EXCLUSION FROM THE STUDY

Your participation is completely voluntary. You have a 48 h delay after: 1) you have filled in the PAR-Q, 2) acquainted yourself with the consent form, and 3) asked for additional explanations from the researcher and confirm your participation in the study, in order to give you time to ask for advice of a third party if need be.

If you wish to be included in the study, we will then ask you for your written consent by signing this form. If you no longer wish to participate, you are free to withdraw at anytime without prejudice and without having to justify your decision. If necessary, you must notify one of the two principal researchers identified at the beginning of this form.

You will be advised of all new information likely to make you reconsider your participation in the study.

COMPENSATION IN THE CASE OF HARM

The University of Montréal is required by law to compensate for prejudices/ injuries which may have been caused by your taking part in this study.

CONFIDENTIALITY OF INFORMATION

All the data and information concerning subjects will remain STRICTLY CONFIDENTIAL and will be saved in individual files identified by a rank number corresponding to the first test taken by all the subjects (from 1 to 30 in the order of inclusion), and subjects real identification will be kept in a separate file kept in another secure place accessible to the researchers only. Individual files will be stored for 7 years after the study to be destroyed thereafter.

The results can be obtained only from the principal researchers or the associated researchers, who are Suzan Kuisis, doctoral student responsible for the project (University of Pretoria, South Africa) and Luc Leger, professor responsible for supervising the project (University of Montreal). Authorized representatives of the 'research institutions, government agencies or ethics committees can possibly ask to examine the personal data for ethical review or follow-up. The original data will be preserved in South Africa but the principal researcher also preserves an electronic copy of the captured data.

QUESTIONS ON THE STUDY (INFORMATION & EMERGENCY)

If you have any questions regarding the study, please communicate with the researchers:

Suzan KUISIS	suzan.kuisis@up.ac.za	Tel: +1 (514)343 6111 Extension 3125
Luc LEGER	luc.leger@umontreal.ca	Tel: +1 (514)343 7792

ETHICS

If you have any ethical problems or concerning the conditions of your participation this study, you can discuss it with the person responsible for the project, or explain your concerns to the president of the Ethical Council of Health Science Research, Marie-France Daniel, telephone (514) 343-5624.

After following this procedure, if you had serious reasons to believe that the answer brought is insufficient, you could enter into communication with the officials of the University, Mrs Marie-José Rivest (telephone (514) 343-2100).

SIGNATURES

TITLE OF STUDY:

COMPARATIVE VALIDITY OF THREE ICE SKATING TESTS TO EVALUATE THE AEROBIC APTITUDE OF ADULT HOCKEY PLAYERS

MAIN RESEARCHER OR RESEARCHER RESPONSIBLE FOR THE STUDY :

(name in well formed letters):

.....

I, (name of the participant in well-formed letters)
declare that I acquainted myself with the attached documents of which I received a copy,
that I discussed it with (name of the investigator in well-formed letters)
and that I understand the aim, nature, advantages, risks and disadvantages of the study in
question.

After some thought and a reasonable period of time, I freely consent to take part in this
study. I know that I can withdraw at any time without any prejudice.

Signature of the participant Date

Signature of the parent if you are under 18 years of age

_____ Date _____

I, (name of the investigator in well-formed letters)
declare that I explained the aim, nature, advantages, risks and disadvantages of the study
to (name of participant in well-formed letters)

Signature of the investigator Date

APPENDIX H

Order of Testing

Order of Testing					
Subject no.	Treadmill	Skating 20 MST	SMAT	FAST	Running 20 MST
1	1	2		3	
2	1	2			
3	1	2			
5	1	4	3	2	5
6	1	3	4	2	5
7	3	2	5	1	4
8	3	1	2	4	5
9				1	
10	3	1	5	2	4
11	2		1	3	4
12		1	2	3	
13	4	3	1	2	5
14	4	2	1	3	5
15	4	1	3	2	5
16	4	2	1	3	5
17	5	2	1	3	4
19	3	2	1	4	
20		1			
21	4	3	1	2	5
22	4	1	2	3	5
23	4	1	3	2	5
24	4	2	1	3	5
25	4	3	1	2	5
26	4	1	3	2	5
27	2		1	3	
28		3	2	1	
29	1	3	4	2	

APPENDIX I

Raw Data Collection Sheet

Subject information					
Subject Name & Surname					
Date of birth					
Age (yrs)					
Position					
Right/ left shoot					
Years of hockey experience					
Level of best play & age					
Height (cm)					
Weight (kg)					
Date of Test					
Borg RPE (6-20)					
Likert Scale (1-7)	Q1	Q2	Q3	Q4	Q5
Treadmill					
Kuisis					
Leone					
FAST					
Runnng 20 MST					
La (mmol L ⁻¹ ; 5 min post test)					
Heart rate data					
Order of testing →					
	Treadmill	Kuisis	Leone	FAST	Running 20 MST
Stage 1					
Stage 2					
Stage 3					
Stage 4					
Stage 5					
Stage 6					
Stage 7					
Stage 8					
Stage 9					
Stage 10					
Stage 11					
Stage 12					
Stage 13					
Stage 14					
Stage 15					
Stage 16					
Stage 17					
Stage 18					
Stage 19					
Stage 20					
Final speed (km h ⁻¹)					
VO ₂ max (ml kg ⁻¹ min ⁻¹)					
Test duration					
Temperature (°C)					
Humidity (%)					
Barometric pressure (mmHg)					

APPENDIX J

Borg Rating of Perceived Exertion Scale

Borg Scale

Rating of Perceived Exertion


6	
7	Very, very light/ Très, très facile
8	
9	Very light/ Très facile
10	
11	Fairly light/ Assez facile
12	
13	Somewhat hard/ Assez difficile
14	
15	Hard/ Difficile
16	
17	Very hard/ Très difficile
18	
19	Very, very hard/ Très, très difficile
20	

APPENDIX K


Likert Scale

Likert scale

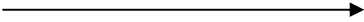
Q1 Similarity of basic skating skills (not puck handling) of test compared to those of a hockey game

LOW  **HIGH**
1 2 3 4 5 6 7


Q2 Resemblance between the maximal intensity of the test & maximal intensity of a hockey game

LOW  **HIGH**
1 2 3 4 5 6 7


Q3 How is the test suited to evaluate aerobic fitness of hockey players

LOW  **HIGH**
1 2 3 4 5 6 7

Q4 How is the test suited to evaluate overall fitness (including muscular and cardiovascular fitness) of hockey players

LOW  **HIGH**
1 2 3 4 5 6 7

Q5 How is the test suited to evaluate overall hockey ability (fitness and technical (skating) skills) of hockey players

LOW  **HIGH**
1 2 3 4 5 6 7

1 **Validity of 3 ice skating aerobic field tests for hockey players.**

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1 **Abstract**

2 Three aerobic maximal multistage ice skating tests have recently been introduced: 1)
3 MS20MST, a continuous 20 m stop-and-go; 2) SMAT, an intermittent 45 m stop-and-go;
4 and 3) FAST, a continuous 48.8 m shuttle with wide turns. In a paired design, the aim
5 was to compare MS20MST, SMAT, and FAST to each other and to treadmill VO_2 max
6 and to the 20 m gym aerobic shuttle run (20 MST) in order to assess the relative validity
7 of these tests to predict maximal aerobic power (VO_2 max), to determine which test is best
8 suited to do so and best rated by subjects, and to determine if these on-ice skating tests
9 are any better than the over-ground 20 MST in 25 adult ice hockey players. Similitude
10 with the intensity of hockey game and suitability as an aerobic test for ice-hockey was
11 determined with a subjective 7-point Likert resemblance scale. FAST showed the lowest
12 ($p<0.05$) Borg RPE, maximal lactate, HRmax, and ratings on the Likert Scale. Compared
13 to treadmill VO_2 max, correlations were 0.74, 0.73, 0.41 and 0.84 for MS20MST, SMAT,
14 FAST and the 20 MST, respectively, and 0.75, 0.78, 0.53 and 0.94, respectively with
15 maximal treadmill speed. FAST is less valid than MS20MST and SMAT, and it's lower
16 HR max and LA max values do not support that test. Correlations between MS20MST,
17 SMAT and 20 MST were approximately 0.7 but lower between these tests and FAST
18 (approximately 0.4). MS20MST or SMAT protocols should be used if ice time is
19 available, alternatively the gym 20 MST.

20

21 **Keywords:** Aerobic power, Skating, Ice-hockey, Modified Skating 20 MST, SMAT,
22 FAST, test, validity, shuttle

1 **Introduction**

2 Maximal aerobic power is a key parameter for sport performance even for a highly
3 anaerobic and high-speed intermittent sport such as ice hockey (Montgomery, 2006).
4 VO₂max values are also specific to the muscles used and the type of activity used by
5 subjects in their training regimen (Léger *et al.*, 1980, Mc Ardle *et al.*, 1978), and
6 demonstrated that as compared to runners, ice-hockey players had a 15% greater
7 mechanical efficiency while skating on the ice and a 7.9% lower mechanical efficiency
8 on the treadmill (Léger, Seliger & Bassard, 1979). Sport specific tests are thus highly
9 valued and have been applied in many sports such as endurance running (Léger &
10 Boucher, 1980), intermittent running sports such as soccer and basketball (Léger *et al.*,
11 1988), cross-country skiing (Doyon *et al.*, 2001; Vergès *et al.*, 2006), badminton (Chin *et*
12 *al.*, 1995), cycling (Ricci & Léger, 1983; Marion & Léger, 1988), swimming (Lavoie *et*
13 *al.*, 1985; Monpetit *et al.*, 1981), water polo (Rechichi *et al.*, 2000), and soccer (Nicholas,
14 Nuttall & Williams, 2000; Labsy *et al.*, 2004).

15 In an attempt to make laboratory testing more specific to ice-hockey, Montgomery's
16 group from McGill University in Montreal (Nobles *et al.* 2003) developed a skating
17 treadmill protocol. The skating treadmill is more “skating specific” than running or
18 cycling, because it mimics the skating movement and solicits same muscle groups; it is
19 also easier to control the speed and distance on a skating treadmill (vs. ice field tests).
20 However the skating treadmill has many disadvantages (grade skating alters the
21 mechanics of skating and increases resistance, low accessibility, high cost, individual
22 testing and non-competitive environment, lack of wind resistance, and higher
23 temperature).

1 Recently three new skating tests to assess aerobic fitness have emerged, namely the
2 Skating Multistage Aerobic Test (SMAT, Leone *et al.*, 2007), the Modified Skating 20
3 MST (MS20MST, Kuisis, 2003), and the Faught Aerobic Skating Test (FAST, Petrella *et*
4 *al.*, 2007). The validity of these three ice-skating field tests is, however, not always
5 obvious since the reported statistical indices (r and SEE) are quite different, probably
6 because they were obtained for different age and gender groups, sometimes with small
7 groups of subjects, wearing different equipment, and using different types of protocols.
8 Among the newly introduced tests, required skating ability and skills are different.
9 Direction changes in the MS20MST and SMAT rely on stop-and-go while FAST requires
10 a wide turn and cross-over skating. Thus with a paired design, the aim of the study was to
11 compare MS20MST, SMAT, and FAST to each other and to a treadmill VO₂max
12 criterion in order to determine the best aerobic skating test; to determine which test is
13 rated by the players as being the best suited and most functional test, and finally to
14 compare each test to the 20 MST (Léger *et al.*, 1988) to determine if these on ice skating
15 tests are any better than the over-ground 20 MST that does not require costly ice time.

16

17

18 **Materials and methods**

19

20 *Subjects and experimental protocols*

21 Adult male ice-hockey players (n=26) of various fitness and ice-hockey levels gave their
22 informed consent to participate in the study approved by the ethics committee of the
23 university approximately six weeks before the start of the ice-hockey competitive season.

1 Only 16 subjects were able to free themselves to complete all five tests (Table 1). All
2 testing facilities, Human Performance Laboratory, Indoor track and Ice arena (55 m x 26
3 m), were located in the university fitness center (CEPSUM, University of Montreal).
4 Subjects performed five maximal multistage aerobic tests on separate days, and were not
5 permitted to participate in more than one test per day on any two consecutive days, where
6 after a minimum period of 24 hours rest was required before the next test. All five tests
7 were however completed within three weeks. Due to the fact that there were up to four
8 subjects participating in the field tests at the same time, test order could not be totally
9 randomized. However, test order was mixed as much as possible to avoid any systematic
10 ordering of the tests. All ice-tests were done on resurfaced ice. Field tests are detailed in
11 Table 2.

12

13 Warm-up before running tests (treadmill and 20 MST) consisted of four to five minutes
14 low intensity jogging (6-8 km h⁻¹), followed by five minutes of stretching. Upon
15 completing the running tests, subjects recovered actively for four to five minutes by
16 walking. Warm-up procedures for all ice protocols (MS20MST, SMAT and FAST)
17 consisted of five minutes of submaximal skating around the outer perimeter of the ice
18 (alternating direction), followed by a few easy stop and go drills, for the MS20MST and
19 SMAT. Finally four to five minutes of stretching was performed. Upon completing the
20 skating tests, subjects recovered actively for four to five minutes by skating slowly and
21 gliding around the ice. Before any of the field tests were begun, the compact disc of the
22 specific test was played, consisting of a brief explanation of the test, leading to a

1 countdown of the start. Set-up, procedures, and termination criteria were used as
2 specified by the respective authors.

3

4 *Dependent variables and methods*

5

6 *Heart rate (HR)*

7 HR was continuously measured with a Polar pulse monitor (Polar Electro, Kempele,
8 Finland). Submaximal HR values were recorded at 15 s intervals. Maximal HR value was
9 recorded at the end of each test as an indication of the overall difficulty or intensity of
10 each test.

11

12 *Blood lactate*

13 A Lactate Pro (Arkray, Inc, Kyoto, Japan) was used to assess finger prick (capillary)
14 lactate between five and eight minutes of recovery. Blood lactate was considered another
15 indication of the overall intensity of the tests, indicating the gross anaerobic contribution
16 of the test.

17

18 *Borg Rate of Perceived Exertion Scale (RPE)*

19 The Borg Rated Perceived Exertion (RPE) (Borg, 1970) was subjectively established on a
20 6 to 20 point scale for every test upon termination of the test to determine the final
21 perceived intensity of the tests.

22

23 *Likert Resemblance Scale*

1 A resemblance score was obtained on a subjective seven point Likert (1932) scale (one
2 being the lowest possible score and seven being the highest possible score, for all
3 questions, the higher the score, the better the result, indicating, for example, greater
4 similarity between the test and an ice-hockey game or greater suitability of the tests to
5 assess aerobic fitness in adult ice-hockey players); after the completion of each test. Each
6 of the tests performed by the subjects was evaluated at five levels:

- 7 1. the similarity of the technical skating skills (excluding stick/puck handling) of the
8 test with those of the hockey game,
- 9 2. the resemblance between the maximal intensity of the test and maximal intensity
10 of the hockey game,
- 11 3. how the test is suited to evaluate aerobic fitness of the hockey players,
- 12 4. how the test is suited to evaluate overall fitness (including cardiovascular and
13 muscular fatigue) of the hockey players, and
- 14 5. how the test is suited to evaluate overall hockey ability (fitness and technical
15 skating skills) of the hockey players

16

17 VO_2 max

18 VO_2 was measured every 30 s with the open circuit method (Moxus Modular VO_2
19 system, AEI Technologies, Pittsburgh, Etats-Unis) during the laboratory treadmill
20 running test. The VO_2 system was calibrated with standard reference gases and for
21 volume approximately five minutes prior to each treadmill test. VO_2 values were
22 recorded every 30 s. This protocol was a continuous multistage test with initial speed set
23 at $10 \text{ km}\cdot\text{h}^{-1}$ with 1 km h^{-1} increment per stage (two minutes) thereafter. The subject ran

1 until volitional exhaustion, and the highest VO_2 achieved (VO_2 peak) was considered
2 VO_{2max} . VO_{2max} values for field tests were also estimated using original regression
3 equation (Table 2)

4

5 *Statistical analysis*

6 Statistical analyses were performed using Statistica software (6th Edition,
7 www.statsoft.com). Descriptive statistics (mean \pm SD) were conducted for all variables.
8 Multiple regression analysis was employed to construct an equation to predict VO_{2max}
9 from the MS20MST using direct VO_{2max} from the treadmill test as the dependant
10 variable and maximal MS20MST speed, height and weight, as the independent variables.
11 Comparisons of maximal values of different variables (VO_{2max} , HR_{max} , Speed max,
12 Lactate_{max}, test duration, Borg RPE max, and Likert scores) were done with a repeated
13 one-way ANOVA to assess similarity in physiological difficulty of each test on the 16
14 subjects that completed all the tests. A posteriori test (Tukey) was used to determine
15 exactly where the differences existed. Pearson correlation coefficients were also
16 estimated for each variable in every test. Regression analysis (scatter plot, Pearson
17 correlation and SEE) were applied between direct treadmill VO_{2max} and maximal speed
18 for each of the four tests to establish predictive model, to determine the external validity
19 and to compare validity of each field test in a pairwise design (n=16 to 23).
20 Another purpose was to establish pairwise equivalence between field tests. Since
21 conventional regression analysis assumes that one variable is independent and the other,
22 dependent, which is not the case when you compare two different field tests and, since,
23 two non algebraically equivalent regressions are obtained depending on the subjective

1 choice of the dependent variable, another approach was taken which would yield a
2 bisectrix regression in the middle of the two others (Andersen et al., 1986). It is like
3 considering perpendicular least squares to the regression line, instead of vertical ones. To
4 get that regression, the slope b of the conventional regression has to be divided by the r
5 value (new slope $b = \text{conventional slope} / r$) and to obtain the new intercept a , the
6 average values of X and Y , have to be entered in the equation ($Y = a + b X$) using new
7 slope b . SEE was obtained using predicted value of that non conventional regression
8 model: $SEE = \sqrt{((\sum(Y_{\text{observed}} - Y_{\text{predicted}})^2)/(n-2))}$.

9

10 **Results**

11 **VO₂max prediction from MS20MST.**

12 Among potential and pertinent predictors of VO₂max such as MS20MST maximal speed,
13 weight and height, only the MS20MST maximal speed (X , km h⁻¹) was retained by the
14 stepwise multiple regression as a significant predictor of VO₂max (Y , ml kg min⁻¹):

$$15 \quad Y = -33.337 + 6.24 X, \quad r = 0.74, \quad SEE = 5.93 \text{ (11.2\%)}, \quad n = 21 \quad \text{EQ-1}$$

16

17 **ANOVA comparisons between tests for each variable.**

18 Anova and a posteriori Tukey tests revealed significant differences between tests (Figures
19 1 and 2). Maximal speed was progressively higher from the MS20MST, SMAT and
20 FAST (13.7, 17.9, 20.3 km h⁻¹, $p < 0.01$). Concerning duration of on-ice skating tests, it
21 increased from MS20MST, to FAST, and to SMAT (5.62, 8.03 and 11.73 min, $p < 0.01$).
22 Maximal HR was higher during the treadmill test than during FAST (189.9 and 183.4
23 bpm, $p \leq 0.01$) and also higher during SMAT than FAST (189.1 and 175.8, $p \leq 0.05$). No

1 other maximal HR difference was observed. Using the 6 to 20 RPE Borg scale, FAST
2 was also subjectively perceived to be less difficult than any of the other four tests (15.1
3 vs. 16.9 and above, $p \leq 0.05$). With regards to maximal lactate, SMAT was higher than
4 treadmill, FAST and 20 MST lactate (12.0, 9.3, 10.2 mM respectively, $p \leq 0.001$) and
5 MS20MST lactate higher than FAST lactate (11.33 and 9.19 mM, $p \leq 0.05$).

6

7 The predicted 20 MST VO_2 max was significantly lower than the other tests except for the
8 SMAT (48.4 vs. 51.8 to 54.0 ml $kg^{-1} min^{-1}$, $p < 0.05$, Figure 1).

9

10 Subjective ratings among the five tests are shown in Figure 2. When subjects rated the
11 similarity of the skating skills (Q1) required by the test as compared to those required
12 during a hockey game (excluding puck handling), both running tests yielded lower
13 ratings than the three ice skating tests. And within the 3 ice skating tests, FAST scores
14 were lower than MS20MST scores. MS20MST and SMAT are the best tests to mimic
15 skating skill.

16

17 With regard to the similarity of the intensity of the tests to the game of ice-hockey (Q2),
18 MS20MST and SMAT are again the best with treadmill and FAST as the worst and
19 20MST in the middle ($p < 0.05$).

20

21 When tests were rated according to their suitability to evaluate aerobic fitness (Q3), and
22 with regard to the suitability to evaluate overall fitness (Q4), FAST is trailing again with
23 the lowest score while only being significantly lower than SMAT.

1 Lastly, with regard to suitability of the test to evaluate overall hockey ability (fitness and
2 skating skills), treadmill and 20MST yield lower scores than the three skating tests while
3 the skating tests were not significantly different from each other

4

5

6 **Correlation and standard error of the estimate between each field test and the**
7 **treadmill criterion test.**

8 Results of criterion treadmill test could be expressed in VO_{2max} units ($ml\ kg^{-1}\ min^{-1}$) or
9 maximal speed units ($km\ h^{-1}$). In general, correlations between maximal speed attained in
10 field tests with criterion treadmill test are slightly better when results of the treadmill test
11 are in speed units (Table 3). For example, for the 20MST, correlation was 0.84 with
12 VO_{2max} units and 0.94 with speed units. That being said, ranking the tests according to
13 their correlation yielded the same pattern whether VO_{2max} or maximal speed units are
14 used. Using VO_{2max} units for example, we can see that FAST test is much less
15 correlated with the treadmill test ($r=0.41$ with a SEE of $7.53\ ml\ O_2\ kg^{-1}\ min^{-1}$ or 14.7% of
16 treadmill VO_{2max} mean) than the two other skating tests, MS20MST and SMAT ($r=0.74$
17 and 0.73 with SEE= 5.93 and $5.65\ ml\ kg^{-1}\ min^{-1}$ or 11.2 and 11 %, respectively). With an
18 r value of 0.84 and SEE of $4.69\ ml\ kg^{-1}\ min^{-1}$ or 9.02%, the running gym test, 20MST, is
19 the best field test, assuming treadmill VO_{2max} is a proper criterion. Finally, the maximal
20 speed attained on the treadmill compared to VO_{2max} obtained during the same test
21 yielded a correlation of 0.84 with a SEE of $4.72\ ml\ kg^{-1}\ min^{-1}$ or 8.95%. These r and SEE
22 values were obtained using the maximum number of subjects for each comparison ($n=17$

1 to 23) but almost the same r and SEE values were obtained using only data from the same
2 16 subjects that did all the tests.

3

4 Scatterplots of the treadmill test as a function of each one of the three ice skating tests
5 clearly demonstrates that to achieve the same aerobic fitness level on the treadmill, one
6 has to skate at high speed in the FAST, medium speed in the SMAT and low speed in the
7 MS20MST. (Figure 3).

8

9 **Inter-correlations between field tests.**

10

11 Table 4 reports correlations and SEE values between maximal speeds attained in each of
12 the four field tests. Only two ice skating tests, MS20MST and SMAT, compare well to
13 each other ($r=0.84$ and $SEE=0.50$ or 0.58 km h^{-1} depending on which test is considered as
14 the dependent variable). The FAST is much less related to the two other ice skating tests
15 ($r=0.58$ or 0.61 for MS20MST and SMAT respectively with SEE up to 1.89 km h^{-1} or
16 9.25%). Even the 20MST, a running gym test, is better correlated to the two other ice
17 skating tests ($r=0.83$ and 0.87 for MS20MST and SMAT, respectively. with SEE less
18 than 0.73 km h^{-1} or 5.83%). Equivalence regression coefficients are given in Table 4.

1 **Discussion**

2 **Random error of field tests.**

3 One purpose of this study was to establish a regression for the adaptation of 20MST, a
4 gym shuttle run test, for an on-ice application, the MS20MST. EQ-1 indicates good
5 accuracy ($r=0.74$ and $SEE=5.93 \text{ ml kg}^{-1} \text{ min}^{-1}$ or 11.2%). This is slightly lower accuracy
6 than the one obtained between treadmill $VO_{2\text{max}}$ and maximal speed attained during the
7 same treadmill test ($r=0.838$, $SEE =4.72 \text{ ml kg}^{-1} \text{ min}^{-1}$ or 8.95%). Treadmill $VO_{2\text{max}}$ was
8 considered the criterion test because of its universal use and because similar VO_2 are
9 obtained on the treadmill and on the ice (Leger *et al.*, 1980). There are however some
10 specific adaptations that may explain such a lower correlation. Measurement of $VO_{2\text{max}}$
11 on ice may have been a better choice to validate skating tests at least to know which
12 skating test elicits the highest $VO_{2\text{max}}$ values using portable equipment. Ice skating is
13 much more skill oriented than running and that may also explain lower correlation. To
14 improve accuracy, we plan to investigate some easily measurable biomechanical indices
15 such as the limb frequency at a set speed as was done for swimming (Lavoie *et al.*, 1985).
16 On the other hand, although entered in the regression model we used, weight and height
17 of the subjects were not retained as significant predictors. On the other hand, age and
18 gender were not even considered as potential co-predictors because we feel this is
19 inappropriate since, even though general accuracy may increase, it introduces systematic
20 bias. Taking gender and age as co-predictors will just ensure that the average difference
21 in gender or average age effect is automatically applied leading to systematic
22 underestimation of females that really have same $VO_{2\text{max}}$ than males. In a direct test,
23 male and female terminating at the same stage generally have the same $VO_{2\text{max}}$

1 notwithstanding small differences in mechanical efficiency or measurement errors. With
2 regard to measurement errors, these are more frequent than we think with automated
3 metabolic systems (Babineau *et al.*, 1999) and that is confirmed by the better correlations
4 obtained between maximal treadmill speed (instead of VO_{2max}) vs. maximal speed
5 achieved in other field tests (Table 3).

6
7 Compared to MS20MST, SMAT has similar accuracy (vs. treadmill VO_{2max} , $r=0.73$ and
8 $SEE=11\%$) while FAST has much lower one ($r=0.41$ and $SEE=14.7\%$). This is a bit
9 lower than correlations reported for SMAT in younger 14.7 year old subjects ($r= 0.83$,
10 $SEE=7.0\%$, Leone *et al.*, 2007) and for FAST in 17-19 juniors players ($r=0.67$, Faught *et*
11 *al.*, 2003) and in a large sample ($n=532$) of mixed age male and female players (9-22 year
12 old, $r=0.71$ and $SEE=12.9\%$, Petrella *et al.*, 2007). In the latter study however, r is higher
13 because other predictors were included in the regression (weight, height and gender) and
14 because of a wide range of data while SEE , less sensitive to that, is similar to the one
15 found in our study. With the same data, correlations for each age subgroup vary between
16 0.42 to 0.63; also, for 179 male players aged 19 and above, r was 0.42, very similar to the
17 one obtained in our study. The FAST may thus be less valid because, instructions on how
18 to negotiate the change of direction at each end of the course are not standardized enough
19 and also because, the terminal point is less reliable in a test where the speed increases
20 exponentially with time (as apposed to a linear increase) and a small difference in
21 motivation could make a large difference in the final results of FAST and negatively
22 affects the correlation with treadmill VO_{2max} .

23

1 Equivalence between field tests

2 In our study, FAST was also not well correlated to the other field tests ($r < 0.67$, table 4).

3 Even the gym shuttle run 20MST is better correlated to the two other field tests ($r < 0.83$,

4 Table 4) and to treadmill VO_{2max} ($r = 0.84$, Table 3), confirming its validity. In other

5 words, to be ice skating specific either the MS20MST or SMAT could be used but the

6 20MST is a good alternative, particularly in developing athletes with whom the ice time

7 is often limited. It is not excluded that another version of the FAST with stage of constant

8 speed increment and constant stage duration would be more accurate.

9

10 Systematic differences between tests.

11 The MS20MST had the lowest maximal skating speed among the skating tests (Figure 3),

12 and even if it correlated well with the treadmill speed, it may be questionable. Although

13 the MS20MST is specific for ice-hockey with its frequent stop and go over a shorter

14 distance than SMAT, it causes rapid muscular fatigue and limits subjects from attaining

15 higher maximal speed. But as long as that speed is well correlated to VO_{2max} , the final

16 speed is a good indicator of skating aerobic fitness although it does not correspond to

17 speed where VO_{2max} is attained in steady state condition, the so called Maximal Aerobic

18 Speed (MAS). Thus, with regards to maximal speed, the SMAT allows higher maximal

19 speed, while maintaining a ice-hockey specific nature. When comparing the MS20MST

20 to the SMAT, they have a similar speed increment per min, but the SMAT has a 30 s rest

21 period after each one minute stage, and has a longer course (45 m as apposed to 20 m in

22 the MS20MST), requiring a lower frequency in direction changes and acceleration

23 phases. Thus to reach the same speed in the SMAT is easier and for the same VO_{2max} ,

1 subjects reach higher speed in the SMAT. On the other hand, the FAST has no rest
2 between stages, and has not stop-and-go pattern (the FAST is continuous and
3 curvilinear), and the stages of the FAST become shorter and shorter meaning that the
4 speed is increasing faster and faster (after every third length of the ice). In the FAST,
5 subjects obtained much higher final skating speeds, as the course is continuous and
6 curvilinear (without stop-and-go) and allows subjects to build up and maintain high
7 skating speeds. In other words, as the test progresses the subjects have to maintain new
8 speed for less time which enables them to reach higher speeds. So even if that was
9 expected, it needed to be statistically confirmed and quantified which it has been done.
10 This indicates that maximal speeds achieved in each of these three skating tests are
11 different and each test imposes different stimuli and demands different skills from the
12 subjects. Furthermore, since these maximal speeds are linked to the nature of the
13 protocol, they do not reflect the difficulty of the test as they do not vary as lactate or RPE
14 do between tests.

15

16 The duration of the treadmill test is the longest, probably because the treadmill protocol
17 has the longest stage duration (2-min). With 2-min stages and 1 km h^{-1} increment per
18 stage, steady state is attained at the end of each stage (Leger *et al.*, 1998), a condition
19 essential to obtain an unbiased measure of VO_2 requirement and the so called MAS.
20 Although total SMAT duration is similar to treadmill one, this is due to introduction of a
21 30-s rest between stage and with 1-min stage added to a recovery rest, stage are not long
22 enough to reach steady state. Similar problems affect all the field tests of this study but as
23 long as we are solely interested in the prediction of $\text{VO}_{2\text{max}}$, the final speeds of these

1 field tests except FAST, appear to be good predictors. Coming back to total test duration,
2 it is clear that MS20MST is the test with the shortest duration, making it the most time
3 efficient. Thus, when ice-time is limited and expensive, it is still possible to administer an
4 on-ice test, if it is time efficient, and for this purpose, the MS20MST would be the best.

5

6 In our study, only the FAST maximal heart rate was significantly lower than the treadmill
7 one, while the two other skating tests also show a trend toward that. Others observed
8 larger differences. Hence, Léger, Seliger & Bassard (1979) demonstrated lower maximal
9 heart rates on-ice for both hockey players and runners ($10 \text{ beats min}^{-1}$), compared to the
10 treadmill test. Vergès, Flore & Favre-Juvin (2003) also found a significant difference in
11 heart rate during laboratory treadmill running ($195.3 \pm 6.8 \text{ beats min}^{-1}$) and field roller
12 skiing ($190.4 \pm 5.6 \text{ beats min}^{-1}$). It is possible that the larger active muscle mass while
13 running versus skating explains these heart rate differences. On the other hand, Petrella
14 (2006) found similar maximum HR during the FAST and treadmill test ($190 \text{ beats min}^{-1}$
15 in both tests). We cannot explain these differences.

16

17 The MS20MST and the SMAT yielded the highest lactate values and FAST the lowest
18 ones, indicating a higher anaerobic contribution in both the MS20MST and the SMAT, as
19 compared to the FAST and the running tests. This may indicate that the MS20MST and
20 the SMAT are more hockey specific than the other tests.

21

22 The perception of less physiological strain in the FAST (Figure 1) may be due to the fact
23 that the FAST is curvilinear in nature (less muscular fatigue as it is continuous with no

1 stop-and-go), and allows subjects to build up speed gradually, and maintain that speed,
2 before the skating speed becomes very fast, and subjects have to stop suddenly without
3 having to sustain fatigue for a long time. It seems that the MS20MST and SMAT have
4 similar perceived intensity despite longer test duration in SMAT. The skating tests are
5 perceived to be easier, but physiologically, they are as taxing as the running tests. This
6 perception may be due to the fact that ice-hockey players are more comfortable in and
7 familiar with their training environment that with running, demonstrating the need for on-
8 ice aerobic tests.

9

10 **Predicted** VO_2 max using original equation developed for SMAT and FAST yields
11 similar values to the treadmill VO_2 max confirming the external validity of these two
12 skating tests in terms of systematic errors. But as discussed before, FAST has much
13 larger random errors than the two other skating tests.

14

15

16 Specificity of testing and practical aspects.

17 Testing players in their training environment more accurately reflects the muscular and
18 metabolic demands of the sport, as well as specific adaptations from training (Daub,
19 1983). Due to the differences in efficiency between running and skating (Léger, Seliger
20 & Brassard, 1979), it is preferable to test ice-hockey players on-ice. In 1976 Simard
21 demonstrated that the best skaters had lower VO_2 max in the laboratory, showing that they
22 were much more efficient on the ice and demonstrating that laboratory testing can yield
23 inaccurate results. The availability of the three new skating field tests of aerobic fitness

1 provides the coach and sport scientist with the option of more specific on-ice field tests
2 that are sometimes more time efficient.
3
4 Cycle ergometry, treadmill running and treadmill skating offer some variation of
5 metabolically demanding exercise, but do not allow the participant to perform the same
6 mechanics of skating on-ice (Petrella, 2007; Leone *et al.*, 2007 In an attempt to make the
7 measurement of VO₂max more sport specific for ice-hockey, Dreger & Quinney (1999)
8 used a skating treadmill protocol. However, the high cost of such a piece of equipment
9 and its availability may make it unsuitable. The MS20MST and the SMAT are very
10 similar with regard to physiological demand (VO₂, HR, and lactate), RPE, and subjective
11 suitability ratings (Likert scale), in which the skating tests consistently scored higher with
12 regards to similarity to the game of ice-hockey, as well as suitability to assess aerobic and
13 overall fitness in ice-hockey players. This clearly demonstrates the need for on-ice
14 skating tests for the assessment of aerobic fitness in ice-hockey. Furthermore, these new
15 tests allow testing many players simultaneously. In fact Petrella (2006) states that the
16 FAST can comfortably test up to eight ice-hockey players simultaneously, and that a full
17 roster hockey team can be completely evaluated within a typical one hour practice
18 session. When using the SMAT, between 10 and 15 players can be tested on-ice at the
19 same time, depending on their body size (Leone, Léger & Comtios, 2006); the same
20 applies for the MS20MST. These tests also require less time than laboratory treadmill
21 testing, less equipment, and are less expensive, as they can be easily administered during
22 a training session, wearing either complete (SMAT and MS20MST) or partial ice-hockey
23 equipment (FAST)

1 **Conclusion**

2 The main purpose of this study was to assess and compare validity and specificity of
3 three aerobic skating tests. For almost all measured variables, FAST has the lowest scores
4 (correlation with treadmill VO_2 max, correlations with the two other skating tests (even
5 lower than the 20MST running test), maximal lactate, maximal heart rate, rated perceived
6 exertion and Likert resemblance scores with the hockey game requirements). On the
7 other hand, SMAT and MS20MST revealed similar and much better results as ice hockey
8 specific tests and are to be preferred to the FAST.

9

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18

1 **Tables and Figures**

2

3

4

Table 1: Subject Characteristics of the Sample Used (n=16)

	Age (yrs)	Years of hockey (yrs)	Height (cm)	Weight in lab (kg)*	Weight with full kit (kg)**	FAST weight (kg)***	Treadmill VO₂max (ml kg⁻¹ min⁻¹)
Mean	32.1	22.0	176.7	78.7	88.6	73.0	51.8
SD	12.7	12.3	7.4	15.0	15.1	7.4	8.6
Minimum	20	3.0	165.0	56.7	67.0	64.0	37.2
Maximum	59	54.0	193.4	117.10	129.0	80.0	64.4

5

* measured in the laboratory on a calibrated balance scale on the day of treadmill testing

6

** measured in the ice-arena on a bathroom scale with subjects wearing full kit and holding hockey stick, on the day of MS20MST or

7

SMAT

8

*** measured in the ice-arena on a bathroom scale with subjects wearing a tracksuit, helmet, gloves and holding hockey stick

9

1

 2 **Table 2: Characteristics of the maximal multistage running & ice-skating field tests**
 3 **to be used in this study**

	20-m shuttle run (20 MST)¹	20-m shuttle skate (MS20MST)²	45-m shuttle skate (SMAT)³	48.8 m shuttle skate (FAST)⁴
Source	Léger <i>et al.</i> (1988)	Kuisis (2003)	Leone <i>et al.</i> (2007)	Petrella <i>et al.</i> (2007)
Displacement technique	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
Protocol Type	Max Multistage Continuous	Max Multistage Continuous	Max Multistage Intermittent	Max Multistage Continuous
Speed vs. Stage	Linear	Linear	Linear	Curvilinear
Stage duration	1 min	1 min	1 min	45 s → 19.5 s
Rest interval	0 s	0 s	30 s	0 s
Initial speed	8.5 km h ⁻¹	10.0 km h ⁻¹	12.6 km h ⁻¹	15 s (11.7 km h ⁻¹)
Speed increase	0.5 km h ⁻¹	~0.5 km h ⁻¹	0.72 km h ⁻¹	-5 s (0.4→2.0 km h ⁻¹)
Equipment	Running shoes	Full hockey kit (+ portable VO ₂ system ^{**})	Full hockey kit	Skates, stick, helmet, gloves

4 ^{**} In experimental phase of original study only5 ¹ VO₂max (ml kg⁻¹ min⁻¹) = -27.4 + 6.0 (running speed, km h⁻¹) (Leger *et al.* 1988)6 ² VO₂max (ml kg⁻¹ min⁻¹) = -33.337 + 6.24*Speed (in km h⁻¹). (This study, n=20)7 ³ VO₂max (ml kg⁻¹ min⁻¹) = 16.151(maximal skating velocity in skating velocity is in m s⁻¹)-29.375 (Leone *et al.* (2007)8 ⁴ VO₂max = {0.428(F-length)} - {0.348(weight in kg)} + {25.434(height in m)} - {11.09(gender, 1=male)} +27.196
9 (Petrella *et al.*, 2007)

- 1 Table 3. Correlations and standard errors of the estimate predicting treadmill VO_2max
- 2 and maximal speed from field test maximal speed.

Treadmill (Y)	n	Predicted variable	r	SEE ml kg⁻¹ min⁻¹ or km h⁻¹	SEE %
MS20MST (X)	21	VO₂max	0.74	5.93	11.2
		Max speed	0.75	1.23	8.07
SMAT (X)	20	VO₂max	0.73	5.65	11.0
		Max speed	0.79	1.16	7.73
FAST (X)	20	VO₂max	0.41	7.53	14.7
		Max speed	0.53	1.59	10.6
20MST (X)	17	VO₂max	0.84	4.69	9.02
		Max speed	0.94	0.70	4.59

3

- 1 Table 4. Equivalence between field tests using regression model without dependant and
 2 independent variables.

Independent variable (X)	Dependent variable (Y)	n	r	Y = a + b X*		SEE** km h ⁻¹	SEE %
				a	b		
SMAT	MS20MST	20	0.84	-1.863	0.866	0.50	3.68
MS20MST	SMAT			2.149	1.155		
20MST	MS20MST	16	0.83	3.172	0.837	0.62	4.49
MS20MST	20MST			-3.780	1.194		
20MST	SMAT	17	0.87	5.286	1.003	0.62	3.47
SMAT	20MST			-5.284	0.998		
FAST	20MST	17	0.67	0.944	0.573	0.99	7.87
20MST	FAST			-1.648	1.746		
FAST	MS20MST	19	0.58	4.056	0.472	0.89	6.51
MS20MST	FAST			-8.643	2.123		
FAST	SMAT	21	0.61	6.863	0.540	0.95	5.32
SMAT	FAST			-12.702	1.852		

- 3 * b of this regression model is obtained dividing b of conventional model by r; then a is
 4 obtained substituting average values of Y and X and new value of r in : Y = a + bX
 5 ** SEE = $\sqrt{((\sum(Y_{\text{observed}} - Y_{\text{predicted}})^2)/(n-2))}$ using predicted value with the new model.

1 Figure captions

2

3 Figure 1: Comparison of maximal values attained in investigated tests (n=16)

4

5 Figure 2: Comparison of resemblance scores with ice hockey for investigated tests on the
6 1 to 7 point Likert scale (1=no, 7= yes)

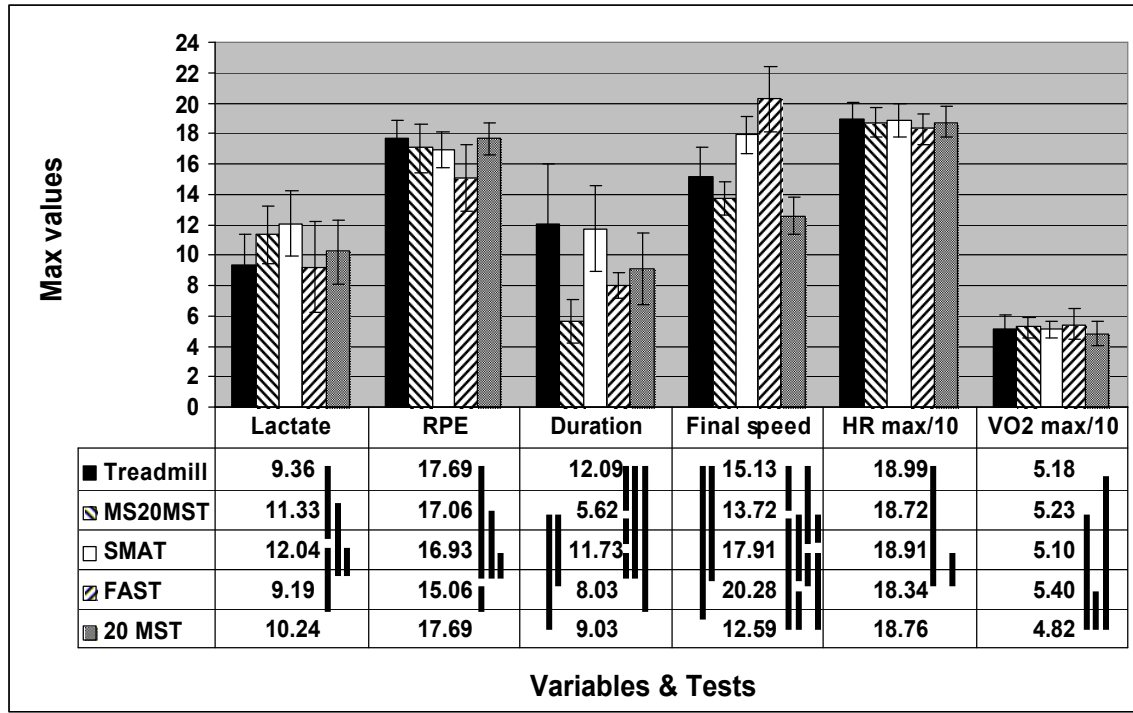
7

8 Figure 3. Scatterplots of maximal treadmill speed as a function of maximal speed of each
9 ice skating test

10

Figure 1: Comparison of maximal values attained in investigated tests (n=16)

4



5

6 Note 1: Lactate is in mmol L⁻¹, RPE is on a scale of 6-20, Duration is in min, Final speed is in km h⁻¹, HR
 7 is in beats min⁻¹, VO₂ max is in ml kg⁻¹ min⁻¹

8 Note 2: HR and VO₂ max are divided by 10 so they could be plotted on the same graph.

9 Note 3: Pairs of values joined by a vertical bar are different (p<0.05)

10

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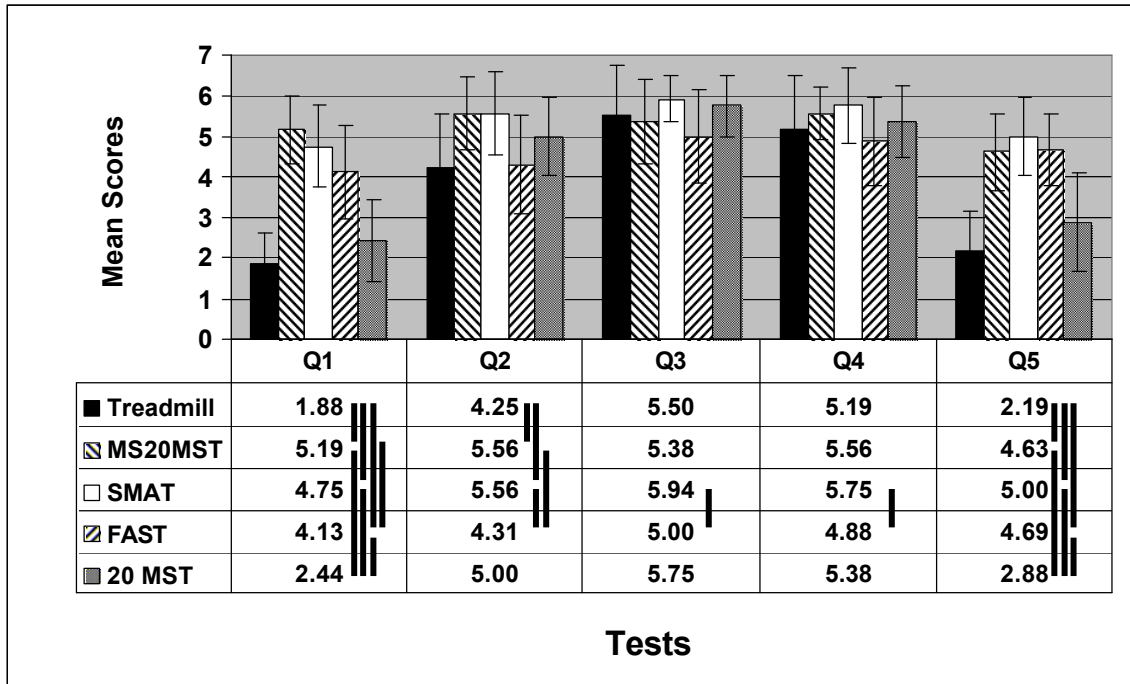
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1 **Figure 2: Comparison of resemblance scores with ice hockey for investigated tests**
 2 **on the 1 to 7 point Likert scale (1=no, 7= yes)**
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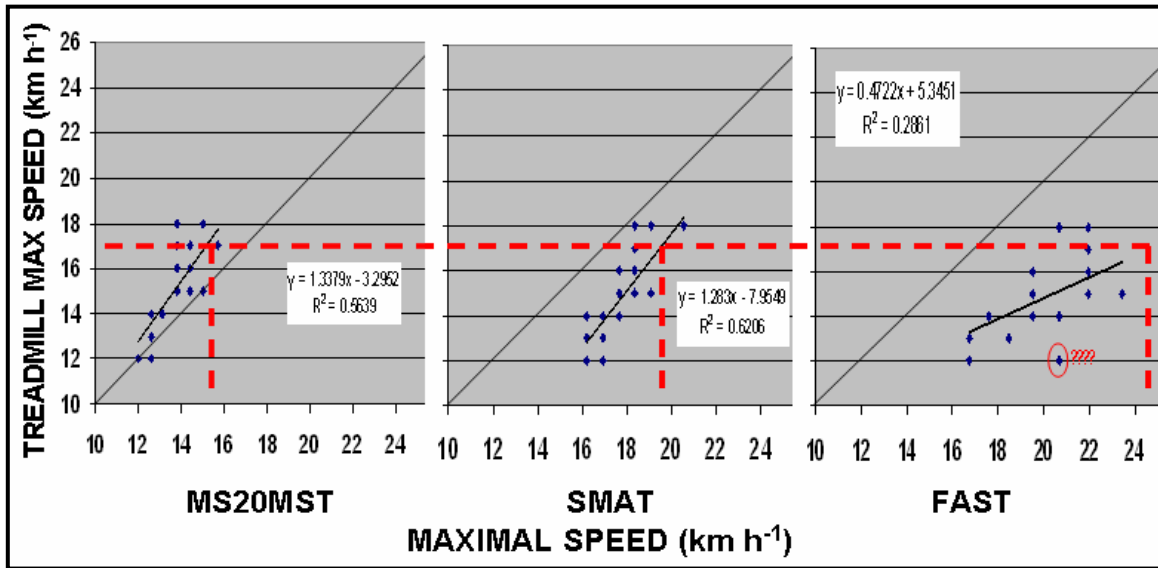
- 4
- 5 Q1 Similarity of basic skating skills (not puck handling) of the test compared to those of a hockey game
- 6 Q2 Resemblance between maximal intensity of the test & maximal intensity of a hockey game
- 7 Q3 How is the test suited to evaluate aerobic fitness of hockey players?
- 8 Q4 How is the test suited to evaluate overall fitness (including muscular & cardiovascular fitness) of
- 9 hockey players?
- 10 Q5 How is the test suited to evaluate overall hockey ability (fitness & skating skills) of hockey players?

11 Note: Pairs of values joined by a vertical bar are different ($p < 0.05$)

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- 1 **Figure 3. Scatterplots of maximal treadmill speed as a function of maximal speed of**
- 2 **each ice skating test**

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Validity of 3 ice skating aerobic field tests for hockey players.

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INTRODUCTION. Three multistage aerobic ice skating field tests have recently been introduced: 1) maximal continuous multistage stop and go 20-m shuttle skating test (Modified Skating 20 MST, MS20MST, Kuisis 2003), 2) maximal intermittent multistage 45-m ice skating shuttle test with stop and go (SMAT, Leone 2006), both using full ice hockey equipment; and 3) maximal continuous multistage 160ft (48.8m) ice skating shuttle test with wide turns wearing only gloves, hockey stick and helmet (FAST, Petrella 2006).

OBJECTIVES and METHODS. The relative validity of these 3 tests was assessed comparing maximal speed of these tests to VO₂max (Moxus) and maximal speed of a multistage treadmill test and the gym 20-m shuttle run test (Leger 1988) in 25 adult ice hockey players of various fitness levels but with good skating skills.

RESULTS. Expectedly, maximal speed increased from MS20MST to SMAT and to FAST protocols but the later shows lowest Borg RPE and max lactate and heart rate ($p < 0.05$, Repeated ANOVA and Tukey test). Similitude with the intensity of hockey game and suitability as an aerobic test for ice-hockey was also judged lowest by the subjects for the FAST test on a 7 points subjective scale. Compared to treadmill VO₂max, correlations were 0.74, 0.73, 0.41 and 0.84 for MS20MST, SMAT, FAST and the 20-m gym test, respectively. Correlations were slightly better with treadmill max speed (0.75, 0.78, 0.53 and 0.94, respectively) due to small but common accuracy problem of VO₂measure. Thus using treadmill test as a standard, the FAST is less valid than the 2 others skating protocols admitting that the ice skating protocol that elicits the highest VO₂max values would be a better standard. Nevertheless lower HR max and LA max values for the FAST do not support that test. Correlations between the MS20MST, SMAT and 20-m gym tests were around 0.84 but lower between these tests and FAST (around 0.63).

CONCLUSIONS. Based on these results, it is recommended to either use MS20MST or SMAT protocols in elite players if ice time is available or the 20-m gym test otherwise. Future study is needed to identify which test yields highest VO₂max values on ice.

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