MODIFICATION OF THE 20 METRE SHUTTLE RUN TEST (20 MST) FOR ICE-SPORTS

by

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SYNOPSIS

TITLE	**:** Modification of the 20 Metre Shuttle Run Test (20 MST) for ice-sports
CANDIDATE	**:** S.M. Kuisis
SUPERVISOR	**:** Dr. H.J. van Heerden
DEGREE	**:** M.A. (HMS)

The 20 Metre Multistage Shuttle Run Test (20 MST) was modified for application to ice-sports, more specifically for ice-hockey and figure-skating. Seventy two participants in ice-sports served as the total subject group. Subjects included in the study were National and Provincial standard male ice-hockey subjects (n=67) and female figure skaters (n=5) participating in the Gauteng area of South Africa (altitude of 1497 metres above sea level and barometric pressure of 655 mmHg). The mean age for the total group was 17.44±1.33 years.

The research methodology entailed a repeated measures design to determine:

a) velocity of motion on-ice vs. over-ground;
b) energy expenditure on-ice vs. over-ground; and
c) mechanical efficiency on-ice vs. over-ground.

The mean velocity of motion measured over three distances (0 to 20, 0 to 30 and 0 to 40 m) indicated a significantly ($p \leq 0.05$) faster velocity on-ice (5.99±0.72 m/s) versus over-ground (5.75±0.63 m/s). The corresponding mean time-lapsed on-ice/over-ground ratio was 0.97±0.11.

Differences in mean energy expenditure whilst performing the original 20 MST over-ground as opposed to on-ice were measured at low (at 4 minutes of exercise and 10 km/h), intermediate (after 8 minutes of exercise and 12 km/h), and high intensity (after 12 min of exercise and 14 km/h). The mean of the three indicated a significantly ($p \leq 0.05$) higher energy expenditure over-ground (14.04±4.86 kcal/min) as apposed to on-ice (10.51±2.95 kcal/min). The mean energy expenditure ratio for the three different intensities on-ice vs. over-ground was 0.74±0.21. Similarly, the mechanical efficiency index over-ground (4.92±0.59) was found to be significantly ($p \leq 0.001$) poorer than on-ice (6.83±1.49). The mean mechanical efficiency ratio over-ground/over-ice was 0.74±0.13.

Subsequently, based on the above results, the 20 MST was modified by:

a) adapting (increasing) the velocity of motion required for each level of the test (distance of 20 m per shuttle); and
b) establishing the reliability and validity of the modified 20 MST for use on-ice.

The adapted *20 Metre Multistage Shuttle Skating Test* (the modified (skating) 20 MST) started at a velocity of 2.8 m/s (10.1 km/h) and permitted 7.1 seconds to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an over-all variable-derived on-ice to over ground ratio of 0.84.

Test-retest, on-ice reliability measures (n=15) for predicted VO_2max (49.5±8.37 vs. 49.29±7.95 ml/kg/min) showed a highly significant ($p \leq 0.001$) consistency (r=0.87). Similarly test-retest concurrent validity measures (n=10) for predicted VO_2max over-ground with the original 20 MST (48.09±6.25 ml/kg/min) as designed by Léger and Lambert (1982) versus on-ice values with the adapted on-ice 20 MST (49.98±7.23 ml/kg/min), showed a very significant ($p \leq 0.01$) correlation of 0.73 between the two tests.

In conclusion the original 20 MST, as designed by Léger and Lambert (1982) for over-ground, proved inappropriate for use on-ice. Modification of the starting velocity as well as a progressive increase in velocity for all subsequent stages renders the modified 20 MST for ice-sports a reliable and valid test for cardiorespiratory fitness (VO_2max), with surface-specific utility.

KEY WORDS:

20 Metre Multistage Shuttle Run Test (20 MST); Ice-sports; Velocity of motion; Energy expenditure; Mechanical efficiency; Cardiorespiratory fitness (VO_2max); *20 Metre Multistage Shuttle-Skating Test* [Modified (Skating) 20 MST]; Surface-specific utility.

SINOPSIS

TITEL	**:** Wysiging van die 20-Meter Wisselloop Hardlooptoets (20 WHT) vir ys-sport
KANDIDAAT	**:** S.M. Kuisis
STUDIELEIER	**:** Dr H.J. van Heerden
GRAAD	**:** M.A. (MBK)

Die 20-Metre Wisselloop Hardlooptoets (20 WHT) is gewysig vir toepassing op ys-sport, meer spesifiek vir ys-hokkie en sier-skaats. Altesaam twee-en-sewentig deelneemers in ys-sport het as proefpersone gedien. Proefpersone in die studie was Nasionale- en Provinsiale- standaard manlike ys-hokkiespeelers (n=67) en vroulike sier-skaatsers (n=5) wat in die Gauteng gebied van Suid Afrika deelneem (hoogte bo seespieël van 1497 Metre en lugdruk van 655 mmHg). Die gemiddelde ouderdom van die proefpersone was 17.44±1.33 jaar.

Die navorsingsmetodologie het 'n herhaalde-toetsings ontwerp behels, ten einde die volgende te bepaal:

a) snelheid van beweging op-ys vs. oor-land;
b) energieverbruik op-ys vs. oor-land; en
c) meganiese-doeltreffendheid op-ys vs. oor-land.

Die gemiddelde snelheid van beweging wat oor drie afstande gemeet is (0 to 20, 0 to 30 en 0 to 40 m) was beduidend ($p \leq 0.05$) vinniger op-ys (5.99±0.72 m/s) in vergelyking met oor-land (5.75±0.63 m/s). Die ooreenstemmende gemiddelde tydsverloop-verhouding op-ys vs. oor-land was 0.97±0.11.

Verskille in gemiddelde energieverbruik tydens die uitvoering van die oorspronklike 20 WHT oor-land in vergelyking met op-ys is gemeet teen a lae- (na 4 minute van oefening teen 10 km/uur), intermediêre- (na 8 minute van oefening teen 12 km/uur), en hoë-intensiteit (na 12 minute van oefening teen 14 km/huur). Die gemiddelde van die drie het 'n beduidend ($p \leq 0.05$) hoër energieverbruik oor-land getoon (14.04±4.86 kkal/min) in vergelyking met op-ys (10.51±2.95 kkal/min). Die gemiddelde energieverbruik-verhouding vir die drie verskillende intensitiete op-ys vs. oor-land was 0.74±0.21. Soortgelyks, was die meganiese-doeltreffendheid indeks oor-land (4.92±0.59) beduidend ($p \leq 0.001$) swakker as op-ys (6.83±1.49). Die gemiddelde verhouding vir meganiese-doeltreffendheid oor-land vs. op-ys was 0.74±0.13.

Daaropvolgend, gebaseer op die voorgaande resultate, is die 20 WHT as volg gewysig:

a) aanpassing (verhoging) van die snelheid van beweging wat vir elke vlak van die toets (afstand van 20 m per wisselloop) vereis word; en
b) bepaling van die betroubaarheid en geldigheid van die gewysigde (skaats) 20 WHT vir gebruik op-ys.

Die gewysigde *20 Metre Wisselloop Skaats-Toets* het teen 'n snelheid van 2.8 m/s (10.1 km/uur) begin en het 7.1 sekondes toegelaat om elke wisselloop vir die eerste vlak van die toets te voltooi, wat dan progressief by elke vlak verminder is. Dit was gegrond op 'n algehele veranderlik-afgeleide op-ys tot oor-land verhouding van 0.84.

Toets-hertoets, op-ys betroubaarheidsmetinge (n=15) vir voorspelde VO_2maks (49.5±8.37 vs. 49.29±7.95 ml/kg/min) het 'n hoogs-beduidende ($p \leq 0.001$) herhaalbaarheid (r=0.87) getoon. Soortgelyks het toets-hertoets geldigheidsmetinge (n=10), vir voorspelde VO_2maks oor-land met die oorspronklike 20 WHT (48.09±6.25 ml/kg/min) soos ontwerp deur Léger en

Lambert (1982) versus op-ys waardes met die gewysigde (op-ys) 20 WHT (49.98±7.23 ml/kg/min), 'n baie beduidende ($p \leq 0.01$) korrelasie van 0.73 tussen die twee toetse getoon.

In gevolgtrekking is die oorspronklike 20 WHT, soos ontwerp deur Léger en Lambert (1982) vir oor-land gebruik, bewys om ontoepaslik te wees vir gebruik op-ys. Aanspassing van die beginsnelheid, sowel as 'n progressiewe verhoging in snelheid vir alle opvolgende vlakke, maak die gewysigde (skaats) 20 WHT vir ys-sport 'n betroubare en geldige toets vir kardiorespiratoriese fiksheid (VO_2maks), met oppervlak-spesifieke bruikbaarheid.

SLEUTELWOORDE:

20-Metre Wisselloop Hardlooptoets (20 WHT); Ys-sport; Snelheid van beweging; Energieverbruik; Meganiese-doeltreffendheid; Kardiorespiratoriese fiksheid (VO_2maks); *20 Metre Wisselloop Skaats-Toets* [gewysigde (skaats) 20 WHT]; Oppervlak-spesifieke bruikbaarheid.

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LIST OF ABREVIATIONS

°/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)
ft	foot (linear measurement of distance)
g	gram (unit of mass)
HR	heart rate (measured in beats per minute)
HRmax	maximal heart rate (measured in beats per minute)
J	Joule (unit of work; represents the application of 1 Newton (N) through a distance of 1 metre)
Kcal/min	kilocalories per minute (expression of work or energy; used in text as an indicator of energy expenditure)
Kg	kilograms (unit of mass)
Km/h	kilometres per hour (unit of speed or velocity)
LT	lactate threshold (level at which blood lactic acid levels begin to show a systematic increase above a resting level)
m	metre (linear measurement of distance)
m/min	metres per minute (unit of speed or velocity)
m/s	metres per second (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)
mg/dl	milligrams per decilitre (the concentration of one substance per unit of another substance; unit of measurement of blood lactic acid)
min	minute (unit of time)

ml millilitre (unit of volume or capacity)

ml/kg/min millilitre per kilogram of body mass per minute (unit of oxygen consumption)

mmHg millimetres mercury (unit of measure of barometric pressure)

mmol/L millimole per litre (unit of molecular weight of a substance; unit of measurement of blood lactic acid)

mph miles per hour (unit of speed or velocity)

n number of participants in a group

NHL National Hockey League

O_2 oxygen

r correlation

r^2 coefficient of determination

RCE cycle ergometer test of six 15-second exercise:rest periods

RER respiratory exchange ratio

RSS Reed Repeat Sprint Skate Test (requires players to skate 55 m six times every 30 seconds)

s seconds (unit of time)

SAS_{40} 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)

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)

VO_2 oxygen consumption (expressed in text as VO_2)

VO_2max maximal oxygen consumption (measured in litres per minute or as millilitres per kilogram per minute); expressed in text as VO_2max

W / kg	watt per kilogram (unit of power)
WAT_{40}	Wingate test lengthened to 40 seconds
μ	coefficient of friction
R	normal (perpendicular) reaction force
μ_s	static friction
μ_k	kinetic friction

CHAPTER 1

THE PROBLEM

1.1 Introduction

Cardiorespiratory endurance is generally recognized as a major component of evaluating physical fitness and maximal oxygen consumption (VO_2max) and is considered the most valid measure of cardiorespiratory fitness (Gabbard, 1992). The test for VO_2max 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, and is probably the best assessment of the athlete's endurance capabilities (Hawley & Burke, 1998).

Although *direct measurement* is the single best measure of cardiorespiratory fitness or aerobic capacity, laboratory tests of VO_2max involve complexities and require extensive and sophisticated equipment, are time consuming and have a large financial cost. These maximal tests are also restricted to testing one subject at a time. Laboratory tests are often restricted to exercising on a treadmill, cycle or simulation ergometre with the subject required to wear a mask which is attached to a gas analyser, and requires the subject to remain close to the equipment. Often, these are restricting factors for many people due to unfamiliarity and discomfort in the artificial conditions when compared to the actual sporting event. This artificiality often affects the results obtained (Léger & Boucher, 1980; Ahmaidi *et al.,* 1992; Grant *et al.,* 1995).

According to Bouchard *et al.* (1988) there is an intra individual day-to-day variability of 4- 6% in tests using ergometres due to factors such as errors in gas analysis and calibration, equipment calibration and familiarization with the task.

Reproducibility on the cycle ergometre and treadmill are similar but bicycle VO_2max values are 7-8% below the treadmill values. For these reasons a test without any respiratory equipment and required expertise is perceived as a real advantage (Leger *et al.,* 1980; Boreham *et al.,* 1990). In contrast sport-specific tests are highly valued in exercise science, including tests for cardiorespiratory endurance and maximal oxygen consumption. The test has utility in the physiological assessment of athletes in their natural environment 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.

Existing laboratory test protocols for ice-sports use are not specific to ice-sport. Treadmill and cycle ergometre protocols are commonly used to test VO_2max. Most tests specific to ice-hockey measure variables related to anaerobic metabolism. Among these tests the *Sargeant Anaerobic Skate Test* (SAS_{40})*,* which 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; the *Reed Repeat Sprint Skate Test (RSS)*, which requires players to skate 55 m six times every 30 seconds; the *Wingate test lengthened to 40 seconds* (WAT_{40})*;* and a cycle ergometre test of six 15 second exercise:rest periods *(RACE).* Other field-tests for ice-hockey are skill-related and very few are fitness-related.

As laboratory tests only allow one athlete to be tested at a time, a field-test which is more sport-specific and that allows for groups of athletes to be tested simultaneously will be of great value. A sport-specific test to determine cardiorespiratory fitness in ice-sport participants has not been reported in the literature.

The 20 metre multistage shuttle run test (20 MST) is a versatile field-test. The test which was originally designed by Léger & Lambert (1982) and later refined (Léger *et al.*, 1988) is a popular field-test of aerobic power. It fulfils all three of the below-mentioned requirements of an exercise test, and is relevant to sports such as soccer and hockey (Grant *et al.*, 1995), where turning is a feature of the game. Furthermore Paliczka *et al.* (1987) state that the 20 MST is an appropriate field-test of aerobic endurance because the requirement for pace judgment is eliminated by the use of a pre-recorded audio signal; the incremental nature of the test ensures a gradual rise in work-rate and therefore heart rate; the test has proved to be valid and reliable (highly reproducible) in predicting maximal aerobic power (r=0.975; Léger & Lambert, 1982); and large numbers can be tested simultaneously. The 20 MST is similar to treadmill protocols in being a safe progressive and maximal test, but is less expensive and time consuming than direct measurements (Van Mechelen *et al.*, 1986; Boreham *et al.*, 1990). It can thus be accepted that the 20 MST appears to be a valuable test in predicting the maximal aerobic power of both males and females when performed over-ground on most types of natural and synthetic gymnasium surfaces (Léger & Lambert, 1982; Van Mechelen *et al.*, 1986; Paliczka *et al.*, 1987; Léger *et al.*, 1988; Boreham *et al.*, 1990).

Snyder & Foster (1994) believe that an exercise test can benefit the athlete and coach only if it meets three criteria: a) there must be a high correlation between the test measure and subsequent competitive performance; b) the test must be able to detect changes in the competitive fitness of the athlete; and c) the test must allow the athletes to set goals. The 20 MST fulfils all three of these requirements, and additionally allows for large groups of people to be tested simultaneously.

The nature of the 20 MST makes it ideal for use in ice-sports. However, since the refinement and validation of the 20 MST for over-ground use (Léger *et al.*, 1988), its application for use on ice has not been equally researched. In response Kuisis and Van Heerden (2001 – Appendix A) recently studied the relationship between the actual and estimated VO_2max responses while performing the MST on-ice, and found an over-estimation of the predicted VO_2max.

1.2 Statement of the Problem

The 20 MST is an appropriate over-ground field-test for many reasons. To name a few, it is inexpensive, large groups can be tested at the same time; it is sport-specific and does not require extensive and expensive equipment. However, because motion on ice is much easier than over-ground, the alternative nature of the surface precludes its immediate utility for use in ice-sports such as figure skating and ice-hockey. Thus, extensive investigation needs to be done in order to adapt or modify the test for use on ice.

1.3 Aim

In cognisance of the foregoing, the aim of the study was to modify the 20 MST for application to ice-sports, more specifically ice-hockey and figure-skating.

The process entailed a repeated measures research design to determine:

a) velocity of motion (ease of motion) on-ice vs. over-ground;
b) energy expenditure on-ice vs. over-ground; and
c) mechanical efficiency on-ice vs. over-ground.

Subsequently, based on the above, the 20 MST was modified by:

a) adapting the velocity of motion required for each level of the test (distance of 20 m per shuttle); and
b) establishing the reliability and validity of the modified 20 MST for use on-ice.

CHAPTER 2

LITERATURE REVIEW

2.1. Nature of Ice-Hockey

It has been stated that ice-hockey is the fastest and most high intensity game in the world played on two feet. In addition, the game is rough, requiring at times intense physical contact, aggressive play and exercise intervals at maximal capabilities. When compared with other team sports, some authors have suggested that ice-hockey predisposes an athlete to premature and chronic fatigue (Mascaro *et al.,* 1992; Gilder & Grogan, 1993; Cox *et al.*, 1995). Cox *et al.* (1995) have presented factors that relate to successful athletic performance at the elite level (Figure 2.1) which also applies to ice-hockey.

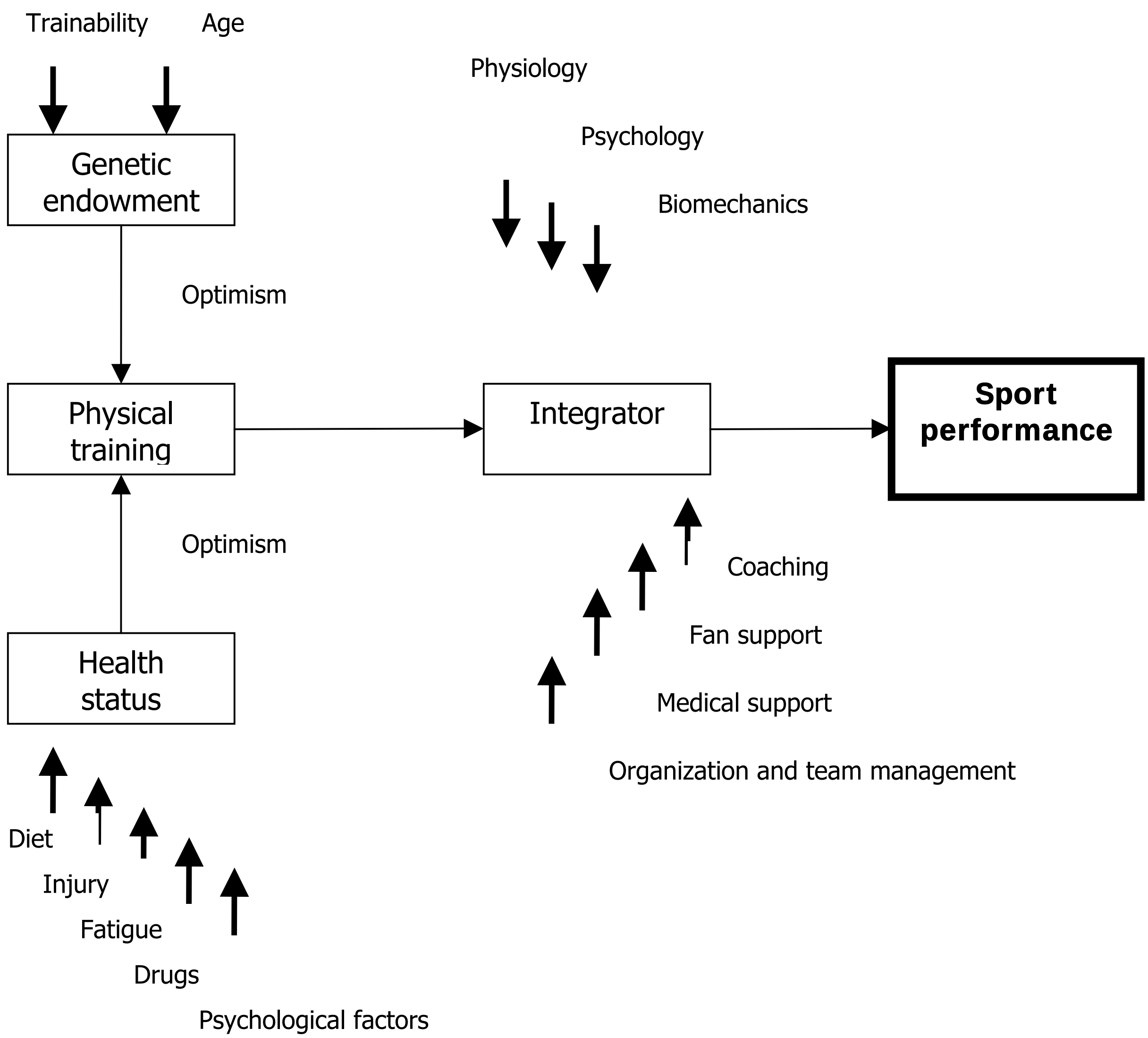


FIGURE 2.1 THE INTEGRATION OF FACTORS THAT RELATE TO SUCCESSFUL ATHLETIC PERFORMANCE AT THE ELITE LEVEL (Cox *et al.*, 1995).

2.1.1. History of ice-hockey

Ice-hockey originated in Canada in the early 1800s and has been an Olympic sport since 1920 (Montgomery, 1988; Montgomery *et al.,* 1990; Snyder & Foster, 1994). Ice-skates evolved from a blade attached to a walking boot. There is evidence that the first skate blades were made in the Scandinavian countries. The shank or rib bones of elk, oxen and reindeer were secured to the boot long before the discovery of iron (Montgomery, 1988).

Modern hockey skates are designed for protection as well as performance. Ice-hockey skates differ from those of the speed skater in blade length, blade rocker, boot structure, and skate weight to match performance needs of the skater. 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).

Cousin to the frenzied-paced sport of ice-hockey, inline skating is based on the same principles, only a lot drier and warmer. The game has blossomed into one of the fastest growing sports in the USA and Canada, recording a growth rate from 1.5 million in 1993 to approximately 6 million just five years later, and the numbers are still growing. Hockey is not a cheap sport. A modest kit set-up will cost approximately R 2 500 (SA Sports Illustrated, 2001).

2.1.2. Time Motion Analysis

Total duration of a game

Ice-hockey is played on an oval ice that measures approximately 61 m x 30.5 m and is generally played indoors (Snyder & Foster, 1994). The ice-hockey game takes place in three 20 minute periods, with 12 intermissions between periods. Ice-hockey teams generally have about 15 players and 2 goalkeepers, with three forwards, two defensemen, and 1 goalkeeper on the ice at one time. A team generally has three of four lines (shifts) of forwards and two or three lines of defensemen (Snyder & Foster, 1994). Green *et al.* (1976) state that the total actual playing time constituted 24.5 minutes.

Phases of play (stoppages)

Ice-hockey is a high speed game of intermittent activity. The mean non-stop time of an ice-hockey shift is 150 seconds. The shift is intermittent with 30 seconds of work followed by about 30 seconds of rest. This means that during the 150 second shift a player has approximately three 30-second work periods interrupted by two 30 second rest periods (i.e. stoppages in play).

At the professional level, the game is characterized by intense bouts of play lasting 45 to 60 seconds, and seldom exceeding 90 seconds. The length of a game is 60 minutes consisting of three 20 minute periods with a 15 minute rest interval following periods 1 and 2. Typically, the average National Hockey League (NHL) player receives less than 16 minutes of actual playing time extended over three hours. However, some players may receive as much as 35 minutes playing time during a game (Cox *et al.*, 1995).

As the recovery time between shifts was 3.8 minutes, the total playing time was 24.5 minutes. Defensemen generally play for more minutes than forwards do because there are fewer defensemen. Defensemen also tend to skate at slower velocities (62 % of the velocity of forwards) (Snyder & Foster, 1994).

In an ice-hockey game, the length of a shift can vary from several seconds to greater than 2 minutes. During this time, high intensity exercise with few breaks is performed (Snyder & Foster, 1994).

Green *et al.* (1976) state that an average shift included 39.7 seconds of the uninterrupted play followed by a 27.1 second play stoppage, repeated 2.3 times. The actual playing time increased over the 3 periods (+17.4 %), as did 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 %).

In a study of three junior and one professional game, Thoden & Jette (1975) observed that hockey players averaged 5 to 6 shifts of 70 to 80 seconds per period with 3 to 4 minutes of recovery on the bench between shifts. Within a shift, there were 5 to 7 bursts ranging in duration from 2.0 to 3.5 seconds. Total burst time per game averaged 4 to 6 minutes with players on the ice for 15 to 21 minutes per game. Forwards displayed more anaerobic activity than defensemen.

According to Léger *et al.* (1980) forwards and defensemen had similar (88.5 versus 84.9 seconds, respectively) playing time per shift. Since the defensemen spent less time on the bench between shifts, the ratio of bench time:ice-time was higher for the forwards (2:3) than defensemen (2:1).

According to Green (1978), defensemen had a longer playing time (+33 %), a greater number of shifts (+17 %) and a longer playing time per shift (+21 %) with less recovery time between shifts (-35 %). Defensemen averaged only 61.6 % of the skating velocity of forwards. Green *et al.* (1976) state that defensemen played much longer than forwards (+21.2 %) due to a greater number of shifts (+26.1 %) and much shorter recover period (-37.1 %). Each shift was shorter in duration (-7.4 %), shorter in continuous play time (-10.1 %), and longer in the time taken to resume play (+12.9 %).

According to Montgomery (1988), there are several physiological reasons why the coach should employ short shifts:

a) the heart rate drops by an average of only 10 beats/min during on-ice play stoppage;
b) the overall intensity of play is very high during a shift on the ice; and
c) short shifts reduce lactate build-up in the muscle by allowing time for restoring the ATP-CP stores.

Long shifts of high intensity result in accumulation of lactate in the muscle. Lactate removal is slow. If sufficient lactate is produced, the increase in muscle acidity causes metabolic and contractile disturbances that result in decreased work performance (Green, 1978). High intensity intermittent work (10 bouts of 60 second duration) also causes rapid reduction (29 % decline over the 60 minutes) in muscle glycogen particularly from fast twitch fibres (Montgomery, 1988).

If each shift on the ice is terminated prior to excessive accumulation of lactate, recovery characteristics are much faster. The recovery period can be used to reload myoglobin stores and resynthesize phosphocreatine. Due to a shorter shift, there is a larger contribution of phosphocreatine and oxidative phosphorylation to ATP turnover. With a reduced contribution from anaerobic glycolysis, glycogen reserves are depleted at a slower rate (Montgomery, 1988).

Distance skated during a game

Seliger *et al.* (1972) estimated that players from the Czechoslovakian national team (n=13) averaged 5160 m (range 4860 to 5620 m) during a game. Montgomery (1988) states that top-performance players can skate 6400 to 7200 m per game. According to Green *et al.* (1976), during 24 minutes of actual playing time, the players skated 5553 m. From heart rate telemetry, energy expenditure was estimated at 70 to 80 % of VO_2max. Table 2.1 indicates a time-motion analysis of game play.

Skating velocity

Skating velocities between 50 and 400 m/min would be expected during game play. However, the university players averaged only 227 m/min. the authors concluded that 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 form velocity analysis. Mascaro *et al.* (1992) determined forward skating speed by a 54.9 m sprint skate test.

TABLE 2.1 TIME-MOTION ALALYSIS (MEAN± SE) 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 (sec)	293±16	189±18	225±25	329	147.5	276.3±14.0	228
Ice/shift time (sec)				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 (sec)	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 (sec)	57.9±2.5	73.1±4.7	85.4±3.1	86.9		139.1±10.5	94.9
Total stoppage time/shift (sec)	58.2	79.3	62.3	59.4		75.3±8.8	
Play stops/shift (sec)	2.0±0.1	2.6±0.2	2.3±1.0			3.5±0.3	2.3
Time/play stoppage (sec)	29.1±3.3	30.5±4.1	27.1±1.4			21.5	
Playing time between stoppage (sec)	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)

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. A large difference was noticed in the average velocity where defensemen only averaged 61.6 % of the value obtained by the forwards.

According to Mascaro *et al.* (1992), 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 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.

Gilder & Grogan (1993) state that forward skating speeds average 35 mph (56 km/h) backward speeds average 15 mph (24 km/h). Sliding speed can be up to 15 mph (24 km/h), slap shots range from 60 to 100 mph (96.5 to 161 km/h). The force generated during skating push-off can reach 1.5 to 2.5 times the player's body weight and is one of the underlying factors causing injury to the groin. The average ice surface is 200 by 85 ft (61 by 26 m) or smaller, giving little room for the hockey player to decelerate before impact.

Movements (kinesiology) / Mechanics

According to Snyder & Foster (1994), the ice-hockey skate is very different from the speed skate, having a shorter blade and a stiffer, taller boot. The ice-hockey skating stroke, like that of the speed skater, involves three components:

a) a glide with a single leg support;

b) propulsion with a single leg support; and

c) 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. 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 (Montogery, 1988).

The ability to accelerate quickly characterizes the elite hockey player. Skilled skaters are able to exceed a velocity of 8 m/s after just four strides. Forward propulsions are impeded by the frictional resistance of the ice, air resistance, drag, and contact from opponents. External power is equal to the product of the work per stroke and the stroke frequency (Montgomery, 1988).

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.

Marino (1984) states that increases in maximal horizontal velocity of hockey players during the ages 8 to 15 years are accompanied by increases in skating stride length with no significant changes in skating stride rate.

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. Montgomery (1988) states that 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) 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.

Effect of added mass

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).

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. Eleven hockey players were tested in mid-season in each of four conditions:

a) normal body mass;

b) 5 % added body mass; and

c) 10 % added body mass

(Montgomery, 1988).

The mass was secured to the waist and shoulders of a weighted vest. It did not interfere with skating movements. 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. 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).

According to Mascaro *et al.* (1992), added mass due to an increase in equipment weight has been shown to result in a significantly slower performance on the speed component of a hockey fitness test. In addition, performance time increases due to increased mass of the skates worn during the test. Furthermore, the goalie is not trained in speed performance as the other position players.

Chomay *et al.* (1982) investigated the effect of experimental alterations in skate weight on performance in the repeat skate test. Subjects (n=11) performed the repeat sprint skate test under three conditions:

a) with normal skate weight;

b) 227 g of weight added to each skate; and

c) 55 g of weight added to each skate.

During the added skate weight conditions, there was a significant ($p<0.005$) 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.

The effect of equipment weight on aerobic skating performance is evident from the results of Léger *et al.* (1979). Ten hockey players performed a 20 m shuttle skating test to determine VO_2max. While the VO_2max 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 (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) (Montgomery, 1988).

Bioenergetics of skating

Ferguson *et al.* (1969) developed test procedures for measuring VO_2max while skating around a 140 m oval course. Workloads consisted of skating 3 minutes at increasing velocities. Velocities of 350, 382, 401, 421, and 443 m/min were selected since they correspond to 24, 22, 21, 20, and 19 seconds per lap. The velocities were chosen to increase oxygen consumption by 300 ml/min. test retest correlation on 17 hockey players was 0.94 with values of 54.7 and 55.3 ml/kg/min obtained on test 1 and 2, respectively. The relationship between skating velocity and VO_2max (ml/kg/min) was linear between 350 and 443 m/min.

Another factor that will influence the maximum velocity of movement and the energy requirements at a given velocity is skating efficiency. It takes many years of apprenticeship to develop a fluent style of skating. Skating mechanical efficiency is calculated by measuring the oxygen cost of skating at a set velocity.

$$\text{Efficiency} = \frac{\text{Velocity (m/min)}}{VO_2\text{max (ml/kg/min)}} \times 100$$

(Montgomery, 1988).

Energy systems

Johansson *et al.* (1989) and Reilly & Borrie (1992) include hockey among sports with a 30 % aerobic and 70 % anaerobic contribution to energy expenditure and it is appropriate to view the game at top level as aerobically demanding with frequent though brief anaerobic efforts superimposed. Apart from a high aerobic power, the game of hockey demands that the player has the capability to accelerate and decelerate quickly. Acceleration is critical to hockey performance rather than maximal speed. Heart size of field hockey players is greater than that noted in ice-hockey (Reilly and Borrie, 1992).

The challenge during the game itself and through preparative procedures is to maximize the contribution of aerobic metabolism to energy supply. In a training program that is focused on development of aerobic power, the amount of change that can be expected is in the order of 15 to 20 %. Improvements appear to depend on both increases in oxygen transport to the working muscles and improved ability of the working muscle to extract and use the oxygen. Individuals with a high aerobic power are characterized by large cardiac outputs and large muscular blood flows. In addition, the trained muscle has a large capillary supply and a high mitochondrial potential. For a given amount of work, individuals with a well developed aerobic system are able to reduce the depletion of a key muscle fuel, namely glycogen, and reduce the lactate formed from glycolysis and consequently to minimize the acid-base disturbances (Green, 1994).

Ice-hockey as a sport is metabolically unique. Ice-hockey is physically demanding, requiring finely trained aerobic and anaerobic energy pathways. The sport demands intense glycolytic activity related to bursts of intense muscular activity, but also exceptional aerobic power and endurance. With ice-hockey, the involvement of the anaerobic system may be dependent on the efficiency of the aerobic system (Cox *et al.*, 1995).

Besides well developed aerobic and anaerobic energy pathways, the nature of the game also requires a large, lean body mass and exceptional strength. Thus, ice-hockey can be considered a sport in which total body fitness is compulsory. Correspondingly, appropriate training and maintenance of sport-specific fitness levels may help to prevent injury and offset premature fatigue to maintain performance (Cox *et al.*, 1995).

In an ice-hockey game, the length of a shift can vary from several seconds to greater than 2 minutes. During this time, high intensity exercise with few breaks is performed. Blood lactate concentrations of ~ 12 mmol/L have been observed after one period of play. The high intensity and intermittent nature of the activity can produce two metabolic problems:

a) depletion of muscle glycogen; and
b) slow recovery from metabolic acidosis
(Snyder & Foster, 1994).

Green (1978) had ice-hockey players either skate continuously for 60 minutes (~ 55 % of VO_2max) or perform intermittent exercise (ten 1 minute bouts with 5 minutes recovery between each, ~ 75 % of VO_2max). Biopsies from the vastus lateralis muscle and blood samples were obtained following 30 and 60 min of activity. During the intermittent activity, blood glucose, lactate, glycerol, pyruvate, plasma free fatty acids, and hematocrit were all increased significantly at both 30 and 60 minute measurement periods. During the continuous skating, only blood glucose (30 and 60 minute) and lactate (30 minute) showed small, but significant, increases. Within the muscle, decreases in adenosine triphosphate (18 %) and phosphocreatine (37 %) occurred during the intermittent exercise, whereas muscle lactate concentration was 10 fold higher following the intermittent exercise than following the continuous exercise. Muscle glycogen was reduced by 29 % by the continuous exercise; with intermittent exercise, glycogen was reduced by 45 % after 30 minutes and by 75 % after 60 minutes. Following the intermittent exercise, the greatest depletion of muscle glycogen occurred in the Type I muscle fibres, but some depletion also occurred in the Type II fibres. Thus, at least during a simulated hockey competition, carbohydrate (glucose) metabolism was used extensively, and depletion of muscle glycogen did occur. Green (1978) measured blood lactate levels of 10.9±1.2 mmol/L following 30 minutes and 13.3±0.6 mmol/L following 60 minutes of intermittent exercise.

The study by Kjaer & Larsson (1992) indicates that ice figure skating is associated with high aerobic power. Blood lactate concentration was measured as 2.2±0.8 and 1.5±0.5 mmol/L for the males and females respectively, and rose in response to skating to 9.0±1.3 and 7.4±0.6 mmol/L respectively, and therefore indicate that pronounced anaerobic power is required during elite figure skating. Most of the work performed during on-ice workouts was above the anaerobic threshold, where progressive increases in blood lactate were observed (Mannix *et al.,* 1996). A possible reason for figure skaters (19±1.4 mmol/L) being able to skate to much higher levels during the on-ice skated 20

MST than ice-hockey players (13.8±1.3 mmol/L), could be due to the fact that figure skaters seen to have a high lactate tolerance.

Muscle fibre type profile

It is well established that athletes who specialize in sprint type events have a predominance of fast twitch fibres in their leg muscles, while athletes involved in endurance type events display a predominance of slow twitch fibres. The requirements of ice-hockey are a compromise between the two extremes. Since the game involves both high intensity skating at maximal velocity and requires distribution of energy over a period of 2 to 2.5 hours, it is not surprising to find a wide range of fibre composition among elite players (Montgomery, 1988).

Tissue samples from the vastus lateralis muscle in elite ice-hockey players from university, junior, and professional divisions. No significant differences were observed among the muscle samples from athletes playing in the different leagues. The fibre type distribution was typical of that of an untrained individual, i.e.:

a) 49.6±2.7 % slow twitch (Type I);
b) 38.0±2.3 % fast twitch, oxidative-glycolytic (Type IIA); and
c) 12.2±2.5 % fast twitch, glycolytic (TypeIIB)
(Snyder & Foster, 1994).

Relative muscle fibre area was:

a) 47.1±3.2 % Type 1;
b) 40.4±2.5 % Type IIA; and
c) 12.5±2.8 % Type IIB
(Snyder & Foster, 1994).

According to Montgomery (1988), within a group of 25 junior, university and professional players, slow twitch fibre composition of the vastus lateralis ranges from 20 to 71 %.

Hockey players display a muscle fibre profile similar to the average untrained individual. Muscle biopsies from the vastus lateralis of 48 Canadian hockey players revealed no difference in the type I fibre distribution of university (47.8±2.5 %), junior (50.2±2.9 %) and professional (50.1±3.2 %) players (Green *et al.*, 1977). There was no difference in the percentage of type I fibres between positions (goalkeepers, 47.4 %; defensemen, 51.7 %; and forwards, 48.1 %). European hockey players may have a higher percentage of slow twitch muscle fibres than Canadian players may have. The Finnish national team (n=13) had 61±12 % slow twitch muscle fibres in the vastus lateralis (Montgomery, 1988).

Muscle fibre composition has been examined at the start and end of a hockey season. Muscle biopsies from the vastus lateralis of elite hockey players revealed pre- and post-season values of 49.6 % and 50.8 % slow twitch fibres. In the fast twitch fibre subgroups, there was an increase (38.0 to 45.2) in the percentage of fast twitch a fibres and a decrease (12.2 to 3.9) in fast twitch b fibres from pre- to post-season (Montgomery, 1988). Prolonged endurance activity has been known to decrease the proportion of fast twitch b fibres and increase the proportion of fast twitch a fibres. Hockey training can bring about interconversions in the fast twitch metabolic profile. Hockey training can also cause a significant increase in the size of the fast twitch a (22 %) and fast twitch b (28 %) fibres. There was no change in the area of the slow twitch fibres (Montgomery, 1988).

The activities of the enzymes phosphorylase, phosphofructokinase, and lactate deydrogenase were all similar to those observed in control subjects. Activities of 3-hydroxyacyl CoA dehydrogenase and succinate dehydrogenase were significantly greater in the ice-hockey players than in the control subjects (Snyder & Foster, 1994).

Muscle glycogen depletion

According to Montgomery (1988), several laboratories have used the muscle biopsy technique to examine the demands that are placed on the muscle's fuel storage. During high intensity, intermittent exercise carbohydrate utilization is important. Muscle glycogen depletion has been associated with a decrease in physical performance. Because the vastus lateralis is active during intensive intermittent skating, it is selected as the muscle for biopsy examinations. Muscle glycogen concentrations (mmol/kg wet tissue) was 89.3±13.6 for forwards (n=5) and 85.0±3.7 (n=3) for defensemen prior to a hockey game (Green*,* 1978; Johansson *et al*, 1989). Muscle glycogen declined an average of 60 % for both forwards and defensemen. Glycogen was utilized from type I, IIa, and IIb fibres with the greatest depletion from the type I fibres. Since a large amount of glycogen remained in type II fibres, it does not appear that glycogen depletion is the cause of fatigue.

The intermittent nature of hockey play and the maintenance of low lactate levels are important factors in utilizing plasma free fatty acids as an energy source. During a hockey game, there is a two fold increase in plasma free fatty acid levels, which provides a glycogen-sparing effect in the exercising muscles (Green *et al.,* 1978). Green (1978) studied the glycogen depletion patterns from the vastus lateralis muscle during continuous and intermittent ice-skating. Eight subjects performed intermittent skating consisting of 10 bouts of high intensity work corresponding to 120 % of VO_2max. Each bout consisted of 1 minute of skating followed by a 5 minute recovery period. This schedule was selected to represent the extreme example of play during the actual hockey game. The continuous skating was performed at 55 % of VO_2max for 60 minutes. Muscle biopsies were taken at the start of each skate and after 30 minutes (5 work bouts) and 60 minutes (10 work bouts).

During continuous skating, glycogen showed a 29 % decline over the 60 minutes with a more pronounced loss from the type I fibres. During the intermittent condition, there was a two fold increase in depletion of muscle glycogen (70 %) with a preferential loss from type II fibres, particularly type IIb fibres. Muscle lactate was 2.7 mmol/L after 60 minutes of continuous skating and 26.4 mmol/L after the intermittent high intensity skating. Either a high concentration of lactate or an excessive amount reduction of glycogen in type II fibres could reduce the muscle's potential to sustain work output (Green, 1978). Following intense efforts, recovery of the muscles to normal homeostatic conditions is a relatively slow process. The half-life for removal of lactate is estimated at 9.5 minutes (Montgomery, 1988).

Muscle biopsy studies using players from the Finnish national team (Montgomery, 1988) have demonstrated that the hockey player can have a high muscle glycogen concentration before the game. During two matches against the USSR team, muscle glycogen concentration was lowered from 53 to 33 g/kg of wet muscle tissue in game 1 and from 50 to 6 g/kg in game 2. During two matches against the USA team, pre- to post-game values were 46 to 20 g/kg in game 1 to 18 to 12 g/kg in game 2. In the game against USA when the pre-game muscle glycogen level was 18 g/kg, blood lactate and glucose were lowest.

Glycogen depletion from the vastus lateralis has been examined in a game simulated task (Montgomery, 1988). Pre- to post-task comparisons (n=8, university players) were 1.98 to 0.88 g/100g of wet muscle tissue respectively. There was preferential glycogen utilization by the slow twitch fibres but also significant depletion from the fast twitch fibres. Montgomery (1988) reported that slow twitch fibres are depleted of glycogen by 80 % after a hockey match in comparison with pre-game levels. The fast twitch fibres' supply of glycogen had not been challenged.

Many hockey leagues schedule games on consecutive days. Since there is significant utilization of muscle glycogen stores during a hockey game, this substrate may be reduced to the point where performance is impaired. Green (1978) investigated this possibility by studying three hockey games, separated by 15 hours. Blood samples taken from 14 players prior to the games and after each period were analyzed for glucose and lactate. Lactate averaged 4.9 and 4.7 mmol/L during games 1 and 2, respectively. The goaltender showed little elevation of blood lactate. During game one, blood glucose at the end of each period was elevated above the resting value. During game two, lower values were evident after each period. There was a progressive decline in blood glucose with the final value (90±17.4 mg/dl) lower than the pre-game value. Forwards had lower values throughout game two. It is speculated that the depressed glucose levels in game two may have reflected elevated levels of plasma insulin causing increased uptake by the exercising muscles, or may have been due to reduced releases of hepatic glucose. The back-to-back games may have reduced both liver and muscle glycogen levels. Muscle biopsies from two players indicated that glycogen (56 mmol/kg) had not been replenished prior to game two. The *ad libitum* diet of the two players between games contributed to the low glycogen level (Montgomery, 1988).

Disturbances in temperature regulation

Since ice-hockey is played in environments where there is a relatively wide gradient between body and ambient temperatures, there is little risk of encountering heat-related ailments. Because protection is needed in this high speed, contact game, the player suits up with shoulder pads, padded pants, leg guards, gloves and helmets with face shields and throat protectors. The result is a uniform that reduces heat transfer. In warm arenas, profuse sweating typically brings about 2 to 3 kg weight loss during a hockey game despite *ad libitum* rehydration (Montgomery, 1988; Snyder & Foster, 1994).

Associated with this loss of body fluid is at least a 2 % increase in hematocrit following a single period of play. The reason ice-hockey players lose so much weight during play is that heat dissipation is limited by their protective clothing so that core temperature rises and stimulates excessive sweating. To reduce this effect of clothing on fluid loss, the following has been suggested:

a)removal of helmet and gloves between shifts;

b)encouragement of greater intake of liquids;

c)wearing of underwear made from polypropylene or other fabric that "wick" sweat away from the skin; and

d)use of open neck porous jerseys

(Snyder & Foster, 1994).

Duration & intensity

Each exercise, drill, and training session causes fatigue in the athletes. The type of exercise, intensity and duration determines the type of fatigue: acute neuromuscular or longer term metabolic. Most physical activity, especially strength training cause's immediate neuromuscular fatigue, which decreases the level of performance. Usually recovery from short intense exercise is quite rapid. When the duration of an intense exercise session gets longer lactic acid formation will increase and this has a detrimental effect on force development, speed, strength and power. If intense exercise sessions follow one another without adequate recovery, the fatigue will become chronic and affects the energy metabolism, hormonal systems in addition to the neuromuscular system (Smilios, 1998).

Existing training procedures may develop chronic muscular fatigue in hockey players. Lactic acidosis is associated with the onset and persistence of muscular fatigue. Muscle force output remains impaired throughout the hockey player's typical cycle of practices and games. Strength decrements during the hockey season are attributed to a lack of specifically designed strength maintenance programs. During the competitive season, quick and accurate testing of the speed-strength and explosive power will provide the coach information on fatigue and overtraining. This information helps the coach to design and develop training sessions and the loading of the players for example in on-ice training sessions (Smilios, 1998).

Speed & Acceleration

According to Song & Reid (1979), success in ice-hockey can be attributed to many factors, but skating ability is probably the single most important attribute possessed by an ice-hockey player. A faster skater has a definite advantage. The ability to accelerate quickly characterizes the elite hockey player. Skilled skaters are able to exceed a velocity of 8 m/s after just four strides (Montgomery, 1988).

Song & Reid (1979) found that hip adduction and ankle dorsiflexion showed a certain degree of relationship existed between strength and skating speed. No correlations were found between anthropometric and speed measures. The implication of this finding was that body shape was not an important factor contributing to the ability to skate quickly.

Wolynski *et al.* (1998) state that hockey involves skating at speeds approaching 20 to 30 miles an hour. A strong leg muscle can exert forcefully to produce great power and high speed. The strength of muscles and flexibility of joints in the legs affect the speed at which hockey players skate. The speed of movement of a limb is directly proportional to the strength value obtained from the same movement (Song & Reid, 1976).

According to Hawley & Burke (1998), a male sprinter weighing approximately 80 kg and who attains a peak velocity of 11.5 metres per second generates about 1300 W for several seconds to accelerate his body mass to reach this speed. Minimizing the time taken from the start is one of the principal concerns for the optimization of peak performance in sprinting. In speed skating events, Dr Jos de Koning of the Free University, Amsterdam, found a good correlation (r=0.72) between the mean acceleration during the very first second of the start phase and the final race time for competitors at the 1988 Winter Olympics. This means that even in a group of elite speed skaters, about 50 % of the differences in their final times for 500 metres could be explained by the differences in the initial acceleration phase of the race. Such a finding highlights the need for a short-as-possible start and acceleration phase.

There is a significant difference between male and female sprinters in the phases of a race (Table 2.2). Males have a longer acceleration phase and reach top speed later in a race than females. However, when they reach their maximal velocity, males are able to sustain that speed longer than females (Hawley & Burke, 1998).

TABLE 2.2: RANGE OF TIMES FOR THE DIFFERENT COMPONENTS OF A 100 METRE SPRINT FOR TOP-LEVEL RUNNERS

Race component	Men (seconds)	Women (seconds)
Reaction time	0.10-0.30	0.10-0.30
Drive from blocks	0.30-0.40	0.30-0.40
Acceleration phase	5.50-7.00	5.00-6.00
Maximum speed	1.50-3.00	1.50-2.50
Deceleration	1.00-1.50	1.50-2.50

(Hawley & Burke, 1998).

At the 1991 World Athletics Championships, the first four runners did not reach top speed until after 70 or even 80 metres (Table 2.3). This is much later than traditionally thought. Even more unusual was that Lewis actually accelerated from 90 metres until the finish (Hawley & Burke, 1998).

TABLE 2.3: ANALYSIS OF SPRINTING AT THE HIGHEST LEVEL-A BREAKDOWN OF THE MEN'S 100 METRES FINAL AT THE 1991 WORLD ATHLETICS CHAMPIONSHIPS

Variable	Carl Lewis (USA)	Leroy Burrell (USA)	Dennis Mitchell (USA)
Reaction time (m/s)	140	120	90
10 metre speed (m/s)	5.31	5.46	5.56
20 metre speed (m/s)	9.26	9.43	9.35
30 metre speed (m/s)	10.87	10.99	10.75
40 metre speed (m/s)	11.24	11.36	11.36
50 metre speed (m/s)	11.90	11.49	11.49
60 metre speed (m/s)	11.76	11.63	11.49
70 metre speed (m/s)	11.90	11.49	11.63
80 metre speed (m/s)	12.05	11.90	11.63
90 metre speed (m/s)	11.49	11.24	11.36
Finishing speed (m/s)	11.63	11.49	11.24
Finishing time (seconds)	9.86	9.88	9.91
Stride length (metres)	2.37	2.41	2.25
Stride rate (strides/ sec)	4.51	4.40	4.70

(Hawley & Burke, 1998).

A high maximal aerobic power is now a prerequisite for most players participating in team sports at a high level. Additionally, all outfield players are required to sprint at maximum speed and to accelerate from stationary positions throughout the duration of the game. Thus, any battery for evaluating the physiological status of players involved in team sports should include a measure of maximum sprint speed and acceleration. An example of such tests is presented in Table 2.4. For these tests, which can be conducted on a level field or in a gymnasium, an electronic sprint timer with photoelectric sensors is set at chest height and placed at 10, 20, 30, and 40m intervals from a start line. After a thorough warm-up and some acceleration runs of increasing speed, the player is instructed to position himself, in a standing start position, close to the start line without breaking the beam of the start sensor. Upon an auditory countdown signal, the player sprints maximally for 40 m, passing through the sensors. The player completes two flat-out runs, separated by a five minute recovery period. The instantaneous times at 10, 20, 30, and 40 m are recorded for each run, as well as the fastest split and total time attained during either run. Some coaches like to determine the speed of their players over a short distance from a moving or rolling start. Such a test negates some of the disadvantage that the heavier players have when commencing the sprint run from a stationary position. The start is always the slowest segment of any sporting movement (Hawley & Burke, 1998).

TABLE 2.4: PERFORMANCE TESTS AND MINIMUM STANDARDS FOR 100 METRE SPRINTERS OF DIFFERENT ABILITIES

Skill	100 m (10.70)	100 m (10.50)	100 m (10.20)	100 m (10.0)
Sprint 30 m from a crouched start (seconds)	4.1-4.2	4.0-4.1	3.8-3.9	3.7-3.8
Sprint 30 m from a rolling start (seconds)	2.9-3.0	2.8-2.9	2.8	2.7
Maximum sprint velocity (m/s)	10.86	11.11	11.62	11.90
Sprint 150(seconds)	15.7	15.2	14.8	14.7
Sprint 30m (seconds)	35.2-36.2	34.0-35.0	32.4-33.2	32.0-32.4
Standing long jump (m)	2.85-2.90	2.90-3.00	3.00-3.10	3.00-3.10
Standing triple jump (m)	8.60-8.80	8.90-9.20	9.30-10.0	9.30-10.0
10 hops from a standing start (metres)	33-34	34-35	35-36	35-36

(Hawley & Burke, 1998).

Anaerobic power & capacity

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). Table 2.5 shows anaerobic results of elite ice-hockey teams.

Three different tests have been used to measure anaerobic power and capacity, namely, the Wingate test, an intermittent cycle ergometre test (six 15 second repetitions performed with a 15 second recovery following each exercise bout), and a 2 x 60 second cycle test (60 second all-out effort is followed by a second 60 second all-out effort). Independent of the test used, forwards and defensemen had similar anaerobic abilities when expressed per unit body mass. Because defensemen weigh more than forwards do, defensemen had greater absolute anaerobic ability than forwards did. Peak power for ice-hockey players in the Wingate test has been reported to be 11.0$\pm$0.8 W/kg, whereas mean power was 8.8$\pm$0.6 W/kg (Snyder & Foster, 1994).

Most tests specific to ice-hockey have measured variables related to anaerobic metabolism. Among the tests used has been the Sargeant Anaerobic Skate test (SAS_{40}), which 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. Mean anaerobic capacity scores for this test was 9.7$\pm$0.8 W/kg. Another test that has been used is the Reed Repeat Sprint Skate test (RSS), which requires players to skate 55 m six times every 30 second. Mean anaerobic capacity measured was 9.3$\pm$0.8 W/kg. The Wingate test lengthened to 40 seconds (WAT_{40}) has also been used and mean anaerobic capacity scores were 7.7$\pm$0.2 W/kg. The last test mentioned was a cycle ergometre test of six 15 second exercise:rest periods (RCE) which rendered mean anaerobic capacity scores of 8.2 W/kg. Blood lactate concentrations following the performances of these anaerobic tests ranged from 10.7 to 13.7 mmol/L. It has been observed that the results for the RSS and (SAS_{40}) were more related to each other than either of these variables in the WAT_{40} (Snyder & Foster, 1994).

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 (Montgomery, 1988).

An ice-hockey shift is an intermittent activity that demands periodic bursts of maximal effort. The Wingate test is a single effort of 30 seconds' duration. Montgomery (1988) developed an intermittent cycle ergometre test that is a measure of the anaerobic endurance of ice-hockey players. The test consists of six 15 second repetitions with an exercise to recovery ratio of 1:1. 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 discriminated between varsity, junior varsity and non-varsity players.

TABLE 2.5: ANAEROBIC RESULTS (MEAN± SD) OF ELITE HOCKEY TEAMS

Reference	Group	n	Peak power (W/kg)	30-second anaerobic endurance (W/kg)
Smith *et al.* (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 *et al.* (1986)	NHL defense	27	12.0±1.5	9.5±1.0
	NHL forwards	40	12.0±1.2	9.1±5.5
	NHL goaltenders	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)

Members (n=27) of the Finnish National team (1978) have been subjected to two 60 second all-out efforts on a cycle ergometre. The tests were separated by a 3 minute recovery period. Power output was 383 and 326 J/kg on the first and second test respectively. Defensemen had the highest mean value with the goaltenders having the lowest mean power output. The blood lactate concentration increased significantly from 13.8 to 17.6 mmol/L. These values reflect a good anaerobic lactate capacity in elite hockey players (Montgomery, 1988).

Using a treadmill test, Green & Housten (1975) found similar maximal lactate values for forwards and defensemen playing junior hockey (elite players between 16 and 20 years of age). A pre- and post-season comparison revealed an improvement in run time from 64.3 to 74.8 seconds. Maximal blood lactate concentration increased from 11.9 to 13.3 mmol/L.

Blood lactic acid levels

One of the problems associated with lactate accumulation in ice-hockey players is that the lactate is metabolized only slowly when the skaters sit on the bench between the shifts on the ice. Watson & Hanley (1986) examined blood lactate concentrations following participation in a variety of activities during the 15 minute intermission periods to see if lactate level could be reduced. The subjects spent the first 3 minutes sitting, the next 10 minutes in either active or passive recovery, or the last 2 minutes sitting. The active recovery consisted either of a) bench stepping (with skates removed) at a cadence required to produce a heart rate of 120 beats/min, or b) continuous skating at a heart rate of 120 beats/min. Post –recovery blood lactate levels were slightly lower following bench stepping (6.1±2.2 mmol/L) than following continuous skating (6.7±1.4 mmol/L) and significantly lower than following passive rest (8.1±1.6 mmol/L). Perhaps gliding was the main activity during low intensity skating so that relatively little lactate was metabolized. 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.

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, respectively) then declined during the third period (mean 4.9 mmol/L). 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 for the forwards and 2.9 mmol/L for the defensemen. It appears that European hockey is characterized by higher levels (9 to 11 mmol/L) of blood lactate. Both blood lactate concentration and heart rate 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 seconds. 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 coasting. 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).

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 seconds 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.

Following high intensity skating that elevated blood lactate, 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 (Watson & Hanley, 1986).

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 VO_2max, 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, energy reserves etc. Blood lactic acid concentrations are generally lower in the cold. Sometimes the increase in lactate is two fold less important. 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 that 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 phosphorlyation. Thus, training increases the capacity to produce work without blood lactate accumulation and glycogen utilization. Shivering uses lactate as a substrate and it may be thought that there is an increase in the utilization of lactate rather than a decrease in production.

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 increase of their lactic acid concentration in the blood than people with low endurance. This is the result of the positive dependence of VO_2 on the intensity of the load.

According to Cox *et al.* (1995) there seems to be no question that some type of active recovery following exercise that promotes lactate accumulation is superior to a passive recovery. However, there may be several critical factors to consider, such as:

a) the duration and intensity of the exercise performed;
b) proper recovery intervals;
c) appropriate recovery time; and
d) individuality of the athlete.

Anaerobic threshold

Cox *et al.* (1995) measured the individual lactate threshold (LT) (Table 2.6). They assess changes in LT on a regular basis throughout the season. The basis of testing assumes that:

a) VO_2max is an indicator of central adaptation and LT is an index of peripheral muscular adaptation;
b) LT provides a highly specific and accurate baseline to construct individualized training programs, as well as a baseline to evaluate detraining and rehabilitation programs; and
c) LT will be more influenced by specificity of training, that is, proper and specific training that leads to a right-shifted lactate curve.

TABLE 2.6: LACTATE THRESHOLD (LT) FOR 24 NHL PLAYERS AS IT RELATES TO WATTS AT LT, PERCENTAGE OF MAXIMAL HEART RATE AT LT, AND PERCENTAGE MAXIMAL OXYGEN UPTAKE (VO_2MAX) at LT

	Watts at LT	% HR max	% VO_2max
Mean	352.7	89.5	82.5
Standard error	±9.9	±0.9	±0.85
Median	348.0	90.5	82.0
Range	228-440	77-96	73-92

Cox *et al.* (1995)

The classic curvilinear rise, of one mmol of lactate per litre with increasing work rate, for this determination occurred on average within a 4-beat heart rate (HR) range. These data illustrate the difficulty when prescribing a training program that is based solely on HR for elite hockey players. Such a small increment in HR would make the precision of the training program almost impossible without determination of the individual LT (Cox *et al.,* 1995).

Cox *et al*. (1995) state that lactate accumulation depends on:

a) fitness level;
b) state of training;
c) active muscle mass;
d) muscle fibre composition;
e) nutritional status;
f) blood flow; and
g) fatigue.

These same variables may affect recovery time and lactate clearance.

2.1.3. Cardiorespiratory Characteristics

Lung function

Maximal ventilation volume averaged at 130 L/min STPD and was not different among the three different playing positions (Cox *et al.,* 1995).

Aerobic endurance & VO_2max

During most forms of continuous exercise, the body depends on oxygen to help provide the energy that it requires. Oxygen is extracted from the air by the lungs, and is transported via the blood stream to the working muscles. As exercise intensity increases, there is a corresponding increase in the body's demands for oxygen. Exercise, which is largely dependent on oxygen for the provision of energy, is known as aerobic exercise. This steady, endurance-type exercise provides the basis for many individual and team sports. However, with everyone there comes a point when the intensity of exercise increases to such an extent that the supply of oxygen can no longer satisfy the oxygen demands of the active muscles. At this stage, the muscles have to obtain the majority of the additional energy by anaerobic metabolism, using mechanisms that do not require oxygen. The main disadvantage of anaerobic metabolism is that it can only sustain high rates of energy production for short periods of time (Brewer *et al.,* 1988).

A person's maximum oxygen uptake value (VO_2max) represents the maximum amount of oxygen that can be extracted from the external environment (the air breathed in) and transported to, and utilized by the working muscles. This is usually measured in millilitres of oxygen per kilogram of body mass per minute. Individuals with a high maximum oxygen uptake values are likely to be those most able to sustain high energy-use rates aerobically, thus avoiding the high levels of fatigue associated with anaerobic exercise. This is clearly shown in marathon and long distance running, where the faster international athletes have much higher VO_2max values than slower club athletes are. In sports such as soccer, rugby and hockey, the highest rates of work are likewise usually sustained by the players possessing the highest VO_2max values. Maximum oxygen uptake has been shown to increase with appropriate training. However it is to a large extent genetically predetermined for each individual, and will not increase above a certain critical value- although improvements in performance can often still be obtained with further training. One should also bear in mind that the large improvements in physical performance, which often result from training, might not always be reflected in equally large increases in maximal oxygen uptake. Nevertheless, it is still the most used and most important indicator of potential in aerobic or endurance based sports. The most accurate determination of VO_2max is obtained by measuring it directly in the laboratory. However, because one cannot easily test large numbers of people under these conditions, in view of the expertise and equipment that are required, many attempts have been made to predict VO_2max from simple field tests. Nevertheless, it is important to stress that field tests only provide an estimate of maximum oxygen uptake; the most accurate measurements can still only be obtained under conditions of direct measurement (Brewer *et al.,* 1988).

The physiological demands imposed during a hockey game are not confined to the anaerobic systems. Improving aerobic capacity reduces fatigue and improves player performance. The aerobic endurance of hockey players has frequently been assessed on both the treadmill and a cycle ergometre. Treadmill testing usually gives values that are 10 % higher than the cycle ergometre. Few studies have measured skating VO_2max (Montgomery, 1988).

According to Snyder & Foster (1994) ice-hockey players, even more so than speed skaters, tend to have relatively ordinary aerobic abilities. Values for VO_2max ranging from 4.3-4.7 L/min (53-57 ml/kg/min) have been reported for ice-hockey players who completed treadmill running tests. It has been reported that ice-hockey players had a mean VO_2max of 57.2 ml/kg/min during running tests, 53.4 ml/kg/min during cycling tests, and 55.5 ml/kg during skating tests. As expected the running test produced slightly greater (~ 7 %) VO_2max levels than did the cycling test, with the skating test values falling between running and cycling.

The VO_2max values of ice-hockey players are presented in Table 4.5. The VO_2max values of ice-hockey players (43.7±6.6 ml/kg/min; as directly determined by the *Aerosport*$_{TM}$ portable gas analyser whilst subjects performed the on-ice skated 20 MST) reported in a study by Kuisis and Van Heerden (1999) are lower than the VO_2max values reported in the literature (Snyder & Foster, 1994), but it should be kept in mind that the subjects in this study were provincial level ice-hockey players.

Like speed skaters and ice-hockey players, figure skaters were initially described as having fairly unremarkable maximum values for aerobic power (Niinimaa, 1982).

Research by Niinimaa (1982) showed that when compared to a sedentary population of the same age, figure skaters have cardiovascular fitness levels which are 50 %-60 % higher (McMaster *et al.,* 1979), but when compared to endurance athletes (94 and 77 ml/kg/min in male and female cross-country skiers) the figure skaters had far lower values. Physical stress during free skating is approximated at 75 % to 80 % of the skater's maximal aerobic power. According to Kjaer & Larsson (1992) work intensity during simulated competitive figure skating corresponded to 89 % VO_2max, and thus, high levels of aerobic power are required in elite figure skating. *Mannix et al.* (1996) state that except for the highest ranking competitors, most of those aspiring to attain "greatness" in figure skating have average aerobic power.

The figure skaters in Kuisis & Van Heerden (2001) had VO_2max values (as directly determined by the *Aerosport*$_{TM}$ portable gas analyser whilst subjects performed the on-ice skated 20 MST) far lower (38.9. 3.5 ml/kg/min) than the previously mentioned studies (Niinimaa, 1982; Kjaer & Larsson, 1992; in which the subjects were elite level skaters), this is possibly due to the fact that the subjects in this study were all provincial level skaters. Canadian hockey players appear to have the same VO_2max when tested on the ice and on the treadmill (Lariviere *et al.*, 1976; Léger *et al.*, 1979; Montgomery, 1988).

Defensemen have lower VO_2max values than forwards do, with goalkeepers generally having the lowest VO_2max values (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 VO_2max (ml/kg/min) values.

The functional capacity of the cardiovascular system of young players (age 10 years) is similar to elite adult players. A VO_2max of 56.6 ml/kg/min has been reported for boys involved in a competitive league (Montgomery, 1988).

A correlation of 0.60 between a 12 minute skate test and VO_2max was as high as the correlation between a 12 minute run test and VO_2max for a team of Bantam All-Stars (Hockey & Howes, 1979). The somewhat low correlation can be 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 during the skate test.

According to Montgomery (1988) the individual variability of VO_2max ($\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. Green (1979) has also observed substantial inter-individual differences in skating efficiency.

Players (n=13) of the Czechoslovakian national team were studied during one shift averaging 1.17 minutes followed by 21 minutes of recovery. Energy expenditure was measured by indirect calorimetry and corrected for basal metabolic rate. Based on oxygen consumption during this one shift and the prolonged recovery period, 69 % of the oxygen consumed was in the recovery period. Oxygen consumption during the shift averaged 32 ml/kg/min or 66 % of VO_2max during the model game. Seliger *et al.* (1972) characterized ice-hockey as an activity showing mostly a submaximal metabolic rate with a great participation of anaerobic metabolism (69 %), but simultaneously with high requirements for aerobic metabolism (31 %). During simulated play, the on-ice heart rate averaged only 152 beats/min, while pulmonary ventilation was 92 L/min. These values however seem to underestimate the aerobic intensity. Green e*t al.* (1976) in Montgomery (1988) estimated the on-ice energy requirements at

70 to 80 % of VO_2max in university players, while Paterson *et al.* (1977) estimated on-ice aerobic involvement in excess of 80 % of VO_2max in young boys.

2.2. Methodology of Fitness Testing

2.2.1. Purpose of Testing

Player selection

For the first century of existence, Canada dominated ice-hockey. 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).

According to Cox *et al.* (1995), today's ice-hockey players are physically bigger and have improved levels of physiological fitness when compared with their predecessors. A great need exists to apply exercise science to the game of ice-hockey. Player selection has become more consistent concerning the physical characteristics needed to play professional ice-hockey. Beginning in 1993 the NHL adopted centralized physiological testing for all NHL entry draft players. In 1984, several NHL teams implemented a variety of rigorous conditioning programs that were based upon proven scientific methods specifically designed to improve the central cardiorespiratory systems. These programs were in sharp contrast to traditional NHL training methods (Cox *et al.,* 1995).

According to Gunning *et al.* (1996), there are low levels of participation in ice-hockey in Australia. Women's ice-hockey, however, is on the rise as a collegiate sport. At the 1998 Winter Olympic Games in Nagano, Japan, the USA women's team, comprised of current and former collegiate players, won the gold medal. According to USA Hockey, there are 77 college women's teams in the United States. There are many similarities between the men and women's games. The game length is 60 minutes, the equipment is the same, and the basic rules are the same. The primary difference in the rules of the women's game is that body checking is not allowed, which makes for a slightly less physical game. The women's game does involve physical contact, and appropriate protective clothing is worn (Parakh & Domowits, 2000).

Why testing is necessary 

The primary purpose of testing is to monitor the effectiveness of a particular training program or other intervention (such as dietary modification, injury rehabilitation, or psychological counselling). It is obvious that the tests should be repeated at regular intervals, ideally before and after each phase of training. It is important that the results of tests are interpreted directly to the coach and athlete and that the sport scientist advises the coach of the most suitable and practical methods of implementing specific training interventions (Hawley & Burke, 1998).

The superior performances of the modern-day athlete are the product of a complex interaction of physiological, biomechanical, nutritional, and psychological factors. Coaches now recognize that the most consistently effective methods of preparing their athletes for the demands of top competition are those based on proven scientific principles rather than on trial and error.

Therefore, it has become commonplace to seek input from qualified sport scientists in order that athletes might reach their full potential (Hawley & Burke, 1998).

Sport evaluations play an important role in identifying and developing sport talent. A county's future success in any sport at the highest level is likely to be determined by the ability of its sport scientists to identify individual with special sporting talent and to initiate the appropriate research programs to foster the specific human factors that determine success in that sport (Hawley & Burke, 1998).

The competition in sports including ice-hockey is getting tougher year after year. The teams and organizations are facing more and more demanding challenges. Overall, the players are getting bigger, faster and tougher and the game itself is getting more and more physical placing increasing demands on the physique of the players. There is increasing competition between the players to make the team- since there are more players available. There is also increasing pressure to get the players back to the competition faster after the injury (Hawley & Burke, 1998).

One particular source that has accumulated substantial information on ice-hockey is Canadian Sports Therapy (2003). The following sections of information are primarily sourced from their website.

Performance in hockey depends upon many factors. The following five represent major factors, which are individual or collective in nature. These elements are:

a) player physical fitness (off-ice testing);
b) player technical skill (on-ice testing);
c) player and team tactical performance;
d) player and team psychological preparation; and

e) social cohesion within the team
(Canadian Sports Therapy, 2003).

It is obvious that some of these components are difficult to evaluate. In a team sport such as hockey, it is virtually impossible to develop a series of objective tests, which would serve as a valid measure of total team performance. We can however develop tests to validate an individual's performance. Objectively, this website will evaluate the first two factors of the list, the players' physical and technical abilities. The rest are up to the coaches (Canadian Sports Therapy, 2003).

From a coach's perspective:

There are several reasons why the players and team should be evaluated periodically. Among the most important of these is the need to:

a) keep the players updated of their progress;
b) diagnose their physical and technical weaknesses;
c) guide the coach/trainer in the development of the training program, both on and off-ice;
d) chart the player's improvement;
e) motivate the players by seeing improvement throughout the season;
f) verify the effectiveness of the physical preparation program (off-ice); and
g) selection of players for a team (try-outs)
(Canadian Sports Therapy, 2003).

From an individual's perspective:

It has been said that when a player is more physically fit than the rest of the team, that player is more likely to stand out among the others. Hockey scouts will look at players throughout a whole game. Players who are able to continue at the same physical level in the late stages of the third period as they did in the first, will stand out to the scouts that count, the NHL Scouts (Canadian Sports Therapy, 2003).

The importance of pre-season medicals

The time between just finishing the play-offs in April and arriving back to training in September passes quickly. Another long and gruelling hockey season begins in September. Over the summer, most athletes will have kept active in some way, either through an off-season conditioning program or playing other sports. Unfortunately, injuries will occur throughout the summer and these problems need to be addressed before the long season begins. This is where the pre-season medical can be extremely beneficial (Canadian Sports Therapy, 2003).

The policy at Canadian Sports Therapy is that, "Prevention is the key to success". Although there are several ways to prevent injuries, the main one should be determining before competition if the athlete will be predisposed to injuries in the upcoming year. There are several ways a trained professional (Athletic Therapist, Medical Doctor) can determine this (Canadian Sports Therapy, 2003).

A pre-participation exam should always start with a questionnaire regarding the athlete's past and present medical problems. Most teams already do this, but once they notice a problem, and should be equipped to deal with the particular situation. If a child presents as being epileptic (seizures) or diabetic, it is important that the coaching staff understand how to deal with this emergency when it arises. The pre-participation exam questionnaire should consist of emergency telephone numbers, the child's health card number, and several questions regarding any present or past medical conditions this particular athlete has had, so that the situation can be dealt with effectively (Canadian Sports Therapy, 2003).

The next step would be to conduct a simple postural evaluation. Through a postural scan, the examiner can scrutinize for several problems, such as uneven curvatures of the spine (Scoliosis), knee dysfunctions, poor posture of the shoulders (which often lead to sore necks and backs) and other muscle imbalances or postural problems. Through this evaluation, the professional can recommend several stretches and strengthening exercises that can easily correct these problems. Some problems require further medical attention to rectify the condition. These problems can often be corrected with simple exercises while children are still growing. If these problems go unattended, chronic injuries are far more likely to occur (Canadian Sports Therapy, 2003).

Osgoode Shlatter's is a good example of a common chronic injury that children experience in the knees. Pain will often be located just below the kneecap over the tendon. This problem often occurs due to a rapid growth spurt, which children go through between the ages of 11-16. The femur (large leg bone) grows extremely quickly, however, the quadriceps (thigh muscles) can not keep up with this rapid growth. This will correspond to the muscle becoming tighter, which causes undue stress upon the kneecap. The kneecap problem will then lead to excessive stress upon the tendon that attaches the kneecap to the lower leg. This problem can be easily avoided with proper stretching of the quadriceps muscle group, and correction of postural dysfunctions of the pelvis (Canadian Sports Therapy, 2003).

Furthermore, the knee and shoulder tend to be the most commonly injured joints in hockey. Therefore, the pre-season medicals should address these two problem areas. Ligament stress tests of the joints can give the examiner an idea whether the athlete may be predisposed to injuries in the upcoming year. An athlete can often have loose ligaments, and not know this. When it comes to a simple stop or cut on the ice, these ligaments may not be able to handle the excessive stress, and give way. The loose ligaments can only be surgically repaired, but a proper exercise program to strengthen the muscles around the joint can help avoid these unnecessary ligament injuries (Canadian Sports Therapy, 2003).

Another stage that needs to be addressed is the actual physical fitness level of the athlete. A physical fitness test should be conducted that is hockey-specific. Therefore, one should look at the strength and flexibility of the lower extremity, and the cardiovascular condition of the player. Often examiners will perform a vertical jump test to determine the leg strength of the hockey player. These tests should be guided to the age of the athlete, and the particular sport they are participating in. Sport-specific tests are important (Canadian Sports Therapy, 2003).

Astoundingly 40 % of all hockey injuries are either muscle pulls or contusions. These can be easily prevented through proper equipment fitting and conditioning of the athlete. An in-season off-ice exercise program would also be strongly recommended in the overall goal of preventing injuries. This would be especially important for athletes who have participated in some form off-ice program over the summer. The strength that was built up over the four months may reduce unless the athlete continues some form of conditioning away from the rink (off-ice). Professional hockey players will continue to work out off-ice all year long, even when they are playing and practicing every day (Canadian Sports Therapy, 2003).

Elite training requires high performance testing

According to Snyder & Foster (1994), few studies have attempted to increase the aerobic power and/or anaerobic capacity of hockey players through additional on-ice or non-ice training. While the duration of the added training program was brief in all cases (6-7 wk), improvements in aerobic power and skating speed and acceleration were achieved. Daub *et al.* (1983) in Snyder & Foster (1994) found no change (relative to control subjects) in the maximal or submaximal skating abilities of players who incorporated low-intensity (~ 74 % VO_2max) cycling exercise into an ice-hockey training program.

Off-ice testing *versus* on-ice testing

The cycle ergometre is frequently used to evaluate the aerobic and anaerobic capabilities of hockey players in the laboratory settings. Some research has indicated that the glycogen depletion patterns and muscles used in cycling are similar to those used in skating (Green*,* 1978).

According to Montgomery (1988), several studies have examined the specificity of on-ice testing versus laboratory testing of hockey players. Daub *et al.* (1983) examined the specificity of the metabolic and cardiorespiratory responses to training programs and to varied testing modalities and protocols. Training-induced adaptations were determined during submaximal and maximal conditions while skating and cycling. Ice-hockey training caused no change in VO_2max, HRmax or VEmax during the maximal skating test. Hockey training reduced both blood lactate, VE/VO_2, and R during the submaximal skating test;

however, these changes were not evident during maximal and submaximal cycling.

Another group of hockey players supplemented their training with 3 sessions per week of continuous cycling at 70 % of VO_2max. Initial duration was 30 minutes and progressed to 45 minutes. Hockey practices or games averaged 6 days per week over the 14 week season. The hockey and cycling programs resulted in adaptations similar to those observed during submaximal ice skating following hockey training. There was no significant decrease in heart rate during the submaximal cycling test. The conclusions were that the adaptive response was specific to the type of work used in training and the type of ergometre used to evaluate training (Montgomery, 1988).

In an investigation of the specificity of the VO_2max response, runners and hockey players were tested on-ice and on the treadmill (Léger *et al.,* 1979). Hockey players had the same VO_2max 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 *et al*. (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 VO_2max testing, both runners and hockey players had a 10 beats/min lower maximal heart rate 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). Since the test duration was relatively short (5 to 10 minutes), the subjects probably did not elevate the core temperature to an extent where it could compensate for the lower ambient temperature (Montgomery, 1988).

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. On-ice performance tests are recommended as an essential part of the hockey player's physiological profile.

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

Mascaro *et al.* (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. The vertical jumps scores, as calculated by the Lewis formula, were highly correlated with knee extension power at 180 °/sec.

Why testing off-ice is important

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 (Canadian Sports Therapy, 2003).

Once the athletes have attained a general fitness level, they should strive to attain a higher level of sport-specific physical fitness. Such specificity can vary considerably from one sport to another. For instance, the specific physical fitness requirements differ considerably between a long distance runner, a football player and a hockey player. Therefore, the fitness evaluation should, as much as possible, be specific of the sport. For example, one would not test a hockey player for their vertical jumping abilities as they rarely jump in the game of hockey. However, in a sport such as volleyball or basketball, the vertical jump test would be essential to the physical abilities of the athlete. The overall evaluation of the athlete should include measurement of both the general and specific components of physical fitness. The tests selected here to have the greatest significance in relation to the sport of hockey. The tests that are performed are easy to administer. They are not time-consuming and require little special equipment. Furthermore, most of these tests can easily be incorporated into an off-ice training program and become an incentive for the players, as well as, a source of information for the coach. The tests and measurements are easy to interpret and should be carried out regularly before and throughout the entire hockey season (Canadian Sports Therapy, 2003).

The basic recommended off-ice tests and measurements aim to evaluate:

a) body weight;
b) height;
c) muscular endurance;
d) muscular power;
e) aerobic power; and
f) anaerobic endurance

(Canadian Sports Therapy, 2003).

The validity and reliability of the proposed tests have already been established in the literature. Furthermore, these tests have been widely used in field evaluation. Several other tests and measurements could also be included in this battery; the recommended list should be sufficient to meet the needs of most coaches (Canadian Sports Therapy, 2003).

The tests are:

a) height measurement;
b) weight measurement;
c) sit and reach (back and hamstring flexibility);
d) grip Strength (arm power)*;
e) sit-ups (trunk and abdominal endurance);
f) push-ups (upper body endurance);
g) broad Jump (lower body power);
h) 50 metre (55.5 yards) sprint (anaerobic capacity); and
i) 12 minute run (aerobic endurance)

*requires special equipment.

Larivière *et al.* (1976) used the following off-ice tests for evaluating ice-hockey players: hand-grip strength, leg and back extension strength, arm pull-ups and dips, and physical work capacity (PWC_{170}). Mascaro *et al.* (1992) included the following functional off-ice tests in evaluation of ice-hockey players: 40 yard dash, standing long-jump, and isokinetic testing of the quadriceps and hamstrings at speeds of 60 °/s and 180 °/s.

Montgomery *et al.* (1990) validated a cycling test of anaerobic endurance for ice-hockey players. The intermittent cycling test consisted of six repetitions, each 15 seconds in duration with each repetition separated by a 15 second recovery interval resulting in a total work time of 90 seconds and a work to recovery ratio of 1:1. Gilder & Grogan (1993) used tests of flexibility, push-ups, sit-ups, standing long jump, body composition, height and weight as a pre-test before an off-season conditioning program.

Many leading hockey coaches, trainers and teams have recognized the importance of accurate, objective and sport-specific fitness testing in developing the players, coaching and the team or organization. Sport-specific testing allows the players and coaches to optimize training for hockey. Following the athletic and team development with player and team profiles, which are a result of a well-developed testing program, tremendous improvement can be achieved within an organization. The test results offer tremendous potential for positive impact on motivation, skill and fitness development in individual athletes. The test results can be used as milestones, which direct the development of the player (Montgomery *et al.,* 1990).

Individual player results can be pooled to the database and teams can create team profiles, which then can be compared with one another. This information helps coaches to evaluate if players in the team are at the similar physical performance. The team's training programs can be improved by enhancing the performance of players who are behind the others. At the organizational level, the team development can be directed by following the team results to the ones acquired before (the database). Now coaches can compare if the teams in the organization are progressing at the desired level. This is the quality control of coaching in the hockey organization from the grassroots level all the way to the top. Once this approach has been adopted, it will have a profound effect on the success of that particular organization (Montgomery *et al.,* 1990).

If a conditioning program is never evaluated, there is very little way of knowing whether the system is working as effectively as possible. On a personal (player) level the benefit of testing is that it provides the player a target to work towards. A test-retest approach helps the coach to track the individual progress of every player. Testing provides warning signals when the training program is not working or when the players are losing the level of physical performance (Montgomery *et al.,* 1990).

Players can be tested right after the season or at the beginning of the off-season training to give them a base level. Players should be tested at the end of each training cycle to evaluate the performance and fine-tune the program for the next training cycle. At the latest, players should be tested at the beginning of the pre-season training camp. During the season, the players can be tested periodically according to the teams needs.

Testing can be conducted in a variety of ways. It can be done in sports medicine clinics that specialize in testing services. Often these services even though done with highly skilled experts and state-of-the-art equipment, may be impractical and too expensive. Ideally testing should be as specific to the demands of ice-hockey as possible with a good selection of hockey specific field tests (Montgomery *et al.,* 1990).

Identification of physiological attributes which are indigenous to a particular athlete in a given sport helps in player recruitment, helps in identifying strengths and weaknesses in the athlete subpopulation and leads to the development of sport-specific training and testing (Cox *et al.,* 1995).

According to Cox *et al.* (1995) athlete, testing can serve many important functions for a player, team and organization. Athlete testing can help to:

a) identify strengths and weaknesses of the individual athletes;
b) identify physiological potential;
c) identify specific types of injuries that can be reduced or eliminated;
d) identify training regimens;
e) quantify physiologically the response to a training program;
f) monitor the effectiveness of the training programs continuously and adjusted these programs to meet individual needs;
g) promote goal setting in players and increase motivation;

h) yield consistent and comparable results (can compare team and individual scores to the larger population);
i) develop better training programs;
j) improve rehabilitation programs;
k) monitor the fatigue and overtraining in players;
l) identify the strengths and weaknesses at team/ organizational level;
m) aid player selection by the positions;
n) improve talent identification and player scouting;
o) improve time management: testing can be done when needed and where training takes place; and
p) save money – accurate and reliable testing can be done.

Although it is possible that elite hockey players have a genetic physiological predisposition, the ability to potentate this genetic endowment can be a challenging and frustrating undertaking. In this regard, physiological testing not only provides precise information to develop potential, but also offers a motivational basis for training and allows for the establishment of objective measurable goals. Such programs can help offset the rigors of travel during a greater than 95-120 game schedule over 6 to 9 months, depending on championship playoffs. The frequency of games, combined with the travel requirements, can create an atmosphere of mental staleness and lack of desire to physically train. Finally, specific types of injuries may be reduced or eliminated through improved training techniques. Furthermore, physiological assessments provide the basis to evaluate rehabilitation and a player's readiness to return to the game following an injury. Such measures help the team physician determine if the athlete is ready to return while minimizing the risk of injury recurrence (Cox *et al.,* 1995).

As with all sports, for the athletes to benefit from scientific testing the assessment must:

a) be specific to the sport, meaningful and applicable to training development;
b) use measures that are valid and reproducible; and
c) be conducted on a regular schedule (Cox *et al.,* 1995).

According to Snyder & Foster (1994), testing of ice-hockey players has included measures of:

a) anthropometry (height, weight, percentage body fat, lean body mass, and body surface area);
b) anaerobic power and capacity;
c) cardiovascular fitness (usually tested on a treadmill or cycle ergometre, with very few actual skating tests having been performed); and
d) musculoskeletal strength (grip strength, maximal bench press, or isokinetic determination of knee and shoulder strength) and flexibility (tested at the shoulder, hip, and knee joints), but many of the testing protocols have not been specific to ice-hockey.

Physiological testing and injury

According to Cox *et al.* (1995), the probability that a player will be injured during the season is high. Injury patterns also indicate that most injuries occur when players are tired and fatigued, although such subjective observations are difficult to prove scientifically. Human performance assessments provide the basis for both preventative and therapeutic regimens to be developed objectively.

Moreover, such assessments can be used to evaluate rehabilitation and a player's readiness to return to the game following an injury.

Elite athletes are not immune to detraining. The physiological advantages gained through properly designed training programs begin to disappear within 1 to 2 weeks following training cessation. The detraining effect is further exacerbated if bed rest is needed in combination with the termination of training. All those concerned with returning a previously injured athlete to competition must recognize this important fact. For example, if a joint injury removes a player from competition and training for longer than 5 days, the player should be evaluated not only for strength, time to peak torque, speed and specificity of movement pattern, but also for cardiorespiratory reserve. These values must be compared with baseline data collected during the pre-season. Although knee function may be returned, central and peripheral detraining may predispose the athlete to further injury if he is sent into competition prematurely (Cox *et al.,* 1995).

Comparing post injury data with pre-season 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. In the long term, using the science of physiological assessments to help in objective diagnosis and prognosis of athletic injuries will serve the athlete, team and physician well (Cox *et al.,* 1995).

On-ice evaluation

Why testing on-ice is important

Very rarely during a game, a hockey player is required to skate at an average speed for a long period of time. Therefore, cardiovascular efficiency is so vital to most sporting performances that such tests are appropriate for any hockey player. An objective of pre-season, off-ice training should be to increase this cardiovascular endurance. However, in training during the season, the coach must incorporate enough aerobic type exercises in practice sessions to maintain aerobic power at its optimal level. On-ice tests can determine what areas that you the individual or team need to develop to become better all-around players. The on-ice tests are the following:

a) Skating Power

In game situations, a player's shift varies between 45 and 90 seconds in duration. The player must repeat this physical effort several times during a period; thus, there is a requirement for intermittent intensive work. A player will often be required to go all out during a shift, thus utilizing their skating anaerobic (short periods without oxygen) power. This, combined with the brief recovery time between shifts and periods of intense activity within a shift, is why hockey is considered as one of the most strenuous sports. The skating power test is a functional evaluation in that it takes into account physical fitness, as well as, possible skill efficiency differences among players (Canadian Sports Therapy, 2003).

b) Skating Agility With The Puck

This test measures the ability of the player to carry the puck effectively while skating in various directions. The player must carry the puck very often in game situations. Some players show a marked decrease in their skating agility and speed as soon as they have to control the puck. A beginner carrying the puck usually shows a decrease in skating ability, but this difference should be minimized in the more advanced player categories (Canadian Sports Therapy, 2003).

c) Skating Agility Without The Puck

This is also a very important skill for any hockey player. The ability of the player to manoeuvre around opposing players or to support their team's tactical play (i.e. breaking out of the zone) is of prime importance. Furthermore, skating agility relies upon several other skating skills such as stopping, turning, crossing-over, etc. For these reasons, skating agility represents an excellent evaluation of the player's overall skating skill (Canadian Sports Therapy, 2003).

d) Forward Skating Speed

Forward skating speed is needed in many game situations when the player must break away from an opponent or cover their opponent in a back-checking situation. Hockey is a game of constant acceleration and deceleration. The capacity of a player to increase their skating speed from a stationary position is a tremendous asset to their hockey performance (Canadian Sports Therapy, 2003).

e) Backward Skating Speed

Hockey coaches often underestimate the importance of backward skating skills for players other than the defensemen. All players must develop excellent backward skating speed and agility because very often they will be called upon to change positions while the play is developing. For instance, a forward may temporarily replace a defensemen caught deep in the offensive zone. Of all the skating skill tests, backward skating must be considered as one of the best for discriminating between good, average, and poor skaters (Canadian Sports Therapy, 2003).

From a coaches perspective;

Determining the teams' physical strengths and weaknesses will make them a winning team. This process can make the coach's job easier, and establish what areas their team needs to focus on to obtain that winning formula (Canadian Sports Therapy, 2003).

From an individuals perspective;

When a player is more physically fit than the rest of the team, the player will stand out among the others (Canadian Sports Therapy, 2003).

Merriefield and Walford (1968) state that the use of well-constructed tests can aid the coach in recognizing different ability levels, in determining progress, in selecting best performers, and in recognizing strengths and weaknesses of the participants within the activity. The authors used a battery of six skill tests. These tests included forward skating speed, backward skating speed, skating agility, puck carrying, shooting, and passing.

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. Bracko (1998) tested 23 female ice-hockey players using the following on-ice tests: 6.10 metre acceleration, 47.85 metre speed, 16.3 metre full speed, agility cornering s-turn, and Reed Repeat Sprint Skate Test (RRS).

Lane *et al.* (1997) investigated the relationship between levels of maximal aerobic power and the ability to recover from high-intensity, on-ice skating sprints. The authors compared peak power from a modified Wingate test and VO_2max from a cycle ergometre test with different segments of a high-intensity, on-ice skating test. This test consisted of eight repeats of 36.6m with each repeat separated by a 20s passive recovery period, regardless of the time taken to skate the trial. Heart rate was recorded every 15 seconds during the 4 minute recovery that immediately followed the last trial of the skating test. The drop-off and the percent heart rate recovery were both significantly correlated with VO_2max. The authors found a significant correlation between peak velocity and peak power. These results indicate that the on-ice skating test can provide information on peak power and the ability to perform the final repetitions at the same level of performance as the initial trials. A slight relationship also appears to exist between VO_2max and the ability to recover form repeated, high-intensity, on-ice sprints.

Ice skating performance tests measure both physiological endowment and skill. One popular test of aerobic endurance is the 8 minute skate. An oval course (140 m) is set with players instructed to skate as far as possible in 8 minutes. Norms have been published for minor league hockey players (Larivière *et al.,* 1976). Average velocity for players was as follows:

a) pee-wee = 295±24m/min;
b) bantam = 316±31m/min;
c) midget = 341±27m/min; and
d) junior = 375±11m/min
(Montgomery, 1988).

Doyle-Baker *et al.* (1993) tested 20 national team female players with on-ice tests. The players performed the following three on-ice tests: 2.1 m and 56.4 m sprint, 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.

The Reed Repeat Sprint Skate Test (Figure 2.2) consists of six bursts of maximum velocity skating for 91.4 m (300 ft). Repeats are initiated every 30 seconds. The time to skate one length of the ice (54 m) is designed as the speed index. The total time for the six repetitions is the anaerobic endurance component. A drop off index is calculated as the time difference between the slowest and fastest repetitions. Heart rates are measured immediately upon completion of the test, and 3 and 5 minutes post-exercise. Recovery is calculated as the difference between the exercise and post-exercise heart rates. The test is widely used in Canada to evaluate on-ice fitness. A modified version (4 repetitions) of the repeat sprint skate test has been used with young hockey players (Montgomery, 1988).

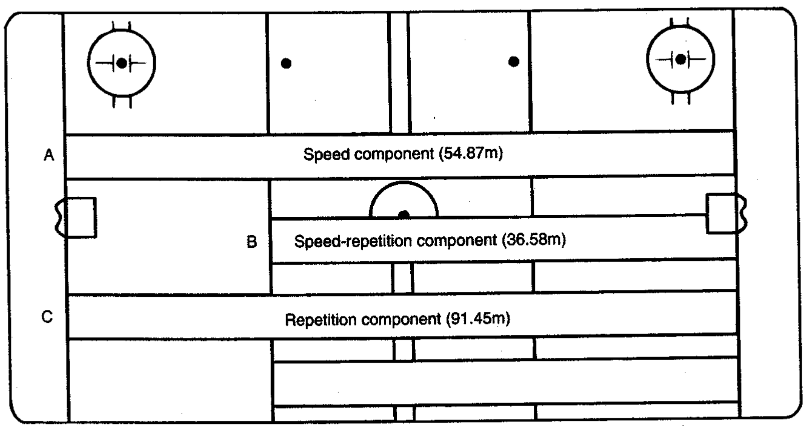


Fig. 4. The Reed Repeat Sprint Skate (RSS) consists of 6 bursts of maximal velocity skating (91.45m), with repeats started every 30 sec. Anaerobic power is indicated by the time to skate 1 complete length of the ice. Anaerobic capacity is assessed by the total time to skate the 6 repetitions.

FIGURE 2.2 REED REPEAT SPRINT SKATE TEST (Cox *et al.,* 1995).

Montgomery (1988) recommended an aerobic skating test indicated in Figure 2.3.

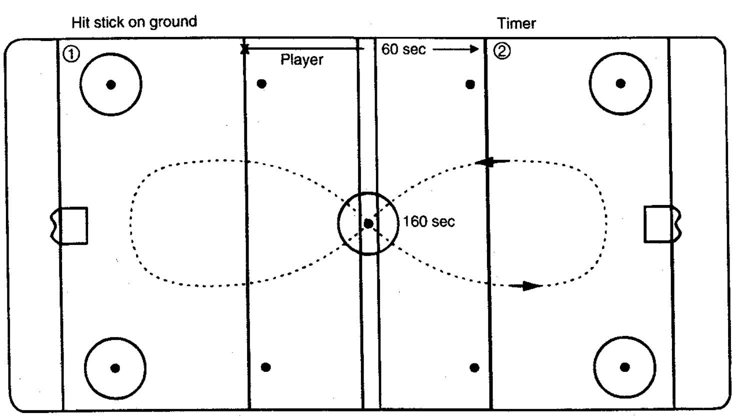


Fig. 3. The aerobic power skate involves a constant paced skate, completing 40 laps in as short as time as possible. Players begin at the centre ice and have a test administrator count and time the laps.

FIGURE 2.3 THE ON-ICE AEROBIC TEST (Cox *et al.,* 1995).

When a battery of ice-hockey tests are 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.

Gunning *et al.* (1996) tested 31 top Australian junior ice–hockey players on- and off-ice. An on-ice sprint test was performed over 78.3 metres. Athletes had to sprint from goal line to goal line (47 metres), pivot, and sprint back up the rink to the zone line (78.3 metres). Each player completed six repetitions with each trial commencing on a 30 second cycle. Split times were recorded at 5, 40, 47 and 78.3 metres. Heart rte was recorded immediately upon completion of the sixth effort and 3 min (4-12 mmol/L) and 5 min (5-14 mmol/L) post exercise. Earlobe lactate samples were drawn at three and 5 minutes post exercise. For sprint testing light-gates (photocells) were placed at 5, 10, and 40 metres). The results are indicated in Table 2.7.

TABLE 2.7 GENERAL MEAN DATA ±SD FOR DIFFERENT ICE-HOCKEY POSITIONS

	Forward (n=17)	Defender (n=10)	Goal Keeper (n=4)	Group Total (n=31)
Age (years)	14.9±0.7	15.1±1.2	15.9±0.8	15.1±0.9
Height (cm)	166.1±7.4	173.9±6.6	174.6±6.3	169.7±7.9
Weight (kg)	57.3±6.6	70.5±9.0	73.0±10.0	63.6±10.4
Sum 8 Skinfold (mm)	76.7±38.4	95.1±40.7	99.3±63.3	85.5±42.2
Vertical Jump (cm)	42.9±8.0	44.5±6.1	46.5±6.6	43.9±7.1
Sit and Reach (cm)	8.4±7.5	7.5±7.6	6.6±9.4	7.9±7.5
VO_2max as estimated by 20 MST (ml/kg/min)	46.21±5.58	46.45±5.29	48.15±5.84	46.54±5.37
5m Sprint (ground) (s)	1.08±0.05	1.09±0.07	1.11±0.06*	1.09.06[a]
40m Sprint (ground) (s)	5.90±0.42	5.87±0.36	5.93±0.37	5.89±0.38[a]
5m Sprint (ice) (s)	1.51±0.15	1.45±0.12	1.72±0.10	1.52±0.16
40m Sprint (ice) (s)	6.19±0.45	6.29±0.31	6.85±0.33	6.31±0.44

* significant difference across positions ($p<0.05$)

[a] significant difference between sprint on land and on ice ($p<0.05$) (Gunning *et al.*, 1996).

2.2.2. Criteria For a Fitness Test

Tests should comply with the following criteria:

a) they should be valid- that is, they measure what they claim to measure;

b) they should be reliable- that is, they are consistent and reproducible;

c) they should be sport-specific;

d) they should be scientifically sensitive to detect small changes in the athlete's state of fitness and performance; and
e) they should cover a wide range of sporting disciplines (Hawley & Burke, 1998).

All laboratory and field tests should be both valid and reliable. This is a function of choosing tests well, and then standardizing the conditions and equipment for testing. In real life, 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).

For some sports, it may be preferable to assess athletes by field tests rather than by 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. 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).

Standardization of testing procedures

Consistency is crucial if the results of various physiological test undertaken at different stages of the athlete's preparation are to be comparable. Testing should be conducted under the following standardized conditions:

a) select a dedicated quiet area which is free from other influences and disturbances;
b) conduct tests in a well ventilated area, with the laboratory temperature 20-22 °C and the relative humidity at less than 60 %;

c) conduct the test procedures without peripheral personnel who may influence the performance;
d) ensure that the same practitioner is employed in subsequent testing; and
e) ensure that all laboratory equipment is calibrated before testing according to the procedures and instructions for that specific apparatus
(Hawley & Burke, 1998).

The athlete(s):

a) check that the athlete is not suffering form any condition, which may adversely affect performance, such as a cold or an injury. An athlete with a viral infection should not be allowed to perform any test, no matter how mild the condition may be considered;
b) ensure that the athlete has not undertaken any intensive training or competition for 48 hours prior to a test, nor performed a similar test with in the previous 72 hours;
c) ensure that the athlete has not eaten for two hours before a maximal test. Allow fluids such as carbohydrate-electrolyte solutions or water to be taken without restriction in the hours before the test. Note that some individuals are susceptible to reactive hypoglycaemia if they ingest beverages with high sugar content in the 30-60 minutes before strenuous exercise. In these athletes this practice should be avoided;
d) prior to any test procedure, allow the athlete to perform their own warm-up routine, which must then be standardized for subsequent tests; and

e) ensure that the athlete uses the same equipment they utilize during training and competition, such as racing shoes, clothing and other specialized gear.
(Hawley & Burke, 1998).

Test procedures:

a) ensure that the athlete is familiar with wall the test equipment before starting any tests;
b) explain, in detail, all the test procedures to the athlete, particularly those with which the athlete is unfamiliar;
c) ideally, allow the athlete to become habituated to all test procedures. Usually it takes two or three performances of the criterion test before the rests reflect true performance; and
d) for the most valid and reliable results, schedule physiological tests during the mid-to-late afternoon or early evening period, when strength and endurance are optimal
(Hawley & Burke, 1998).

Montgomery (1988) recommended criteria to structure a fitness test to evaluate the physical capacity to play hockey. Recommendations for the hockey fitness test were:

a) maximum performance of the anaerobic type;
b) long enough to tax the anaerobic mechanism;
c) repeated efforts for as many bursts as a shift will involve; and
d) assess physical capacity based on one's ability to perform the final repeats at the same level of performance as the initial trial.

Cardiorespiratory endurance is generally recognised as a major component of evaluating physical fitness and maximal oxygen consumption (VO_2max) and is considered the most valid measure of cardiorespiratory fitness (Gabbard, 1992). Sport-specific tests are highly valued in exercise science, including tests for cardiorespiratory endurance and maximal oxygen consumption. 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 Montgomery (1988).

Laboratory determination of VO_2max

The test for VO_2max 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, and is probably the best assessment of the athlete's endurance capabilities (Hawley & Burke, 1998).

VO_2max is a good predictor of endurance potential when a group of athletes with vastly different performance capabilities are studied. It is relatively poor predictor when athletes of similar ability are evaluated. Part of the reason that VO_2max of an athlete is not the single best predictor of athletic potential is because it is only one of many physiological variables positively related to successful endurance performance (Hawley & Burke, 1998).

The most frequently employed laboratory protocols for assessing VO_2max are progressive, incremental exercise tests to exhaustion on either a cycle ergometre or a motor-driven treadmill. Although testing protocols will vary between different sport science laboratories, an athlete will usually be required to exercise for seven to ten minutes while the exercise intensity (either speed of movement or the power output) is progressively increased until the athlete is exhausted. For rowers, the Concept II rowing ergometre is utilized; but instead of a progressive maximal test, the VO_2max values are measured during a simulated competitive effort over 2000 metres. Oxygen uptake (VO_2max) values determined during simulated maximal efforts are typically 6-7 % higher than those recorded during a standard rowing ergometre test of increasing intensity. As such, this value is often referred to as the athlete's peak oxygen consumption (VO_2peak) (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, called the respiratory exchange ratio (RER), allows an estimate of the type of fuel being used during exercise to be determined. The sport scientists have both objective and subjective criteria for determining whether the athlete has produced a true maximal effort. Such criteria include:

a) severe fatigue, or exhaustion resulting in the inability of the athlete to maintain exercise at the desired work rate;
b) a subjective rating by the athlete that their perception of effort is maximal;
c) a plateau in the athlete's heart rate for several minutes despite an increase in the work rate; and
d) an RER value greater than 1.15
(Hawley & Burke, 1998).

Snyder & Foster (1994) believe that an exercise test can benefit the athlete and coach only if it meets three criteria: a) there must be a high correlation between the test measure and subsequent competitive performance; b) the test must be able to detect changes in the competitive fitness of the athlete; and c) the test must allow the athletes to set goals. The 20 MST fulfils all three of these requirements. 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.

Validity and reliability

The 20 metre multi-stage shuttle-run test (20 MST) originally designed by Léger & Lambert (1982), and later refined (Léger *et al*., 1988) is a popular field test of aerobic power. It fulfils all three the above-mentioned requirements of an exercise test, and is relevant to sports such as soccer and hockey (Grant *et al*., 1995), where turning is a feature of the game. Furthermore Paliczka *et al*. (1987) state that the 20 MST is an appropriate field test of aerobic endurance because the requirement for pace judgement is eliminated by the use of a pre-recorded audio signal; the incremental nature of the test ensures a gradual rise in work-rate and therefore heart rate; the test appears to be highly reliable (r= 0.975; Léger & Lambert, 1982); and large numbers can be tested simultaneously. The 20 MST is similar to treadmill protocols in being a safe progressive and maximal test, but is less expensive and time consuming than direct measurements (Van Mechelen *et al*., 1986; Boreham *et al*., 1990). It can thus be accepted that the 20 MST appears to be a valuable test in predicting the maximal aerobic power of both males and females when performed over-ground on most types of natural and synthetic gymnasium surfaces (Léger & Lambert, 1982; Van Mechelen *et al*., 1986; Paliczka *et al*., 1987; Léger *et al*., 1988; Boreham *et al*., 1990). However, the application of the 20 MST to individuals participating in activities such as figure skating and ice-hockey, that are performed on-ice as opposed to over-ground surfaces, has not been investigated in depth.

The 20 MST is based on a linear relation that links the increase of running velocity to the rise in oxygen consumption (Ahmaidi *et al*., 1992). There is a linear relationship between oxygen consumption and running velocity, and a strong correlation exists between running performance (20 MST) and VO_2max when individuals with a large range of VO_2max values are represented (Ramsbottom *et al.,* 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. In adults, VO_2max was related only to maximal speed with similar results for male and female subjects above and below 35 years of age. It is therefore safe to conclude that the 20 MST is a reliable field test to measure VO_2max.

However, according to Léger & Lambert (1982) the prediction of VO_2max from submaximal heart rate has been criticised for its lack of accuracy, especially on an individual basis. Van Mechelen *et al.* (1986) validated the maximal 20 m shuttle run test (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 VO_2max than endurance runs because it has a protocol of increasing speed which is much in accordance with the loading pattern of a VO_2max test. Léger & Lambert (1982) state that the 20 MST has yielded results similar to conventional incline treadmill tests, whether direct or indirect VO_2max values were considered.

The 20 MST has already been proven valid and reliable (repeatable) to measure VO_2max (Léger & Lambert, 1982). Léger *et al.* (1988) state that previous observations regarding the validity of the 20 MST to predict VO_2max are based on the assumption that the maximum work rate is reached at the end of the 20 MST and that such an assumption is supported by: (a) maximal heart rate values reached at the end of the 20 MST; (b) similar values for the VO_2max measured at the end of a maximal multistage treadmill test, and retro-extrapolated VO_2max for the 20 MST; and (c) high inter-correlations between these VO_2max values.

Ice-hockey is of high-intensity and intermittent in nature. The length of a shift can vary from several seconds to over two minutes, with players being active for a total of 15-20 minutes of intermittent play, out of the 60 minutes total duration of a game (Snyder & Foster, 1994). Given the nature of the game, the stop-and-go nature of the 20 MST test would seem to be an ideal field test of aerobic power for ice-hockey (Bracko, 1998). In earlier work, Léger *et al.* (1979) confirmed the specificity of physiological responses of ice-hockey players by showing higher VO_2max and lower lactate values when tested with and without equipment using a 20 m shuttle and 140 m oval course on-ice *versus* a treadmill, respectively.

Since the refinement and validation of the 20 MST for over-ground use (Léger *et al.*, 1988), the relationship between the actual and estimated VO_2max responses while performing the MST on-ice appears not to have been established. In cognisance of the foregoing, the aim of this study was to investigate variations between the predicted indirect VO_2max and the simultaneously measured direct VO_2max values of ice-hockey players and figure skaters whilst performing the 20 MST on-ice.

Hockey and Howes (1979) compared skaters' heart rates 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 VO_2max was 0.62, while that between the 12-minute skate test and the VO_2max was 0.60).

Specificity

According to Montgomery (1988) in the physiological evaluation of athletes, it is imperative that the testing protocol be specific to the demands of the sport. Bracko (1998) states that skating ability is a significant factor when selecting a player for a team. In addition, game performance hockey is such a complex motor skill that it is essential to include valid and reliable on-ice skating tests as part of the testing protocol of hockey players. According to Bunc *et al.* (1987) the specificity of the loading apparatus also helps in evaluating the technique of the movement performed, which is essential in sports events in which training starts early during the growth period.

Bunc *et al.* (1987) state that when trained subjects (female canoeists and rowers) are subjected to an unspecific load (bicycle ergometre), the values recorded of percentage VO_2max 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.

According to Snyder & Foster (1994), cardiovascular fitness has usually been tested on a treadmill and cycle ergometre, with very few actual skating tests having been performed. Most tests specific to ice-hockey measure variables related to anaerobic metabolism. Among these tests the *Sargeant Anaerobic Skate Test (SAS_{40}),* which 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; the *Reed Repeat Sprint Skate Test (RSS)*, which requires players to skate 55 m six times every 30 seconds; the *Wingate test lengthened to 40 seconds (WAT_{40});* and a cycle ergometre test of six 15-second exercise: rest periods *(RACE).* Hockey and Howes (1979) compared skaters' heart rates and predicted caloric expenditure during a 12-minute skate test and a 12-minute run test.

Cardiorespiratory endurance is generally recognised as a major component in physical fitness and maximal oxygen consumption (VO_2max) is considered the most valid measure of cardiorespiratory fitness (Gabbard, 1992). Sport-specific tests are highly valued in exercise science, including tests of cardiorespiratory endurance and maximal oxygen consumption.

According to Ferguson *et al*. (1969), 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.

Léger *et al.* (1979) state that functional skating capacity test or a performance test appears more informative than the VO_2max score to establish the ability of a player to perform aerobic skating. This does not imply that the VO_2max 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.

Ice-hockey is high-intensity and intermittent in nature, the length of a shift can vary from several seconds to greater than 2 minutes (Snyder & Foster, 1994), and during a game of ice-hockey, players are active for a total time of 15-20 minutes of intermittent play (Léger *et al.*, 1979). The 20 MST test was selected due to its stop-and-go nature, which is similar to the mechanics of ice-hockey during a game (hockey players alternate between straight striding, gliding and turning during a game) (Bracko, 1998), due to the fact that it is maximal and progressive, which is similar to treadmill protocols, and also due to its practicability (Van Mechelen *et al.*, 1986; Boreham *et al.*, 1990). Léger *et al.* (1979) also confirm that the skated 20 MST with equipment more closely approximates the nature of skating seen in a game, and appears preferable to the 140 m test. The 20 MST is a practical, less time consuming than direct measurements, inexpensive and safe maximal test. A key advantage being the utilisation of the same protocol for all groups. It therefore has a potential to test large groups at the same time in field settings, and making it possible to do longitudinal or cross sectional comparisons at all ages (Léger & Lambert, 1982).

It can be concluded that the maximal multistage 20 m shuttle run test, with stages increasing by 0.5 km/h or 1 MET (3.5 ml O_2/ kg/ min) every minute from a starting speed of 8.5 km/ h 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 *et al.*, 1986; Paliczka *et al.*, 1987; Léger *et al.*, 1988; Boreham *et al.*, 1990).

The lower values in maximal velocity attained during the 20 MST may be explained by the biomechanical parameter alterations of running back and forth. Starting, speeding up, slowing down, stopping, and changing direction during the 20 MST involves broken acceleration and causes a marked vertical displacement of the centre of mass and lower stride efficiency. As the subject approaches his maximal effort, acceleration plays a critical role in determining the maximal velocity; certain individuals may stop before reaching their real maximal velocity because their acceleration is not sufficient. It should be noted that maximal velocity for the 20 MST is in fact an average velocity over a distance of 20 m and this may explain the lower values (Ahmaidi *et al.*, 1992).

The study by Léger *et al.* (1979) compared the VO_2max of ice-hockey players and runners by using four different tests (a skated 20 MST with and without equipment, a treadmill test, and a 140 m oval course). It was decided to reinvestigate the problem using only the 20 MST as an on-ice skated test to predict the skaters indirect VO_2max, and the *Aerosport*$_{TM}$ portable gas analyser to determine direct VO_2max whilst the subjects skated the on-ice 20 MST rather than using the treadmill or cycle ergometre. According to Léger *et al.* (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, "*requiring 15 % less energy to skate the same speed",* but also requiring 7.9 % more energy to run on the treadmill. Léger *et al.* (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.

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 (VO_2max). Both projected area and drag coefficient decreased progressively from walking and running, to cycling and to skating. The fact that the skaters in this study were wearing full ice-hockey kit and skated with their hockey sticks, would increase air resistance. This, however more closely simulates the game of ice-hockey, and the VO_2max values obtained should be very accurate and in close approximation of the skater true VO_2max.

Snyder & Foster (1994) state that maximal values of aerobic power are generally higher in athletes when they perform *specific skills* rather than generic skills, but found this not to be the case in speed skaters where skaters reached no more than 85-90 % of the VO_2max 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. Di Prampero *et al.* (1976) found that in speed skating VO_2max is about 15 % lower than in treadmill running. In contrast Léger *et al.* (1979) states that VO_2max during skating is either higher or similar to the values obtained during treadmill running.

The nature of the multistage test is such that subjects do not work long enough at higher power output to raise their body temperature to a high level to compensate for the much lower ambient temperature prevailing on the ice (Léger *et al.*, 1979). Ramsbottom *et al.* (1988) found that, during the 20 MST and especially in the later stages, the heart rate response was curvilinear, suggesting that the one-minute interval between shuttle levels, did not allow for steady state conditions to be attained. Thus, modifications to the 20 MST will possibly make the test more appropriate for use on-ice.

2.2.3. Direct (laboratory) vs. Indirect (field) Testing

Laboratory testing

Laboratory testing of athletes to try to identify sporting potential and predict performance is not a new phenomenon. Testing the athlete in the laboratory provides sport scientists with standardized conditions in which to collect reliable descriptive information about athletes. Until recently, this was academic because only a small number of athletes had access to laboratory facilities, and the tests they underwent did not usually allow sport scientists to make particularly accurate predictions of the athletic performance in the field. During the last twenty years, more sophisticated laboratory and field tests have been developed that provide the sport scientist and coach with more precise information about an athlete's potential (Hawley & Burke, 1998).

The primary benefits of laboratory-based exercise testing programs are:

a) to aid in talent identification;
b) to determine the physiological and health status of an athlete;
c) to construct a sports-specific physiological profile of an individual athlete or team;
d) to act as a motivational and educational process whereby the athlete and coach better understand the physiological components of their sport;
e) to provide baseline data for individual training program prescription and to identify each athlete's or player's strengths and weaknesses relevant to their sport; and

f) to provide feedback to coaches so that they can evaluate the success of their training interventions
(Hawley & Burke, 1998).

Although *direct measurement* is the single best measure of cardiorespiratory fitness or aerobic capacity, laboratory tests of VO_2max involve complexities and require extensive equipment, are time consuming and have a large financial cost. These maximal tests are also restricted to testing one subject at a time. Laboratory tests are often restricted to exercising on a treadmill or cycle ergometre with the subject required to wear a mask that is then attached to a gas analyser, and the subject then has to remain close to the equipment. Often, these are restricting factors for many people due to unfamiliarity and discomfort in the artificial conditions when compared to the actual sporting event. This artificiality often affects the results obtained (Léger & Boucher, 1980; Ahmaidi *et al.,* 1992; Grant *et al.,* 1995).

According to Bouchard *et al.* (1988), there is an intra individual day to day variability of 4-6 % in tests using ergometres due to such factors as errors in gas analysis and calibration, equipment calibration and familiarization with the task. Reproducibility on the cycle ergometre and treadmill are similar but bicycle VO_2max values are 7-8 % below the treadmill values. For these reasons, a test without any respiratory equipment and required expertise is perceived as a real advantage (Leger *et al.,* 1980; Boreham *et al.,* 1990).

Grant *et al.* (1995) showed that the 20 MST systematically under-predicted the VO_2max when compared to the treadmill VO_2max. Sproule *et al.* (1993) compared the results of direct (using treadmill running) and indirect (modified 20 MST) measurements of VO_2max of an Asian population and found that 75 % of the subjects had a lower predicted VO_2max value compared with their directly determined VO_2max, when the predicted VO_2max is based on performance in the 20 MST using the results reported by Ramsbottom *et al.* (1988).

Mc Naughton *et al.* (1996) found that the 20 MST (Léger *et al.,* 1988) starting speed of 8.5 km/h and increasing the speed by 0.5 km/h every minute) overestimated the VO_2max measurement by 15 %. The results of a study by 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 VO_2max values were found.

Indirect (field testing)

The 20m progressive multistage shuttle-run test

Fitness is a vital concern to everyone who takes part in sport, the athletes actively involved in their sport, and the coaches who train them have a keen interest in monitoring their progress. This shuttle-run test enables one to monitor one's cardiovascular endurance. This field test also requires minimal equipment, namely a cassette player and two markers placed 20 m apart. Because of its simplicity, this test can be used by thousands of people who do not have access to laboratory equipment. This test can be used by a wide range of sports people, from game players to athletes and a large group of people can be tested at one time. In order for the test to be effective in indicating progress, sensible time intervals (four to six weeks, for example) are required between each testing session. It should be noted that this is a test and a means of monitoring fitness, not a method of training. Because of the physical demands of the test, it would not be sensible to use it too close to competition (Brewer *et al.*, 1988).

This test provides a useful guide to one major aspect of fitness (cardiovascular endurance), which is largely determined by how effectively the heart and lungs are functioning. Measuring maximum oxygen uptake best indicates this. This test provides a sufficiently accurate estimate of oxygen uptake for most purposes (Brewer *et al.*, 1988).

A degree of caution is required in administering the test, in that the subjects have to push themselves relatively hard to the point where they can no longer maintain the pace dictated by the tape. If the subject is suffering from any injury or illness, or if the test administrator has any reason to think that the subject may not be in a good state of health, the subject should consult a doctor before doing this test (Brewer *et al.*, 1988).

The maximal multi-stage shuttle run test was designed by Dr Luc Leger and colleagues from the University of Montreal, Quebec, and first published in the scientific literature in 1988. Since then, the original protocol has been modified slightly by Professor Clyde Williams and co-workers from Loughborough University, England. The testing procedure is uncomplicated: the players are required to run back and forth for a distance of 20 metres on a playing field or gymnasium floor at a pace determined by a sound signal emitted from a pre-recorded audio-tape. The frequency of the sound signal gets progressively faster so that the running speed is increased by 0.5 km per hour for each minute of running. The starting speed is 8.5 km per hour, and, for fit players, the first few minutes of the test act as a good warm-up and allows them to get used to accelerating from a stationary position, decelerating, turning and then accelerating once more. Each stage of the shuttle lasts exactly one minute, and as the speed of each successive shuttle is increased, so to is the number of runs (called levels) within that time. The test is terminated when the player is no longer able to reach a 20 m line at the prescribed time dispute two verbal warnings. The last completed stage is defined as the maximal shuttle run speed.

A players VO_2max can then be obtained immediately upon termination of the test from the norm table. A degree of caution is required in administering the test, in that the subjects have to push themselves relatively hard to the point where they can no longer maintain the pace dictated by the tape. If the subject is suffering from any injury or illness, or if the test administrator has any reason to think that the subject may not be in a good state of health, the subject should consult a doctor before doing this test (Hawley & Burke, 1998; Brewer *et al.*, 1988).

Procedure:

Measure out the 20 metres and mark the ends with the marker cones. Put the cassette into the player. Make sure the tape is rewound to the start of the side (both sides of the tape are the same). It is advisable to warm up in preparation for the test by doing some gentle whole body activity, e.g. jogging, together with some stretching exercises, particularly working on the leg muscles. It is equally important to cool down on completion of the test by continuing to work the affected muscles in a gentle rhythmic fashion, again including some stretching. It would not be advisable to take the test too soon after a meal (Brewer *et al.*, 1988).

Start the cassette player. At the beginning of the tape, two bleeps indicate an accurately timed one-minute interval. Use this to check that the tape has not stretched, and that the speed of the cassette player is accurate. Accuracy within 0.5 sec either way is sufficient. The tape continues with a brief explanation of the test, leading to a four-second countdown of the start itself. Thereafter the tape emits a single bleep at regular intervals. The subject should aim to be at the opposite end to the start by the time the first bleep sounds. They should then continue running at this speed, being at the one end or the other each time there is a bleep. After each minute, the time interval between the bleeps will decrease, so that the running speed will need to be increased. The first running speed is referred to as "Level 1", the second speed as "Level 2", and so on. Each level lasts approximately one minute, and the tape continues up until level 23. The end of each shuttle is denoted by a single bleep; the end of each level is denoted by a triple bleep and by the commentator on the tape. It is important to note that the running speeds at the beginning of the start of the test are very slow. On Level 1, subjects have 9 seconds in which to run each 20-metre shuttle (Brewer *et al.*, 1988).

Subjects should always place one foot either on or behind the 20 m mark at the end of each shuttle. If subjects arrive at the end of a shuttle before the bleep sounds, they should turn around and wait for the bleep, then resume running and adjust their speed. Each subject should run as long as possible, until he/she can no longer keep up with the speed set by the tape, at which point he/she should voluntarily withdraw from the test. In some cases the test administrator may need to withdraw subjects when it becomes apparent that they are dropping behind the required pace. If subjects fail to reach the end of the shuttle before the bleep, they should be allowed two or three further shuttles to attempt to regain the required pace before being withdrawn. Observers should make a note of the level and the shuttles into the level at which the subject withdraws from the test. Using the given table, an estimate of the maximum oxygen uptake can be obtained (Brewer *et al.*, 1988; Cooper & Storer, 2001).

The test is maximal and progressive; in other words, easy at the start but harder towards the end. For the results to be valid subjects must give their maximum effort when performing the test, and therefore attempts to reach as high a level as possible before stopping. Large numbers of people can be tested at any one time, although the observers must be able to cope with the recording of levels and the shuttles as the subjects drop out. Approximately 1 to 1.5 metres of width are required per person (Brewer *et al.*, 1988). According to Cooper &

Storer (2001), the frequency of the cues is increased 0.5 km/h (8.33 m/min) every 2 minutes from a starting speed of 8.0 km/h (133.3 m/min or 5 mph).

Restrictions

a) athletes may not run wide circles, they must place their foot just over the line and then turn immediately to face the opposite direction; and
b) athletes must receive two warnings for not reaching the line at the time of the auditory signal before the test is ended on the third warning.

Scoring:

When the subject is no longer able to reach the 20 m distance on cue (defined as more than 3 m away), the last fully completed stage number is recorded and used to predict maximal oxygen uptake corresponding to the final stage. The athlete's score is taken as the last shuttle where their foot crossed the line prior to or at the same time as the signal (Cooper & Storer, 2001).

$$VO_2max = (5.857\ S) - 19.458$$

a) VO_2max is expressed in millilitres of oxygen per kilograms of body mass per minute;
b) S is the speed corresponding to the last completed stage expressed in kilometre per hour; and
c) Speed can be obtained from the table or calculated in km/hour using the following formula:

$$8 + [0.5(\text{completed stages} - 1)]$$

Table 2.9 indicates speed at each stage, the corresponding time per shuttle (for use in recording the audiotape), shuttles to be completed per minute, distance covered in each stage, and estimated VO_2max (Cooper & Storer, 2001).

In the 1990's the multistage shuttle run has become an integral part of aerobic fitness testing and training for many team sports. It is now widely accepted as the best test for the determination of aerobic fitness in players from team sports. This is because, compared with either the 15 minute run or a laboratory measurement of VO_2max, the shuttle run:

a) is sport-specific;
b) is portable and can be conducted on any playing surface;
c) is simple to administer;
d) does not require expensive or extensive equipment or highly qualified personnel;
e) allows many players to be tested at once, in a competitive setting; and
f) allows the same protocol to be used for players from a variety of sports and varying ages

(Hawley & Burke, 1998).

It is clear that the VO_2max varies between players from different sports and between players from the same sport (Hawley & Burke, 1998). Table 2.8 indicates estimated values for maximum oxygen uptake from the multi-stage shuttle run in players from a variety of different sports.

TABLE 2.8: ESTIMATED VALUES FOR MAXIMUM OXYGEN UPTAKE FROM THE MULTI-STAGE SHUTTLE RUN

Sport	*n*	*Level & Shuttle*	*VO_2max (mi/kg/mm)*
Rugby Union			
New Zealand 'A' (pre-season)			
Forwards	50	L12-S3	54.6
Backs	43	L13-S9	58.6
New Zealand 'B' (pre-season)			
Forwards	19	L12-S8	56.0
Backs	19	L12-S9	56.2
New Zealand Under 19			
Forwards	29	L11-S6	51.9
Backs	24	L12-S4	54.8
South African squad (pre-season)			
Props and locks	6	L11-S2	50.8
Loose-forwards	5	L12-S6	55.4
Fly-halves and centres	4	L12-S6	55.4
Full-backs and wings	4	L12-S8	56.0
English National squad (end season)			
Forwards	9	L12-S10	56.5
Backs	9	L13-S13	60.6
South African Under 19 (pre-season)			
Props and locks	10	L11-S9	53.3
Loose-forwards	12	L13-S2	57.6
Fly-halves and centres	4	L12-S11	56.9
Full-backs and wings	6	L12-S8	56.0
Soccer			
South African squad (early season)	13	L13-S4	58.2

Note n refers to the number of players tested (Hawley & Burke, 1998).

TABLE 2.9: SPEEDS, TIME INTERVALS & PREDICTED VO_2MAX FOR EACH STAGE OF THE 20 MST

Stage	Speed (km/h)	Speed (m/min)	Speed (m/s)	Speed (mph)	Shuttles per min	Time per shuttle (s)	Distance per stage (m)	Total distance	Predicted VO_2max
1	8.0	133	2.22	4.98	6.7	9.00	267	267	27.40
2	8.5	142	2.36	5.29	7.1	8.47	283	550	30.33
3	9.0	150	2.50	5.60	7.5	8.00	300	850	33.26
4	9.5	158	2.64	5.91	7.9	7.58	317	1167	36.18
5	10.0	167	2.78	6.22	8.3	7.20	333	1500	39.11
6	10.5	175	2.92	6.53	8.8	6.86	350	1850	42.04
7	11.0	183	3.06	6.84	9.2	6.55	367	2217	44.97
8	11.5	192	3.19	7.15	9.6	6.26	383	2600	47.90
9	12.0	200	3.33	7.46	10.0	6.00	400	3000	50.83
10	12.5	208	3.47	7.77	10.4	5.76	417	3417	53.75
11	13.0	217	3.61	8.08	10.8	5.54	433	3850	56.68
12	13.5	225	3.75	8.40	11.3	5.33	450	4300	59.61
13	14.0	233	3.89	8.71	11.7	5.14	467	4767	62.54
14	14.5	242	4.03	9.02	12.1	4.97	483	5250	65.47
15	15.0	250	4.17	9.33	12.5	4.80	500	5750	68.40
16	15.5	258	4.31	9.64	12.9	4.65	517	6267	71.33
17	16.0	267	4.44	9.95	13.3	4.50	533	6800	74.25
18	16.5	275	4.58	10.26	13.8	4.36	550	7350	77.18
19	17.0	283	4.72	10.57	14.2	4.24	567	7917	80.11
20	17.5	292	4.86	10.88	14.6	4.11	583	8500	83.04

(Cooper & Storer, 2001).

CHAPTER 3

METHODOLOGY

3.1. Subjects

Seventy-two participants in ice-sports served as the total subject group. Subjects included in the study were National and Provincial standard male ice-hockey subjects (n=67) and female figure skaters (n=5) participating in the Gauteng area of South Africa (altitude of 1497 metres above sea level and barometric pressure of 655 mmHg). The mean age for the total group was 17.44±1.33 years. All subjects who participated in the study were briefed in advance and gave their informed consent (Appendix B).

FIGURE 3.1: SUBJECT PARTICIPANTS

3.2. Study Design

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

a) determine the velocity of motion, energy expenditure, and mechanical efficiency on-ice versus over-ground;
b) adapt the velocity of motion required for each level of the test; and
c) establish the reliability and validity of the modified (skating) 20 MST.

3.3. Procedures and Instrumentation

3.3.1 Velocity of Motion

The purpose of this test was to determine the maximum sprint speed acceleration (velocity of motion) from a stationary position over-ground (on a tarmac surface) versus on-ice. A forty-metre sprint test was used for this purpose. The total number of subjects utilized in this section of the study was 48. All of the subjects were male and the mean age for this group was 19±6.27 years. The equipment required to perform the test was as follows: tape measure, photoelectric sensors, electronic sprint timer, and marking cones.

A thorough warm-up was undertaken before this test was conducted, as it required the subjects to produce an all-out effort. The intention of this warm-up also gave subjects the opportunity to briefly mimic and become habituated to the feeling and technique associated with the criterion performance task. Each subject performed a minimum of 5 minutes of sub-maximal running (or skating), followed by an appropriate stretching regimen, and some acceleration sprints to pace. A straight-line distance of 40 metres was measured using a Featherstone

30 metre measuring tape. Photoelectric sensors were placed along the 40-metre track, set at hip height and coupled to an electronic sprint timer. The sensors were placed at 0 metres (the starting point), 20 metres, 30 metres and 40 metres (the ending point).

Some coaches like to determine the speed of their subjects over a short distance from a moving or rolling start. Although such a test negates some of the disadvantage that the heavier subjects have when commencing the sprint run from a stationary position, the start is always the slowest and thus discriminatory segment of any sporting movement (Hawley & Burke, 1998). For this reason, it was decided to use a dead-start as opposed to a flying start for the 40-metre sprint tests.

Subjects were required to wear full hockey kit and were shod. Subjects were instructed to position themselves in a standing position, on the ground 30 cm behind the starting point and begin sprinting as soon as they heard the starting signal. It was explained to subjects that their sprint time did not depend upon their reaction time (how quickly they got off the mark) as their times only started recording once some part of their body had broken the beam of the first cell. Subjects were instructed to run at maximal speed until they had past the ending point, and not to slow down before they passed the ending point.

For the on-ice testing, subjects were required to wear a hockey uniform and gloves. The subjects were also required to hold a hockey stick with both hands and to keep the stick blade in contact with the ice throughout the test. This procedure was also followed by Song & Reid (1979) when they tested ice-hockey subjects for speed on-ice. The photoelectric sensors were positioned in the same way as for the over-ground sprints.

The split times from 0 to 20 metres, 0 to 30 metres, and 0 to 40 metres were recorded and over-ground vs. on-ice measurements were compared to determine the velocity of motion over-ground as apposed to on-ice, using the following kinematic equation:

$v = d \div t$; where: v = average velocity (m/s)

d = displacement (m)

t = time taken (s)

FIGURE 3.2: VELOCITY OF MOTION PHOTOCELL ASSESSMENT

3.3.2 Energy Expenditure

The purpose of this procedure was to determine the subjects' energy expenditure, via the measurement of oxygen consumption on-ice versus over-ground, whilst performing the 20 MST. Ten subjects comprising male ice-hockey players (n=5) and female figure skaters (n=5) were utilized. The mean age for this group was 18±2.21 years.

The equipment required to perform this test was as follows: a 20 m flat surface, audiocassette, measuring tape to measure 20 m distance correctly and marker cones.

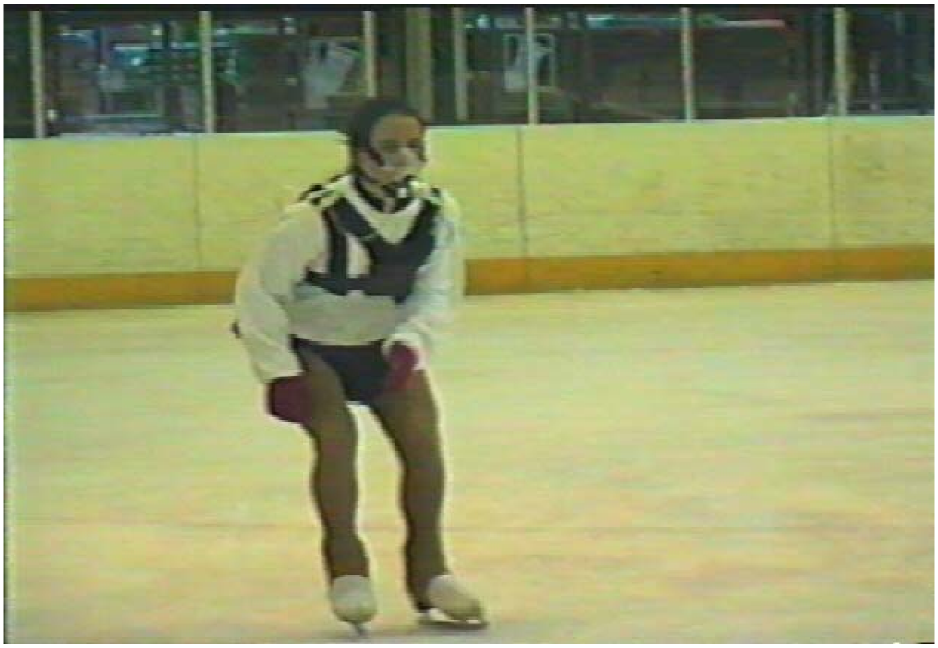
The subjects performed the 20 MST on-ice in its original format (Léger *et al.,* 1988) while simultaneously carrying an *Aerosport$_{TM}$* portable gas analyser on their backs to determine direct oxygen consumption. The *Aerosport$_{TM}$* was calibrated before each subject was tested. Calibration and warm-up time of the *Aerosport$_{TM}$* was approximately four minutes. The skated 20 MST was performed on a 30 m x 60 m ice-rink. Temperature of the ice ranged from -5.5 to -6.0 degrees Celsius, and ice conditions were standard. Although the original over-ground 20 MST was designed to start at a particular level (8.5 km/h), this corresponding speed was found to be too slow on-ice. After experimentation and feedback from the skaters the test was started at level four (10 km/h) for all skaters. Similar modifications were made by Léger *et al.* (1979).

FIGURE 3.3 THE *AEROSPORT$_{TM}$* PORTABLE GAS ANALYSER

On a different occasion, the same subjects performed the 20 MST over-ground. The over-ground running 20 MST was started at the first level (8.5 km/h) of the test. The test was performed in the ice arena, on a level rubber surface. The 20 MST has proved valid and reliable (highly reproducible) in predicting the maximal aerobic power on most types of gymnasium surfaces (rubber floor and vinyl-asbestos tiles) (Léger and Lambert, 1982). Subjects were tested in groups of no more than three to provide a source of motivation. Two cones were placed on the rubber surface 20 m apart. Subjects ran back and forth on this 20 m straight course touching the 20 m line with one foot at the precise moment that a sound signal was emitted from the audiotape.

The ice-hockey subjects performed both the running and skating tests wearing full ice-hockey equipment and carrying their ice-hockey stick. The *Aerosport*$_{TM}$ portable gas analyser and ice-hockey kit weighed less than 10 kg. Figure skaters wore standard figure skating costumes or a tracksuit. Clear and precise instructions were given to all the subjects in all tests so that they clearly understood the procedures of the test and what was expected of them. Motivational techniques were utilized equally in both the over-ground running 20 MST and the on-ice skated 20 MST to ensure that subjects reached their maximum voluntary running and skating speeds. The test was terminated when the subject stopped voluntarily and could not continue despite verbal encouragement, or when the subject failed to be within 3 m of the 20 m line on the sound of the tone on three consecutive occasions. It was then assumed that the subjects had reached their maximal running or skating speed and their VO_2max (Léger *et al.,* 1979; Léger & Lambert, 1982; Léger *et al.,* 1988).

FIGURE 3.4: ASSESSMENT OF ON-ICE DIRECT VO_2MAX



Energy expenditure (oxygen consumption) was determined at three different intensities. The first and lowest intensity was based on the lowest over-ground running speed for the group. This was after 4 minutes of exercise and at a running speed of 10 km/hour. The predicted over-ground VO_2 as derived from the original norm table (Léger *et al.,* 1988) was compared to the direct VO_2max as measured by the *Aerosport$_{TM}$* during the on-ice 20 MST at an equivalent skating speed of 10 km/h.

The second level of intensity was based on the intermediate over-ice skating speed (the mid point between the lowest and the highest skating speed for the group). This was after 8 minutes of exercise time and at a skating speed of 12 km/hour. The direct VO_2max as measured by the *Aerosport$_{TM}$* during the on-ice 20 MST was compared to the predicted over-ground VO_2 as derived from the original norm table (Léger *et al.,* 1988) at an equivalent running speed of 12 km/h.

The final and highest intensity was based on the lowest maximal skating speed attained by all subjects. This was after 12 minutes of exercise time and at a skating speed of 14 km/hour. The direct VO_2max as measured by the *Aerosport$_{TM}$* during the on-ice 20 MST was compared to the predicted over-ground VO_2 as derived from the original norm table (Léger *et al.,* 1988) at an equivalent running speed of 14 km/h.

Energy expenditure was subsequently expressed as metabolic equivalents (METs) i.e. multiples of resting oxygen consumption (3.5 mlO_2/kg/min) and as kilocalories (Kcal/min) with one MET being equivalent to 1.2 Kcal/min (Mc Ardle *et al.,* 1991).

3.3.3 Mechanical Efficiency

The purpose of this procedure was to determine the subjects' mechanical efficiency on-ice versus over-ground. Mechanical efficiency was defined as an index derived by quotient of the velocity (m/min) at which the VO_2max was attained (as numerator) and the VO_2max (ml/kg/min) itself (as denominator) (Montgomery, 1988).

Ten subjects was utilized, comprising male ice-hockey players (n=5) and female figure skaters (n=5). The mean age for this group was 18±2.21 years. The procedures followed to determine the VO_2max were exactly as described in the previous section (3.3.2) for the determination of energy expenditure (oxygen consumption).

3.3.4 Modification of the 20 MST

In order to equate the physiological work load and intensity of skating on-ice over a distance of 20 metres with that required for running over-ground during the 20 MST, the on-ice velocity of motion was adapted (increased). This was done by determining the ratio of on-ice vs. over-ground performances for each of the variables measured, viz. velocity of motion, energy expenditure, and mechanical efficiency. The mean of these ratios was then used to alter (reduce) the time intervals allowed (and increase the velocity of motion) for each level (shuttle) of the 20 MST. The above process resulted in the production of four modified trial versions (compact discs) of the 20 MST for use on-ice (Table 3.1).

The first trial version permitted 6.4 seconds (requiring a velocity of 3.13 metres per second or 11.25 km/h) to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an on-ice to over-ground ratio derived as the mean of:

a) the mean ratio of the sprint times (velocity of motion) for 0 to 20 metres, 0 to 30 metres, and 0 to 40 metres; and the mean ratio of respective on-ice and over-ground World records for 1500 metres, 5000 metres, and 10000 metres;
b) the mean ratio of energy consumption at the three different intensities; and
c) the mean ratio of the derived mechanical efficiency.

The second trial version permitted 7.3 seconds (requiring a velocity of 2.74 m/s or 9.86 km/h) to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an on-ice to over-ground ratio derived as the mean of:

a) the mean ratio of the sprint times (velocity of motion) for 0 to 20 metres only; and
b) the mean ratio of the derived mechanical efficiency.

The third trial version permitted 7.2 seconds (velocity of 2.78 metres per second or 10 km/h) to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an on-ice to over-ground ratio derived as the mean of:

a) the mean ratio of the mean sprint times (velocity of motion) for 0 to 20 metres, 0 to 30 metres, and 0 to 40 metres; and
b) the mean ratio of the derived mechanical efficiency.

The fourth trial version permitted 7.1 seconds (requiring a velocity of 2.82 m/s or 10.14 km/h) to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an on-ice to over-ground ratio derived as the mean of:

a) the mean ratio of the sprint times (velocity of motion) for 0 to 20 metres, 0 to 30 metres, and 0 to 40 metres;
b) the mean ratio of energy consumption at the three different intensities; and
c) the mean ratio of the derived mechanical efficiency.

Subsequently, each trial version of the test was evaluated on-ice. It was found that performing the first version of the test (time of 6.4 seconds for the first shuttle and a velocity of 3.13 metres per second or 11.27 km/h) was too taxing to carry out. In the process of elimination, the fourth version (time of 7.1 seconds for the first shuttle and a velocity of 2.82 metres per second or 10.14

km/h) proved to have the greatest utility, with the same level (shuttle) being reached as in the over-ground version of the test.

FIGURE 3.5: FUTURE ICE-HOCKEY PARTICIPANT IN FULL KIT

TABLE 3.1: ORIGINAL OVER-GROUND AND TRIAL VERSIONS OF THE 20 MST

The original 20 MST					***Trial Version 1***			***Trial Version 2***			***Trial Version 3***			***Trial Version 4***		
Stage (min)	***Number of shuttles***	***sec***	***m/s***	***km/h***	***sec***	***m/sec***	***km/h***	***sec***	***m/sec***	***km/h***	***sec***	***m/sec***	***km/h***	***sec***	***m/sec***	***km/h***
1	7	8.5	2.4	8.5	6.4	3.1	11.3	7.3	2.7	9.9	7.2	2.8	10.0	7.1	2.8	10.1
2	8	8.0	2.5	9.0	6.0	3.3	12.0	6.9	2.9	10.4	6.8	2.9	10.6	6.7	3.0	10.7
3	8	7.6	2.6	9.5	5.7	3.5	12.6	6.5	3.1	11.1	6.5	3.1	11.1	6.3	3.2	11.4
4	9	7.2	2.8	10.0	5.4	3.7	13.3	6.2	3.2	11.6	6.1	3.3	11.8	6.0	3.3	12.0
5	9	6.9	2.9	10.5	5.2	3.8	13.8	5.9	3.4	12.2	5.9	3.4	12.2	5.7	3.5	12.6
6	10	6.6	3.1	11.0	4.9	4.1	14.7	5.7	3.5	12.6	5.6	3.6	12.9	5.5	3.6	13.1
7	10	6.3	3.2	11.5	4.7	4.3	15.3	5.4	3.7	13.3	5.3	3.8	13.6	5.2	3.8	13.8
8	11	6.0	3.3	12.0	4.5	4.4	16.0	5.2	3.8	13.8	5.1	3.9	14.1	5.0	4.0	14.4
9	11	5.8	3.5	12.5	4.3	4.7	16.7	5.0	4.0	14.4	4.9	4.1	14.7	4.8	4.2	15.0
10	11	5.5	3.6	13.0	4.2	4.8	17.1	4.8	4.2	15.0	4.7	4.3	15.3	4.6	4.3	15.7
11	12	5.3	3.8	13.5	4.0	5.0	18.0	4.6	4.3	15.7	4.6	4.3	15.7	4.4	4.5	16.4
12	12	5.1	3.9	14.0	3.9	5.1	18.5	4.4	4.5	16.4	4.4	4.5	16.4	4.3	4.7	16.7
13	13	5.0	4.0	14.5	3.7	5.4	19.5	4.3	4.7	16.7	4.2	4.8	17.1	4.1	4.9	17.6
14	13	4.8	4.2	15.0	3.6	5.6	20.0	4.1	4.9	17.6	4.1	4.9	17.6	4.0	5.0	18.0
15	13	4.7	4.3	15.5	3.5	5.7	20.6	4.0	5.0	18.0	4.0	5.0	18.0	3.9	5.1	18.5
16	14	4.5	4.4	16.0	3.4	5.9	21.2	3.9	5.1	18.5	3.8	5.3	18.9	3.8	5.3	18.9
17	14	4.4	4.6	16.5	3.3	6.1	21.8	3.8	5.3	18.9	3.7	5.4	19.5	3.6	5.6	20.0
18	15	4.2	4.7	17.0	3.2	6.3	22.5	3.7	5.4	19.5	3.6	5.6	20.0	3.5	5.7	20.6
19	15	4.1	4.9	17.5	3.1	6.5	23.2	3.6	5.6	20.0	3.5	5.7	20.6	3.4	5.9	21.2
20	16	4.0	5.0	18.0	3.0	6.7	24.0	3.5	5.7	20.6	3.4	5.9	21.2	3.3	6.1	21.8
21	16	3.9	5.1	18.5	2.9	6.9	24.8	3.4	5.9	21.2	3.3	6.1	21.8	3.2	6.3	22.5

3.3.5 Establishing Reliability

According to Thomas & Nelson (1996), reliability pertains to the consistency, or repeatability of a measure. A test cannot be considered valid if it is not reliable.

The total number of subjects utilized in this section of the study was 15 male ice-hockey players. The mean age for these subjects was 15.7±2.35 years. Each of the 15 subjects was required to skate the modified (skating) 20 MST on-ice with kits & sticks but no helmet. The subjects were briefed and all subjects understood what was required of them. Each of the 15 subjects then repeated the same test with the same procedures on a different occasion, at the same location at the same time of day exactly one week later.

3.3.6 Establishing Validity

According to Thomas & Nelson (1996), validity indicates the degree to which the test measures what it is purports to measure.

The total number of subjects utilized in this section of the study was 9 male ice-hockey players and 1 female figure skater. The mean age for these subjects was 16.5±3.98 years. Each of the 10 subjects performed the modified (skating) 20 MST on-ice. On another occasion at the same time of day and exactly a week later, the same subjects performed the (original over-ground) 20 MST (Table 3.2) as designed by Léger *et al.* (1982) and later adapted by Ramsbottom *et al.* (1988) as a valid indirect estimate of the VO_2max. This served as the criterion variable to which the modified (skating) 20 MST- predictor variable was compared. The choice of the over-ground 20 MST as the criterion measure was motivated by the fact that it is a proven established (validated) measurement tool, as required in the determination of the concurrent validity of a modified or adapted version of a test measuring a similar variable (VO_2max) (Clarke & Clarke, 1984; Thomas & Nelson, 1996). Appendix C contains the modified (skating) 20 MST version with predicted VO_2 values.

3.3.7 Statistical Analysis and Treatment of Data

Dependent t-tests were applied in contrasting variance between sets of data (on-ice versus over-ground means) for the variables of velocity of motion, energy expenditure and mechanical efficiency; while correlation was used to establish test-retest reliability and validity co-efficients. In all statistical analyses the 95 % level of confidence, with alpha set at $p \leq 0.05$, was applied as the minimum to interpret statistical significance. Computations, to determine standard descriptive statistics (mean and standard deviation) and inferential analyses, were performed using the Microsoft Excell 2000 Statistics Package.

FIGURE 3.6: ON-ICE WARM-UP DRILL

TABLE 3.2: ORIGINAL 20MST NORM TABLE

Level	Shuttle	VO_2max	Level	Shuttle	VO_2max	Level	Shuttle	VO_2max	Level	Shuttle	VO_2max
4	2	26.8	10	2	47.4	15	2	64.6	19	2	78.3
4	4	27.6	10	4	48.0	15	4	65.1	19	4	78.8
4	6	28.3	10	6	48.7	15	6	65.6	19	6	79.2
4	9	29.5	10	8	49.3	15	8	66.2	19	8	79.7
			10	11	50.2	15	10	66.7	19	10	80.2
5	2	30.2				15	13	67.5	19	12	80.7
5	4	31.0	11	2	50.8				19	15	81.2
5	6	31.8	11	4	51.4	16	2	68.0			
5	9	32.9	11	6	51.9	16	4	68.5	20	2	81.8
			11	8	52.5	16	6	69.0	20	4	82.2
6	2	33.6	11	10	53.1	16	8	69.5	20	6	82.6
6	4	34.3	11	12	53.7	16	10	69.9	20	8	83.0
6	6	35.0				16	12	70.5	20	10	83.5
6	8	35.7	12	2	54.3	16	14	70.9	20	12	83.9
6	10	36.4	12	4	54.8				20	14	84.3
			12	6	55.4	17	2	71.4	20	16	84.8
7	2	37.1	12	8	56.0	17	4	71.9			
7	4	37.8	12	10	56.5	17	6	72.4	21	2	85.2
7	6	38.5	12	12	57.1	17	8	72.9	21	4	85.6
7	8	39.2				17	10	73.4	21	6	86.1
7	10	39.9	13	2	57.6	17	12	73.9	21	8	86.5
			13	4	58.2	17	14	74.4	21	10	86.9
8	2	40.5	13	6	58.7				21	12	87.4
8	4	41.1	13	8	59.3	18	2	74.8	21	14	87.8
8	6	41.8	13	10	59.8	18	4	75.3	21	16	88.2
8	8	42.4	13	13	60.6	18	6	75.8			
8	11	43.3				18	8	76.2			
			14	2	61.1	18	10	76.7			
9	2	43.9	14	4	61.7	18	12	77.2			
9	4	44.5	14	6	62.2	18	15	77.9			
9	6	45.2	14	8	62.7						
9	8	45.8	14	10	63.2						
9	11	46.8	14	13	64.0						

CHAPTER 4

RESULTS AND DISCUSSION

To recapitulate, the purpose of the study was to modify the 20 MST for application to ice-sports. The process entailed a repeated measures research design to determine:

a) velocity of motion on-ice vs. over-ground;
b) energy expenditure on-ice vs. over-ground; and
c) mechanical efficiency on-ice vs. over-ground.

Subsequently, based on the above, the 20 MST was modified by:

a) adapting the velocity of motion required for each level of the test (distance of 20 m per shuttle); and
b) establishing the reliability and concurrent validity of the modified 20 MST for use on-ice.

The results of the process are presented in tabular and graphic form (Figures 4.1-4.6) and subsequently discussed within the context of the appropriate literature.

4.1. Velocity of Motion

The velocity of motion for the 0 to 20 metres, 0 to 30 metres, and 0 to 40 metres splits determined for the on-ice and over-ground sprint tests are represented in Figures 4.1A and 4.1B.

The results showed that the velocity of motion was greater on-ice than over-ground for all three split distances. The difference between the respective on-ice versus over-ground velocities, for 0 to 20 m (5.51±0.66 vs. 5.41±0.53

m/s) was not significant ($p>0.05$). However, the respective velocities were significantly different for 0 to 30 m (6.04±0.69 vs. 5.81±0.64 m/s; $p\leq0.05$), for 0 to 40 m (6.4±0.8 vs. 6.03±0.75 m/s; $p\leq0.001$) and for the overall mean (5.99±0.72 vs. 5.75±0.63 m/s; $p\leq0.05$).

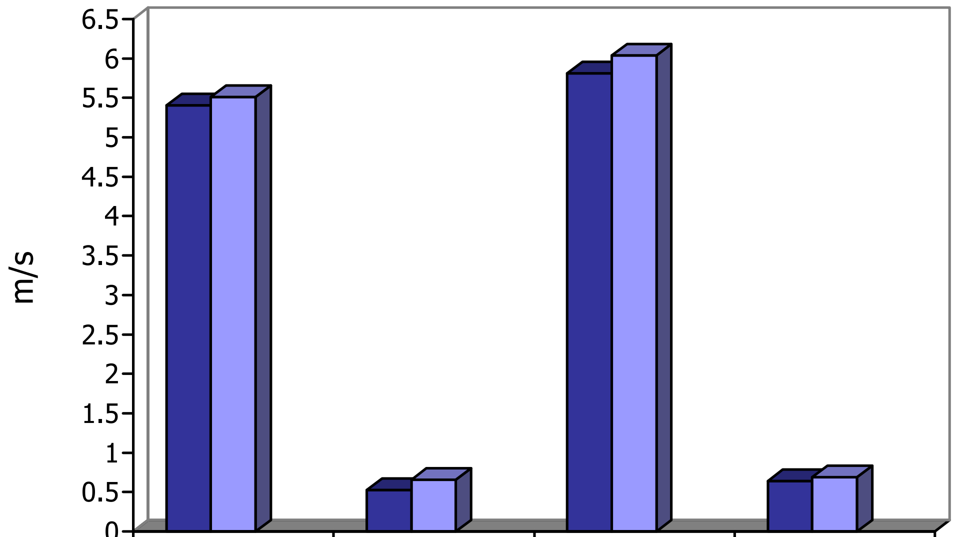
The corresponding ratios for the time taken for each split distance on-ice versus over-ground (Figures 4.1C and 4.1D) were 0.99±0.11 (0 to 20m), 0.97±0.11 (0 to 30 m), 0.95±0.1 (0 to 40 m) and 0.97±0.11 for the overall mean.

Acceleration

The reasoning for the observed differences in the velocity of motion on-ice as opposed to over-ground has a biomechanical basis. In the first instance Newton's Second Law states that acceleration of a body is directly proportional to the force causing it and inversely proportional to the mass (weight) of the body $\bar{a} \propto F/M$. thus, the greater the force, the greater the acceleration (rate at which velocity changes) with the mass of the body remaining constant.

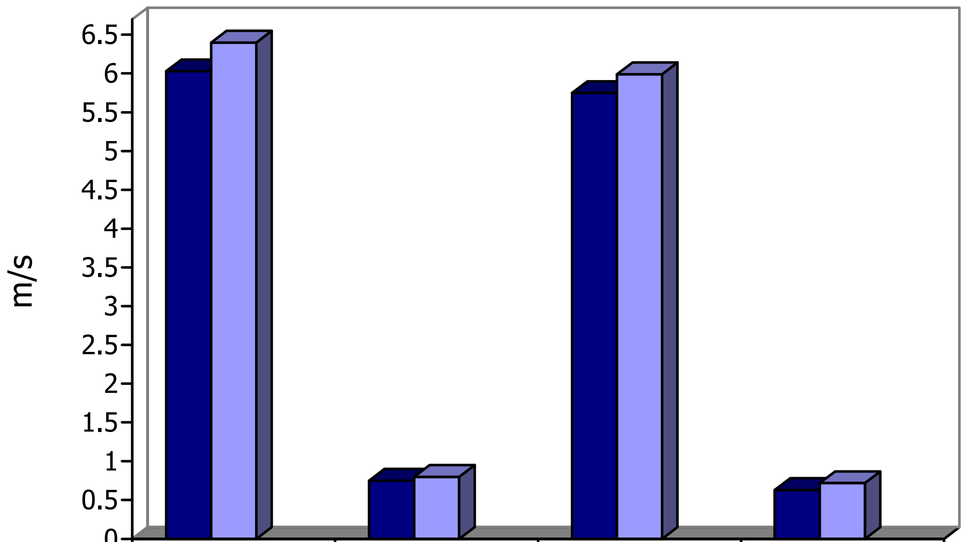
Within context, this implies that the velocity of motion for the same individual should be equivalent over-ground and on-ice unless the force application is impeded in some manner. Whenever one body moves, or tends to move, across the surface of another, force is created. This force, which acts tangential to the point(s) of contact of the two bodies and opposes the motion, or impending motion, is called friction (Hay & Reid, 1982).

Figure 4.1A: Mean Velocity of Motion (n=48)



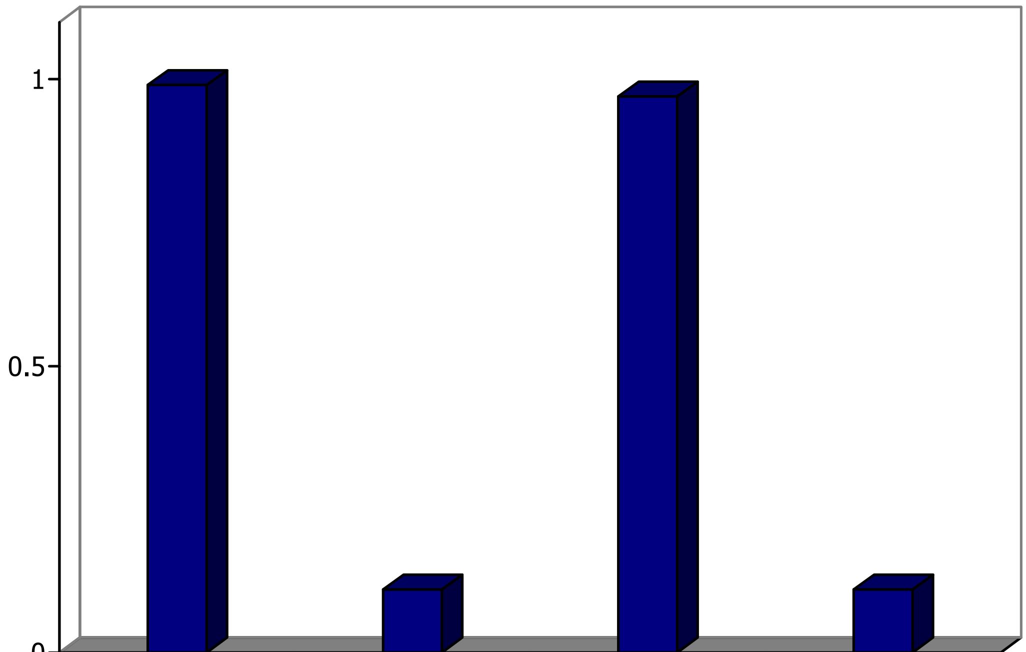
	0-20m	SD	0-30m	SD
Over-Ground	5.41	0.53	5.81	0.64
On-Ice	5.51	0.66	6.04	0.69
Significance	$p > 0.05$		$p < 0.05$	

Figure 4.1B: Mean Velocity of Motion (n=48)



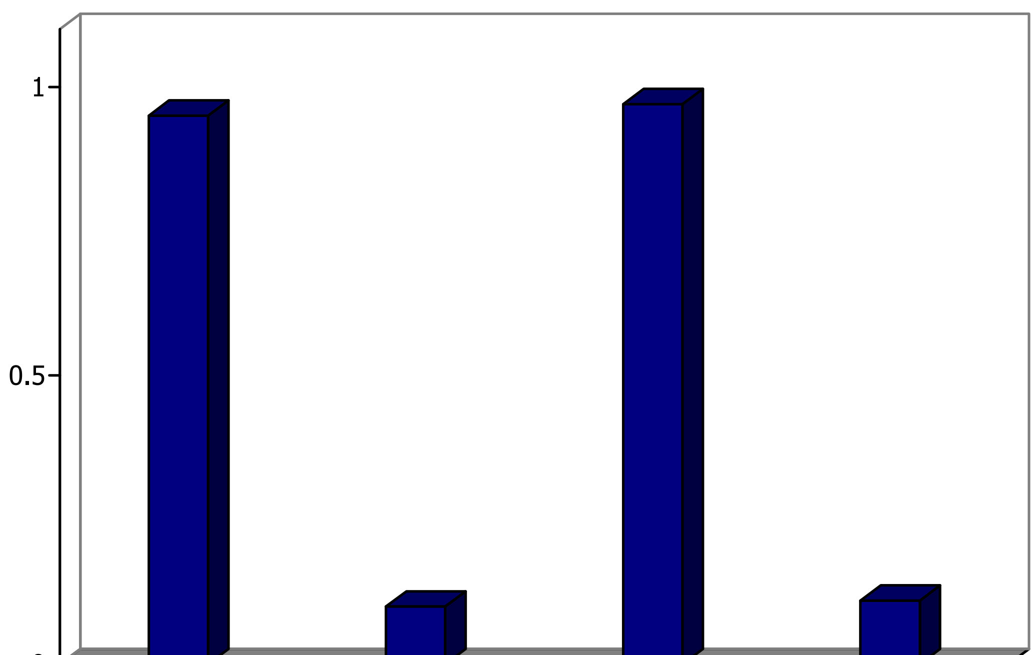
	0-40m	SD	Overall	SD
Over-Ground	6.03	0.75	5.75	0.63
On-Ice	6.4	0.8	5.99	0.72
Significance	$p < 0.001$		$p < 0.05$	

Figure 4.1C: Mean Velocity of Motion Ratios (n=48)



0-20m	SD	0-30m	SD
0.99	0.11	0.97	0.11

Figure 4.1D: Mean Velocity of Motion Ratios (n=48)



0-40m	SD	Overall	SD
0.95	0.1	0.97	0.11

Friction

According to Hall (1999) friction is a force that acts at the interface of surfaces in contact in the direction opposite the direction of motion or impending motion. The magnitude of the generated friction force determines the relative ease or difficulty of motion for two objects in contact.

Two factors govern the magnitude of the force of maximum static friction or kinetic friction (F) in any situation: the product of the coefficient of friction, represented by the Greek symbol mu (μ), and the normal (perpendicular) reaction force (R) or the force holding the two surfaces together, this being synonymous to the weight of a body:

$$F = \mu R$$ (Hall, 1999).

The coefficient of friction (μ) pertains to the nature of the two surfaces in contact and indicates the relative ease of sliding, or the amount of mechanical and molecular interaction between two surfaces in contact. Factors influencing the value of μ are the relative roughness and hardness of the surfaces in contact and the type of molecular interaction between the surfaces. The greater the mechanical and molecular interaction, the greater the value of μ. For example, the coefficient of friction between two blocks covered with rough sandpaper is larger than the coefficient of friction between a skate and a smooth surface of ice. The coefficient of friction describes the interaction between two surfaces in contact and is not descriptive of either surface alone. The coefficient of friction for the blade of an ice skate in contact with ice is different from that for shoes and typical over-ground surfaces (Hall, 1999).

The coefficient of friction between two surfaces assumes one or two different values, depending on whether the bodies in contact are motionless (static) or in motion (kinetic). The two coefficients are known as the coefficient of static friction (u_s) and the coefficient of kinetic friction (u_k). The magnitude of maximum static friction is based on the coefficient of static friction:

$F_m = \mu_s R$

The magnitude of the kinetic friction force is based on the coefficient of kinetic friction:

$F_k = \mu_k R$

For any two bodies in contact, μ_k is always smaller than μ_s. Kinetic friction coefficients as low as 0.003 have been reported between the blade of a racing skate and a properly treated ice rink under optimal conditions. The amount of friction present in a sliding or rolling situation is dramatically reduced when a layer of fluid, such as oil or water, intervenes between two surfaces in contact. Researchers attribute the extremely low coefficients of friction between speed skates and the ice to a liquid-like film layer on the surface of the ice (Hay & Reid, 1982).

The law of friction applies only to dry surfaces. If the surfaces are wet, limiting friction is markedly reduced. For example, when the composition locks used in the rim brakes of a bicycle are wet, the limiting friction drops to one tenth of its dry value.

A simple rearrangement of the equation:

$$\mu = F/R$$

is used to obtain the value of the coefficient of limiting friction in a given case (Hay & Reid, 1982).

The preceding factors thus substantiate the results of this study of greater velocities of motion on-ice versus over-ground primarily due to a corresponding lower coefficient of kinetic friction being experienced on-ice.

According to Mascaro *et al.* (1992), 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 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.

Green *et al.* (1976) state that the average velocity, calculated based on 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.

Gilder & Grogan (1993) state that forward skating speeds average 35 mph (56 km/h) and backward speeds average 15 mph (24 km/h). Sliding speed can be up to 15 mph (24 km/h), slap shots range from 60 to 100 mph (96.5 to 161 km/h). The force generated during skating push-off can reach 1.5 to 2.5 times the player's body weight and is one of the underlying factors causing injury to the groin. The average ice surface is 200 by 85 ft (61 by 26 m) or smaller, giving little room for the hockey player to decelerate before impact.

Table 4.1 indicates the mean velocities (n=48) between 0 and 20 m; 0 and 30 m, and 0 and 40 m represented in both metres per minute (m/min) and kilometres per hour (km/h) that were obtained by the subjects in this study:

TABLE 4.1: MEAN VELOCITY OF MOTION (n= 48)			
		m/min	km/h
0-20 metres	Over-Ground	324.67 ± 32.07	19.48 ± 1.92
	On-Ice	330.91 ± 40.06	19.85 ± 2.4
0-30 metres	Over-Ground	348.99 ± 38.63	20.94 ± 2.32
	On-Ice	362.48 ± 41.37	21.75 ± 2.48
0-40 metres	Over-Ground	361.66 ± 45.29	21.7 ± 2.72
	On-Ice	385 ± 50	23.1 ± 3.01

The ability to accelerate quickly characterizes the elite hockey player. Skilled skaters are able to exceed a velocity of 8 m/sec after just four strides. External power is equal to the product of the work per stroke and the stroke frequency (Montgomery, 1988). 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.

TABLE 4.2: SPRINT RUN TIMES (SECONDS) FROM STATIONARY STARTS FOR PLAYERS FROM A VARIETY OF TEAM SPORTS

Sport	***n***	***10 m***	***30 m***	***40 m***
Soccer				
German professionals	20	1.79	4.19	
German amateurs	19	1.88	4.33	
South African squad (early season)				
Defenders	2	1.77	4.13	5.30
Midfield	5	1.79	4.16	5.34
Forwards	4	1.72	4.09	5.20
Rugby League				
Elite British (end of season)				
Forwards	13			5.61
Backs	12			5.30
Rugby Union				
English National squad (off-season)				
Forwards	9		4.4	
Backs	9		4.1	
English National squad (in-season)				
Forwards	9		4.3	
Backs	9		3.9	
New Zealand 'A' (pro-season)				
Forwards	45		4.5	
Backs	37		4.3	
New Zealand 'B' (pro-season)				
Forwards	12		4.8	
Backs	12		4.5	
New Zealand Under 19 (pro-season)				
Forwards	29		4.6	
Backs	24		4.4	
South African squad (pro-season)				
Props and locks	6	1.83		5.52
Loose-forwards and scrum-halves	5	1.86		5.53
Fly halves and centres	4	1.80		5.21
Fullbacks and wings	4	1.81		5.19

*Note n** refers to the number of players tested (Hawley & Burke, 1998).

Marino (1984) states that increases in maximal horizontal velocity of hockey players during the ages 8 to 15 years are accompanied by increases in skating stride length with no significant changes in skating stride rate.

Rugby and soccer are sports in which the 20 MST has been applied with success. These sports are similar to ice-hockey in that they too have a stop-and-go nature and cardiorespiratory fitness is an important requirement to play the game successfully. Hawley & Burke (1998) present sprint run times from stationary starts for players from a variety of sports (Table 4.2). Comparatively ice-hockey players in this study (n=48) achieved mean sprint run times over-ground of 3.74±0.42 sec, 5.0±1.0 sec, and 6.7±0.94 sec for 0 to 20 m, 0 to 30 m, and 0 to 40 m respectively. Table 4.3 shows differences in skating speeds when skating with and without a stick. Song & Reid (1976) indicate that skating with a stick increased the time taken to skate the same distance without a stick.

TABLE 4.3: SKATING SPEEDS WITH & WITHOUT STICK (n=17)

	With stick	Without stick
Mean	4.18 sec	3.95 sec
Standard deviation	0.78	01.0
Range	3.93-4.11	3.77-4.06

(Song & Reid, 1976).

4.2. Energy Expenditure

The surface upon which an activity is performed may contribute to the advent of distinctive physiological profiles and metabolic costs. The measurement of oxygen consumption is one of the most important indicators of one's potential to move the body and one's ability for sustained exercise and can be converted with ease to METs (multiples of resting oxygen consumption and 3.5 mlO_2/kg/min) or kilocalories (one MET = 1.2 kcal/min) as descriptors of energy expenditure with greater utility (McArdle *et al.,* 1991).

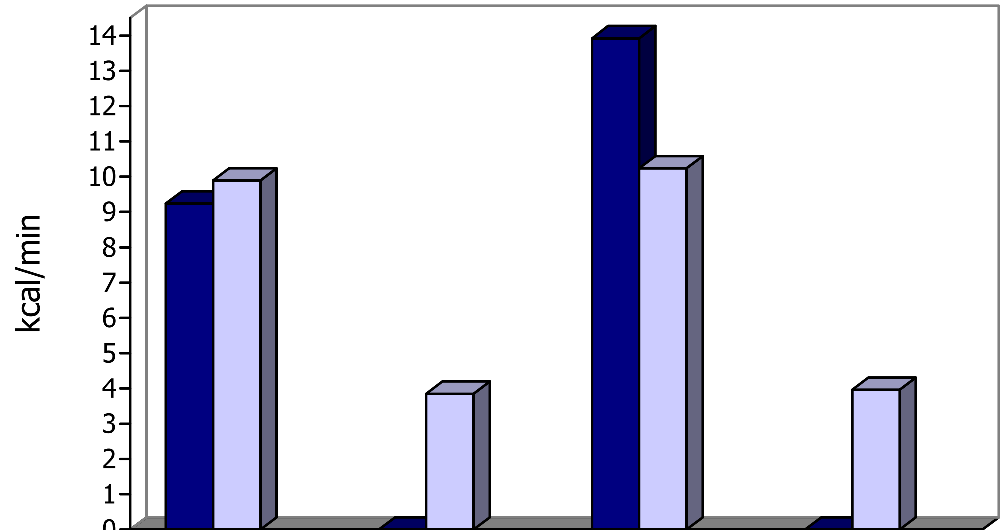
Even though skating velocity represents a major component of work intensity, it singularly underestimates energy expenditure (Léger, *et al., 1979)*. For this reason energy expenditure is determined by measuring oxygen consumption in relation to velocities (intensities) of motion, as performed in this study.

The respective measures for over-ground and on-ice caloric expenditure (kcal/min) during light intensity (after 4 minutes of exercise and at a speed of 10 km/h), moderate intensity (after 8 minutes of exercise and at a speed of 12 km/h), and high intensity (after 12 minutes of exercise and at a speed of 14 km/h), are represented in Figures 4.2A and 4.2B.

The results showed that the caloric expenditure at a low-intensity is greater over-ground than on-ice (9.89±3.85 vs. 9.24±0 kcal/min) but not significantly so ($p>0.05$). For the moderate intensity, caloric expenditure was significantly higher over-ground versus on-ice (13.92±0 vs. 10.24±3.96; $p\leq0.05$). Similarly respective over-ground versus on-ice caloric expenditures were significantly greater at a high intensity (18.96±0 vs. 11.99±2.98 kcal/min; $p\leq0.001$) and for the overall mean (14.04±4.86 vs. 10.51±2.95 kcal/min; $p\leq0.05$).

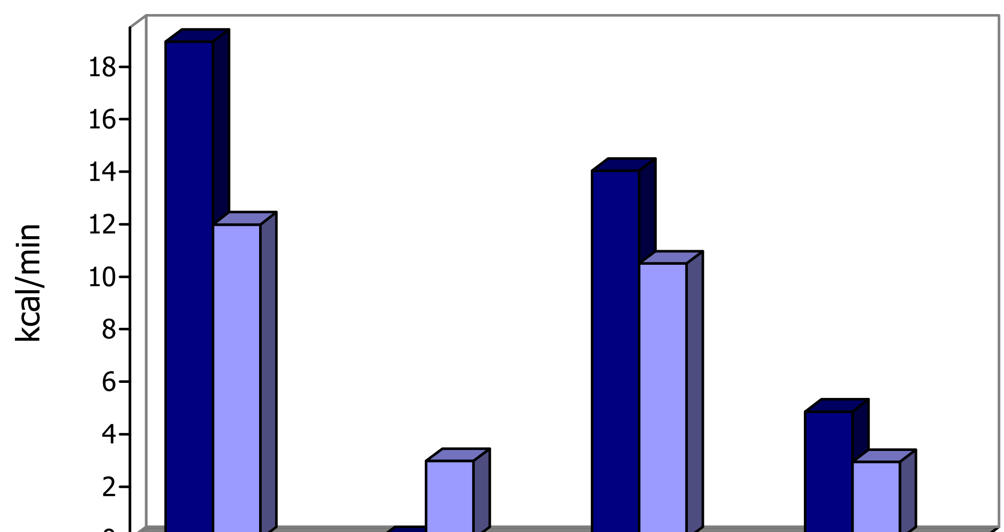
The corresponding ratios for the caloric expenditure for each intensity on-ice versus over-ground (Figures 4.2C and 4.2D) were 1.07±0.42 (low intensity), 0.74±0.29 (moderate intensity), 0.63±0.16 (high intensity) and 0.74±0.21 for the overall mean.

Figure 4.2A: Mean Energy Expenditure / Intensity (n=10)



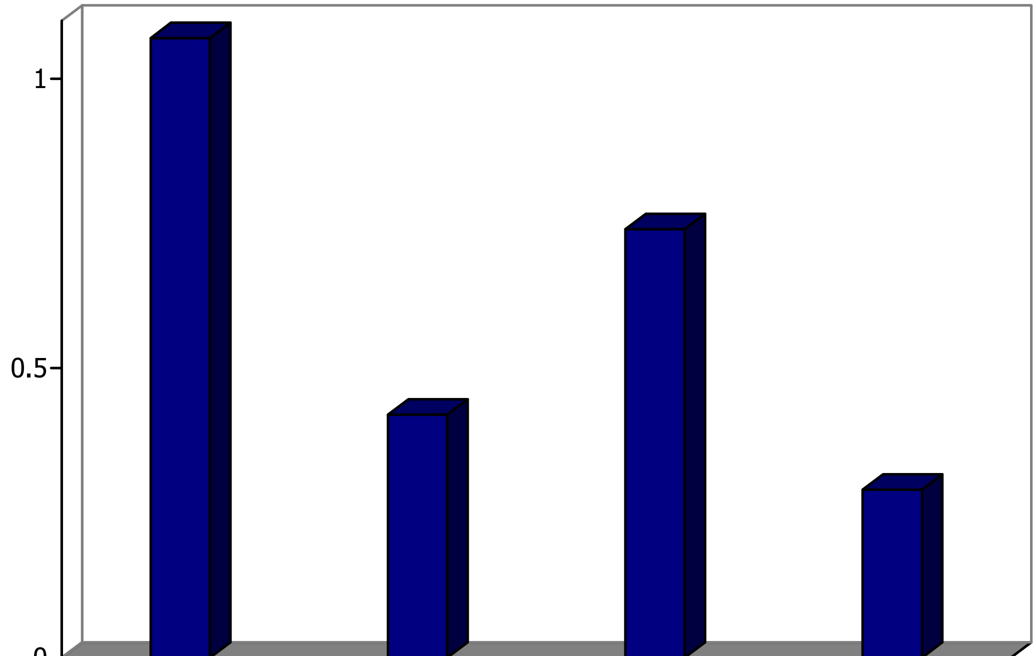
	Low	SD	Moderate	SD
Over-Ground	9.24	0	13.92	0
On-Ice	9.89	3.85	10.24	3.96
Significance	$p > 0.05$		$p < 0.05$	

Figure 4.2B: Mean Energy Expenditure / Intensity (n=10)



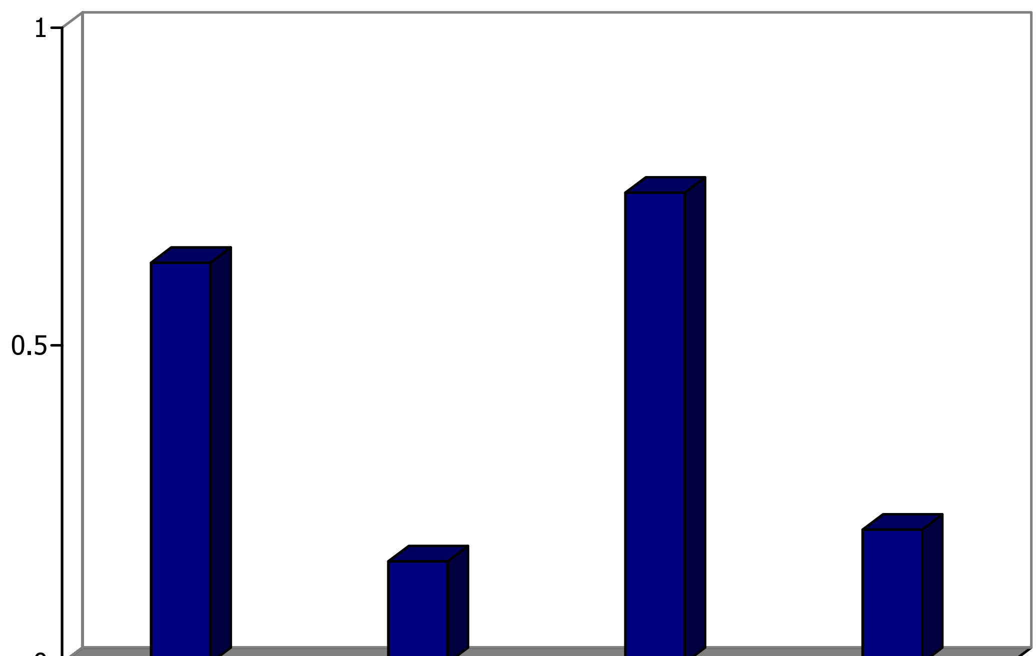
	High	SD	Mean	SD
Over-Ground	18.96	0	14.04	4.86
On-Ice	11.99	2.98	10.51	2.95
Significance	$p < 0.0001$		$p < 0.05$	

Figure 4.2C: Mean Energy Expenditure Ratios (n=10)



Low Intensity	SD	Moderate	SD
1.07	0.42	0.74	0.29

Figure 4.2D: Mean Energy Expenditure Ratios (n=10)



High Intensity	SD	Overall	SD
0.63	0.16	0.74	0.21

Davies (2000) states that sand is a compliant substrate that raises the exertional and metabolic cost of all forms of human locomotion. Davies (2000) states that research into locomotion on sand has shown that energy cost per unit distance is increased approximately 1.8 times when walking, and 1.2 times when running. Comparatively, in this study, the mean ratio of energy expenditure at three different intensities over-ground versus on-ice in this study was 1.44±0.32.

The cost of skating is, however, much higher for ice hockey players than for ice speed skaters. A hockey player, as compared to the unskilled runner, required 15 % less energy to skate at the same speed, but also needed 7 % more energy to run on the treadmill (Léger *et al*., 1979).

Mechanical work

It is evident that initial velocity (low intensity) of motion that is required for the first stage of the 20 MST was unsuitable (too slow) for on-ice motion. This is reflected in the higher low-intensity energy expenditure measured on-ice. As the intensity of exercise increased, the inverse was true, with lower energy expenditure being measured on-ice. The reasoning for this observation is related to the mechanical work being performed viz. W = F*d. considering the lower coefficient of kinetic friction on-ice, as referred to in the previous section, less force would be required for locomotion over an equivalent distance on-ice as opposed to over-ground. Accordingly, less mechanical work being performed would also require lower physiological work output or energy expenditure (Hay & Reid, 1982; Hall, 1999).

4.3. Mechanical Efficiency

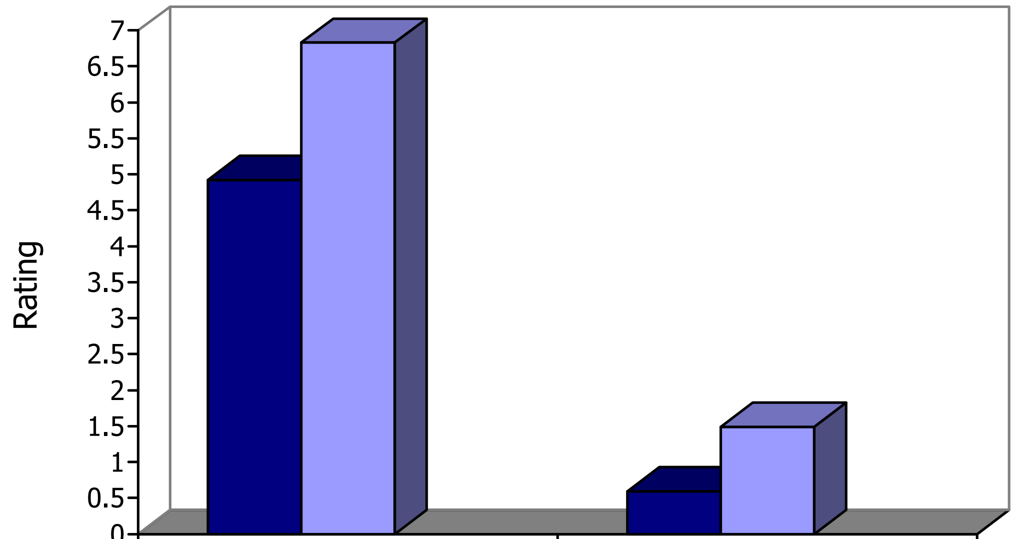
Mechanical efficiency in essence reflects the economy of motion which was expressed as an index derived from the quotient of the velocity at which VO_2max was reached and the VO_2max itself. The higher this index, the better the performance.

The results (Figure 4.3A) showed that the mechanical efficiency index was greater on-ice than over-ground (6.83±1.49 vs. 4.92±0.59). The difference between the on-ice versus over-ground mechanical efficiency was highly significant $p \leq 0.001$). The corresponding ratio for the mechanical efficiency on-ice versus over-ground (Figures 4.3B) was 0.74±0.13.

Economy of motion

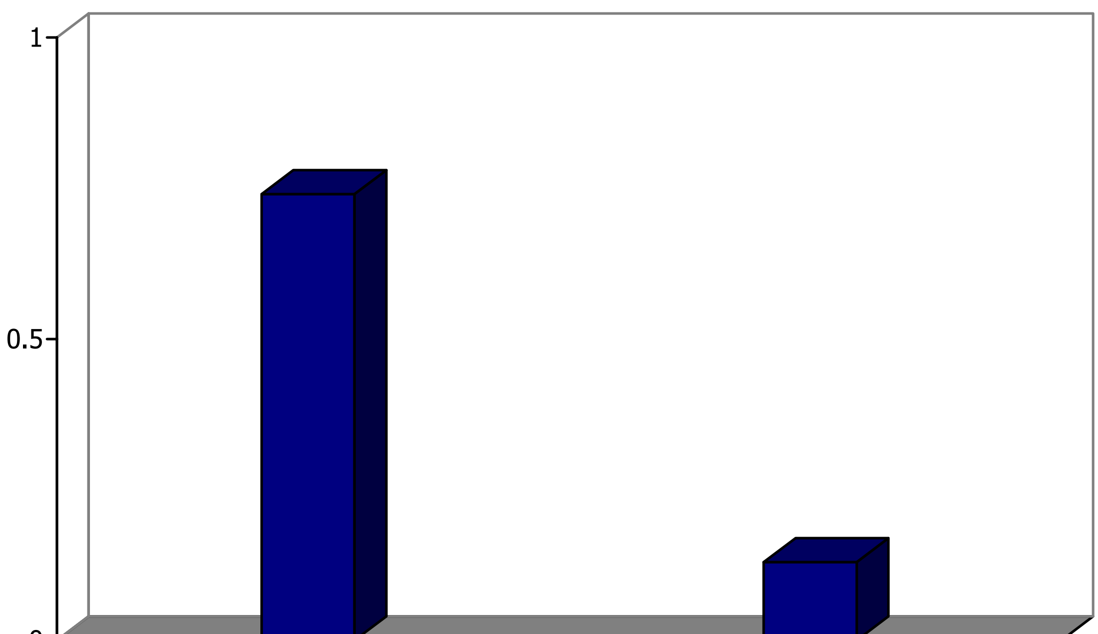
This result is in accordance with expectations based on observations comparing the velocity of motion and energy expenditure on-ice as opposed to over-ground. As indicated in the previous subsections, the energy cost at a given velocity of motion was lower on-ice than over-ground. As a result, in comparison to over-ground motion, subjects were able to continue with the 20 MST to higher levels on-ice (velocity of motion) with less fatigue prior to reaching their VO_2max.

Figure 4.3A: Mean Mechanical Efficiency Index (n=10)



	Mean	SD
Over-Ground	4.92	0.59
On-Ice	6.83	1.49
Significance	$p < 0.001$	

Figure 4.3B: Mean Mechanical Efficiency Ratio (n=10)



Mean	SD
0.74	0.13

A number of years ago Ferguson *et al.* (1969) developed test procedures for measuring VO_2max while skating around a 140 m oval course and illustrated a linear relationship between skating velocity and VO_2max (ml/kg/min) between velocities of 350 and 443 m/min.

On analysis of the primary variables measured viz. velocity of motion, energy expenditure, and mechanical efficiency on-ice vs. over-ground the 20 MST was subsequently modified by adapting the velocity of motion required for each level of the test (distance of 20 m per shuttle). This modification was based on four variable-derived ratios as expounded in Chapter 3.

The first trial modification permitted 6.4 seconds (requiring a velocity of 3.1 m/s or 11.25 km/h) to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an on-ice to over-ground derived ratio of 0.76

The second trial modification permitted 7.3 seconds (requiring a velocity of 2.74 m/s or 9.9 km/h) to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an on-ice to over ground ratio of 0.87.

The third trial modification permitted 7.2 seconds (requiring a velocity of 2.78 m/s or 10 km/h) to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an on-ice to over ground ratio of 0.86.

The fourth trial modification permitted 7.1 seconds (requiring a velocity of 2.82 m/s or 10.14 km/h) to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an on-ice to over ground ratio of 0.84.

Subsequently, each trial version of the test was evaluated on-ice. It was found that performing the first version of the test (time of 6.4 seconds for the first shuttle and a velocity of 3.13 metres per second or 11.27 km/h) was too taxing to carry out. In the process of elimination, the fourth version (time of 7.1 seconds for the first shuttle and a velocity of 2.82 metres per second or 10.14 km/h) proved to have the greatest utility, with the same level (shuttle) being reached as in the over-ground version of the test. Table 4.4. shows the original 20 MST and the modified (skating) 20 MST. The differences in velocities at each stage as well as the time taken to complete each 20 m shuttle can easily be compared.

TABLE 4.4. THE ORIGINAL 20 MST AND THE MODIFIED (SKATING) 20MST

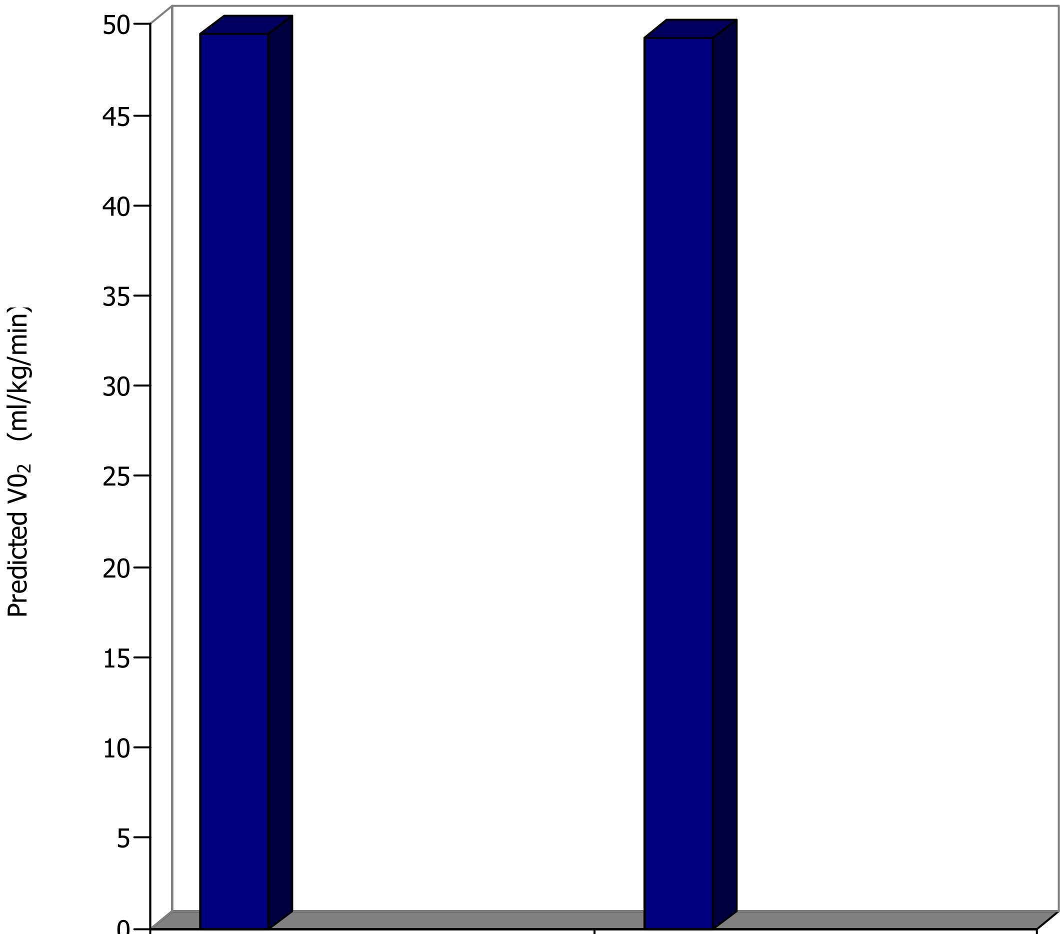
Original 20 MST					***Trial Version 4***		
Stage (min)	***Number of shuttles***	***sec***	***m/s***	***km/h***	***Sec***	***m/sec***	***km/h***
1	7	8.5	2.4	8.5	7.1	2.8	10.1
2	8	8.0	2.5	9.0	6.7	3.0	10.7
3	8	7.6	2.6	9.5	6.3	3.2	11.4
4	9	7.2	2.8	10.0	6.0	3.3	12.0
5	9	6.9	2.9	10.5	5.7	3.5	12.6
6	10	6.6	3.1	11.0	5.5	3.6	13.1
7	10	6.3	3.2	11.5	5.2	3.8	13.8
8	11	6.0	3.3	12.0	5.0	4.0	14.4
9	11	5.8	3.5	12.5	4.8	4.2	15.0
10	11	5.5	3.6	13.0	4.6	4.3	15.7
11	12	5.3	3.8	13.5	4.4	4.5	16.4
12	12	5.1	3.9	14.0	4.3	4.7	16.7
13	13	5.0	4.0	14.5	4.1	4.9	17.6
14	13	4.8	4.2	15.0	4.0	5.0	18.0
15	13	4.7	4.3	15.5	3.9	5.1	18.5
16	14	4.5	4.4	16.0	3.8	5.3	18.9
17	14	4.4	4.6	16.5	3.6	5.6	20.0
18	15	4.2	4.7	17.0	3.5	5.7	20.6
19	15	4.1	4.9	17.5	3.4	5.9	21.2
20	16	4.0	5.0	18.0	3.3	6.1	21.8
21	16	3.9	5.1	18.5	3.2	6.3	22.5

4.4. Reliability of the Modified (Skating) 20 MST

According to Thomas & Nelson (1996), reliability pertains to the consistency, or repeatability of a measure. A test cannot be considered valid if it is not reliable. The reliability for the modified (skating) 20 MST is reflected in Figure 4.5 an on-ice test-retest procedure indicated very close respective predicted mean VO_2max scores (49.5±3.37 vs. 49.29±7.95 ml/kg/min). This yielded a highly significant ($p \leq 0.001$) correlation between scores of 0.87 and a coefficient of determination (r^2) of 76 %. It could thus be claimed that the modified (skating) 20 MST for use on-ice shows good consistency of measurement in the study population.

According to Snyder & Foster (1994) ice-hockey players, even more so than speed skaters tend to have relatively ordinary aerobic abilities. Values for VO_2max ranging from 4.3-4.7 L/min (53-57 ml/kg/min) have been reported for ice-hockey players who completed treadmill running tests. It has been reported that ice-hockey players had a mean VO_2max of 57.2 ml/kg/min during running tests, 53.4 ml/kg/min during cycling tests, and 55.5 ml/kg during skating tests. As expected the running test produced slightly greater (~ 7 %) VO_2max levels than did the cycling test, with the skating test values falling between running and cycling.

Figure 4.4: Reliability of the Modified 20 MST (n=15)



	On-Ice Test 1	On-Ice Retest
Mean	49.5	49.29
SD	8.37	7.95
Correlation	r	0.87
Significance	p	$p < 0.001$
Meaningfulness	Coefficient of determination	76%

The VO_2max values of ice-hockey players are presented in Table 4.5. The VO_2max values of ice-hockey players (43.7$\pm$6.6 ml/kg/min; as directly determined by the *Aerosport$_{TM}$* portable gas analyser whilst subjects performed the on-ice skated 20 MST) reported in a study by Kuisis and Van Heerden (2001) are lower than the VO_2max values reported in the literature (Snyder & Foster, 1994), but it should be kept in mind that the subjects in this study were provincial level ice-hockey players.

TABLE 4.5: VO_2MAX OF ICE-HOCKEY PLAYERS

Author	VO_2max (ml/kg/min)	Modality
Snyder & Foster (1994)	53-57	Treadmill running
Montgomery (1988)	57.2	Running
Montgomery (1988)	55.5	Skating
Montgomery (1988)	53.4	Cycling
Reilly & Borrie (1992) (field hockey)	48-65	
Kuisis & Van Heerden (2001)	43.7±6.6	Skating (20 MST)

The VO_2max values of figure skaters indicated in the literature are shown in Table 4.6. Like speed skaters and ice-hockey players, figure skaters were initially described as having fairly unremarkable maximum values for aerobic power (Niinimaa, 1982).

Research by Niinimaa (1982) showed that when compared to a sedentary population of the same age, figure skaters have cardiovascular fitness levels which are 50 %-60 % higher (McMaster *et al.,* 1979), but when compared to endurance athletes (94 and 77 ml/kg/min in male and female cross-country skiers) the figure skaters had far lower values. Physical stress during free skating is approximated at 75 % to 80 % of the skater's maximal aerobic power. According to Kjaer & Larsson (1992) work intensity during simulated competitive figure skating corresponded to 89 % VO_2max, and thus, high levels of aerobic power are required in elite figure skating. Mannix *et al.* (1996) state that except for the highest-ranking competitors, most of those aspiring to attain "greatness" in figure skating have average aerobic power.

The figure skaters in Kuisis & Van Heerden (2001) had VO_2max values far lower (38.9 . 3.5 ml/kg/min) (as directly determined by the *Aerosport*$_{TM}$ portable gas analyser whilst subjects performed the on-ice skated 20 MST) than the subjects in the previously mentioned studies (Niinimaa, 1982; Kjaer & Larsson, 1992; in which the subjects were elite level skaters), this is possibly due to the fact that the subjects in this study were all provincial level skaters.

TABLE 4.6: VO_2MAX OF FIGURE SKATERS		
Author	**VO_2max (ml/kg/min)**	**Modality**
Niinimaa (1979)	48.9±4.5	Treadmill running
Kjaer & Larsson (1992)	54.7-68.8	Treadmill running
Kuisis & Van Heerden (2001)	38.9±3.5	Skating (20 MST)

A correlation of 0.60 between a 12-minute skate test and VO_2max was as high as the correlation between a 12-minute run test and VO_2max for a team of Bantam All-Stars (Hockey & Howes, 1979), depicted in Table 4.7. The somewhat low correlation can be 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 during the skate test.

TABLE 4.7: MAXIMAL OXYGEN UPTAKE IN 12-MIN RUN & 12-MIN SKATE TESTS		
Test	**Mean**	**Standard Deviation**
Maximal oxygen uptake	53.34 ml/kg/min	5.03
12-Min Run Test	1.60 miles	0.9
12-Min Skate Test	2.65 miles	0.19

(Hockey & Howes, 1979)

Canadian hockey players appear to have the same VO_2max when tested on the ice and on the treadmill (Larivière, 1972; Léger *et al.*, 1979; Montgomery, 1988), although Scandinavian research found a lower VO_2max when skating (Montgomery, 1988).

Defensemen have lower VO_2max values than forwards do, with goalkeepers generally having the lowest VO_2max values (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 VO_2max (ml/kg/min) values. Where age is concerned, the functional capacity of the cardiovascular system of young players (age 10 years) is similar to elite adult players. A VO_2max of 56.6 ml/kg/min has been reported for boys involved in a competitive league (Montgomery, 1988).

According to Montgomery (1988) (Table 4.8) the individual variability of VO_2max (±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. Green (1978) has also observed substantial interindividual differences in skating efficiency.

Players (n=13) of the Czechoslovakian national team were studied during 1 shift averaging 1.17 minutes followed by 21 minutes of recovery. Energy expenditure was measured by indirect calorimetry and corrected for basal metabolic rate. Based on oxygen consumption during this one shift and the prolonged recovery period, 69 % of the oxygen consumed was in the recovery period. Oxygen consumption during the shift averaged 32 ml/kg/min or 66 % of VO_2max during the model game. Seliger *et al.* (1972) characterized ice-hockey as an activity showing mostly a submaximal metabolic rate with a great participation of anaerobic metabolism (69 %), but simultaneously with high requirements for aerobic metabolism (31 %). During simulated play, the on-ice heart rate averaged only 152 beats/min, while pulmonary ventilation was 92 L/min. These values however seem to underestimate the aerobic intensity. Green *et al.* (1976) estimated the on-ice energy requirements at 70 to 80 % of VO_2max in university players, while Paterson *et al.* (1977) estimated on-ice aerobic involvement in excess of 80 % of VO_2max in young boys.

TABLE 4.8: MAXIMUM OXYGEN UPTAKE OF ELITE ICE-HOCKEY TEAMS

Group	n	Mass (kg)	VO_2max	Reference
Treadmill				
USA Olympic 1976	22		58.7	Enos *et al.* (1976)
University	8	70.5	58.1	Montpetit *et al.*(1979)
University	10	72.8	61.4	Léger *et al.* (1979)
Swedish National	24	75.6	57.0	Forsberg *et al.* (1974)
Junior	18	76.4	56.4	Green & Housten (1975)
Finnish National	13	77.3	61.5	Rusko *et al.* (1978)
University	8	77.4	61.3	Green *et al.* (1978a)
University	19	77.6	58.9	Green *et al.* (1979b)
Junior	9	78.7	59.1	Green *et al.* (1979b)
Swedish National 1971	24	78.1	56.3	Wilson & Hedberg (1976)
Junior	44	78.2	55.4	Housten & Green (1976)
University	11	79.5	56.4	Montgomery (1982)
Swedish National 1966	24	80.0	53.6	Wilson & Hedberg (1976)
University	9	80.9	56.3	Hutchinson *et al.* (1979)
Professional	12	83.4	55.3	Green *et al.* (1979b)
Montreal Canadians 1981-82	27	85.9	55.6	Montgomery & Dallaire (1986)
Professional		86.4	53.6	Wilmore (1979)
NHL forwards 1985-86	27	87.1	57.4	Rhodes *et al.* (1986)
NHL defense 1985-86	40	90.3	54.8	Rhodes *et al.* (1986)

NHL goalies 1985-86	8	79.2	49.1	Rhodes *et al.* (1986)
Cycle ergometre				
Quebec Nordiques 1972-73	12	75.9	54.1	Bouchard *et al.* (1974)
University	15	76.9	54.5	Thoden & Jette (1975)
Junior	24	77.0	58.4	Bouchard *et al.* (1974)
University	9	77.1	53.2	Hermiston (1975)
University	18	78.1	55.2	Romet *et al.* (1978)
Canadian National	34	78.5	53.4	Coyne (1975)
Czechoslovakian National	13	79.1	54.6	Seliger*et al.* (1972)
University	5	79.5	54.3	Daub *et al.* (1983)
University	21	79.8	58.4	Krotee *et al.* (1979)
Canadian National	23	81.1	54.0	Smith *et al.* (1982)
Finnish National	27	81.1	52.0	Vainikka *et al.* (1982)
Junior	9	82.4	52.6	Green *et al.* (1979b)
Professional	38	82.3	43.5	Romet *et al.* (1978)
Montreal Canadians 1982-83	29	86.8	51.9	Montgomery & Dallaire (1986)
NHL forwards 1985-86	27	87.1	53.3	Rhodes *et al.* (1986)
NHL defense 1985-86	40	90.3	51.6	Rhodes *et al.* (1986)
NHL goaltenders 1985-86	8	79.2	44.1	Rhodes *et al.* (1986)
Skating				
University	10	72.8	62.1	Léger *et al.* (1979)

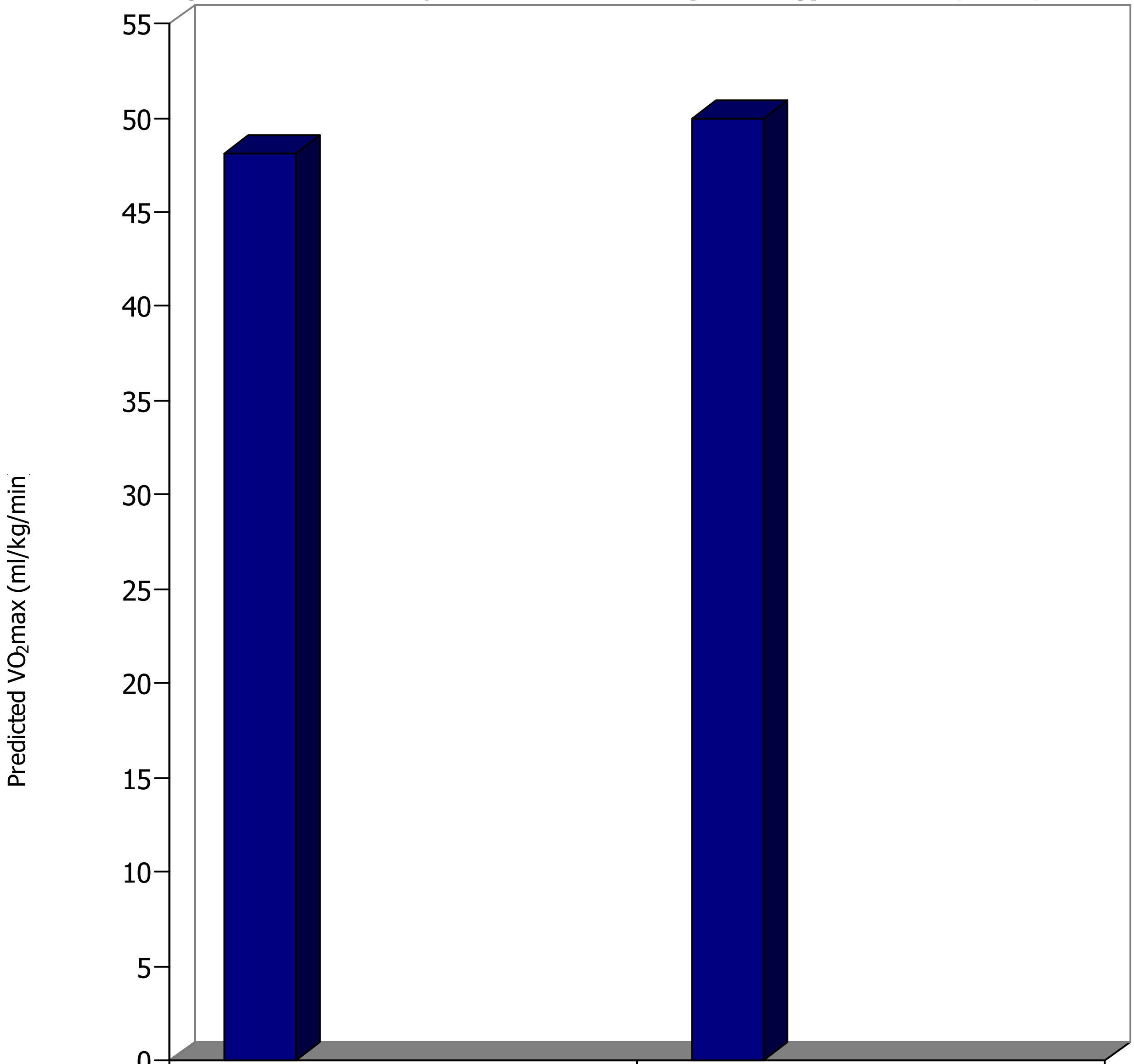
University	17	73.7	55.0	Ferguson *et al.* (1969)
University	8	78.7	52.8	Green (1978)
University	5	79.5	52.1	Daub *et al.* (1983)
Modality of testing not mentioned				
NHL 1980	38	85.3±1.1	54±1.1	Cox *et al.* (1995)
NHL 1984	30	88.2±1.1	54.4±0.8	Cox *et al.* (1995)
NHL 1988	23	91.2±1.5	57.8±1.2	Cox *et al.* (1995)
NHL & Team Canada 1991	72	88.4±0.8	60.2±0.6	Cox *et al.* (1995)
Team Canada training camp 1991	55	89.3±0.8	62.4±0.5	Cox *et al.* (1995)

(Montgomery, 1988; Cox *et al.,* 1995)

4.5. Validity of the Modified (Skating) 20 MST

According to Thomas & Nelson (1996), validity indicates the degree to which the test measures what it is supposed to measure. The validity assessment for the modified (skating) 20 MST is reflected in Figure 4.6. using a test-retest procedure with the (original over-ground) 20 MST format setting as the criterion reference, based on its established validity (Léger & Lambert, 1982), similar predicted mean VO_2max scores were attained during the modified (skating) 20 MST. The respective over-ground versus on-ice scores (48.09±6.25 vs. 49.98±7.23 ml/kg/min) yielded a very significant ($p \leq 0.01$) correlation of 0.73 and a coefficient of determination (r^2) of 53 %. It could thus be claimed that the modified (skating) 20 MST for use on-ice shows both good reliability and concurrent validity, thus offering a useful activity specific indirect assessment tool to measure cardiorespiratory fitness (VO_2max) in the field.

Figure 4.5: Validity of the Modified (Skating) 20 MST (n=10)



	Over-Ground Test	On-Ice Test
Mean	48.09	49.98
Std. Deviation	6.25	7.23
Correlation	r	0.73
Significance	p	$p < 0.01$
Meaningfulness	Coefficient of determination	53%

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

To recapitulate, the purpose of the study was to modify the 20 MST for application to ice-sports.

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

a) determine the velocity of motion, energy expenditure, and mechanical efficiency on-ice versus over-ground;
b) adapt the velocity of motion required for each level of the test; and
c) establish the reliability and concurrent validity of the modified (skating) 20 MST.

The velocity of motion was determined using split-times during a forty-metre sprint test. Results showed higher velocities of motion on-ice as compare to over-ground for 0 to 20 m ($p>0.05$), 0 to 30 m ($p\leq0.05$), 0 to 40 m ($p\leq0.001$) and the overall mean ($p\leq0.05$).

Energy expenditure was determined via the measurement of oxygen consumption on-ice whilst performing the original 20 MST (Léger & Lambert, 1982). Energy expenditure was determined at three different intensities (the lowest intensity being after 4 minutes of exercise and at a running speed of 10 km/hour, the intermediate intensity being after 8 minutes of exercise time and at a skating speed of 12 km/hour, and the highest intensity being after 12 minutes of exercise time and at a skating speed of 14 km/hour). Results expressed in kilocalories per minute (kcal/min) showed higher energy expenditure on-ice versus over-ground ($p>0.05$) at a low intensity only. Energy expenditure was lower on-ice as compare to over-ground for intermediate intensity ($p \leq 0.05$), high intensity ($p \leq 0.0001$), and the overall mean ($p \leq 0.05$).

Mechanical efficiency during the performance of the 20 MST, expressed as an index derived by quotient of the velocity (m/min) at which the VO_2max was attained (as numerator) and the VO_2max (ml/kg/min) itself (as denominator) showed higher mechanical efficiency on-ice as compared to over-ground ($p \leq 0.001$).

The comparable data on all the variables measured concluded that motion on-ice was less taxing than over-ground. The 20 MST was thus modified by adapting (increasing) the velocity of motion required for each level of the test (distance of 20 m per shuttle). The modified test started at velocity of 2.8 m/s or 10.1 km/h and permitted 7.1 seconds to complete each shuttle for the first level of the test, which then decreased progressively at each level. This was based on an overall variable-derived on-ice to over ground ratio of 0.84.

Test-retest on-ice reliability measures (n=15) for predicted VO_2max (49.5±8.37 vs. 49.29±7.95 ml/kg/min) showed a highly significant ($p \leq 0.001$) consistency (r=0.87). Similarly test-retest concurrent validity measures (n=10) for predicted VO_2max over-ground with the original 20 MST (48.09±6.25 ml/kg/min) as designed by Léger and Lambert (1982) versus on-ice values with the modified (skating) 20 MST (49.98±7.23 ml/kg/min) showed a very significant ($p \leq 0.01$) correlation of 0.73 between the two tests.

Cardiorespiratory endurance is generally recognized as a major component of evaluating physical fitness and maximal oxygen consumption (VO_2max) and is considered the most valid measure of cardiorespiratory fitness (Gabbard, 1992).

Based on the results of this study and existing literature, the most important conclusions that can be drawn are:

a) the 20 MST in its original format performed on ice greatly overestimates the VO_2max of both figure skaters and ice-hockey players (refer to Appendix B);
b) the original 20 MST in its current format is inappropriate for use on ice;
c) modification (adaptation) of the 20 MST has resulted in a modified (skating) 20 MST with greater utility for use on-ice;
d) the modified test was found to be reliable for ice-hockey players of a certain age; and
e) the modified test has also been found to be a valid concurrent measure of indirect VO_2max.

Future research

Future research could focus on further modification of the modified (skating) 20 MST for use on-ice in speed skating. Although modification would change the stop and go nature of the test by adapting the test to run on an oval track without stoppages, it would enable indirect measurement of VO_2max in a sport-specific environment for speed skaters. Alternatively the modified (skating) 20 MST could be modified to be an intermittent skating test (with set rest periods) to indirectly predict VO_2max, which would further refine the modified (skating) shuttle-skating test for ice-sports.

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APPENDIX A

Kuisis, S. M. and van Heerden, H. J. (2001). Validity of the 20-Meter Multistage Shuttle Run Test in Assessing Aerobic Power in Provincial Ice-Hockey Players and Figure Skaters. ***African Journal for Physical, Health Education, Recreation and Dance,*** October 2001 (Supplement): 15-32.

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VALIDITY OF THE 20-METER MULTISTAGE SHUTTLE RUN TEST IN ASSESSING AEROBIC POWER IN PROVINCIAL ICE-HOCKEY PLAYERS AND FIGURE SKATERS

S.M. Kuisis and H.J. van Heerden.

Sport-specific tests are highly valued in exercise science, including tests for cardiorespiratory endurance and maximal oxygen consumption. This study investigated the estimated (indirect) and simultaneous direct maximal oxygen consumption (VO: max) of five male ice-hockey players (IH) (17.8+1.8 years) and nine female figure skaters (FS) (15.3+4.1 years, who skated the 20-metre multistage shuttle-run test (20-MST) on-ice. The relative VO_2 *max (ml/kg/min) estimated during the skated MST highly over-estimated the simultaneous direct* VO_2 *max of both IH (62.4+4.6 vs. 43.7+6.6; p<0.01) and FS (80.6±5.1 vs. 38.9+3.5; p<0.0001). No significant difference was found between the direct* VO_2 *max values of IH players and FS (43.7+6.6 vs. 38.9+3.5; p>0.05) but the indirect* VQ_2 *max, as predicted by the on-ice skated 20 MST, was higher for FS than IH players (80.6 6±5.1 vs. 62.4+4.6; p<0.0001). In conclusion, the 20-MST as originally designed for use over-ground is unsuitable to assess aerobic fitness in ice-hockey players and figure skaters.*

Key words: Ice-hockey, figure skating, 20-MST, VO_2 max

INTRODUCTION

Cardiorespiratory endurance is generally recognised as a major component of evaluating physical fitness and maximal oxygen consumption (VO_2 max) and is considered the most valid measure of cardiorespiratory fitness (Gabbard, 1992). Sport-specific tests are highly valued in exercise science, including tests for cardiorespiratory endurance and maximal oxygen consumption. The physiological assessment of athletes in their environment is worthwhile in providing information on acute adaptation to specific activities, which may be different from adaptations found under controlled laboratory conditions involving treadmill running and cycling. Snyder and Foster (1994) believe that an exercise test can benefit the athlete and coach only if it

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meets three criteria: a) there must be a high correlation between the test measure and subsequent competitive performance; b) the test must be able to detect changes in the competitive fitness of the athlete; and c) the test must allow the athlete to set achievable goals.

The 20-metre multi-stage shuttle run test (20-MST) originally designed by Leger & Lambert (1982), and later refined (Leger, Mercier, Gadoury & Lambert, 1988) is a popular field test of aerobic power. It fulfils all three the above-mentioned requirements of an exercise test, and is relevant to sports such as soccer and hockey (Grant, Corbett, Amjad, Wilson & Aitchison, 1995), where turning is a feature of the game. Furthermore Paliczka, Nichols & Boreham (1987) state that the 20-MST is an appropriate field test of aerobic endurance because the requirement for pace judgement is eliminated by the use of a pre-recorded audio signal; the incremental nature of the test ensures a gradual rise in work-rate and therefore heart rate; the test appears to be highly reliable (r= 0.975; Leger and Lambert 1982); and large numbers of subjects can be tested simultaneously. The 20-MST is similar to treadmill protocols because it is a safe progressive and maximal test, but is less expensive and time consuming than direct measurements (Van Mechelen, Hlobil & Kemper, 1986; Boreham, Paliczka & Nichols, 1990). It can thus be accepted that the 20-MST appears to be a valuable test in predicting the maximal aerobic power of both males and females when performed over-ground on most types of natural and synthetic gymnasium surfaces (Leger, Mercier, Gadoury & Lambert, 1988; Leger & Lambert, 1982; Van Mechelen et al., 1986; Paliczka et al., 1987; Boreham et al., 1990). However, the application of the 20 MST to individuals participating in activities such as figure skating and ice-hockey, that are performed on-ice as opposed to ground surfaces, has not been investigated in depth.

Ice-hockey is a high-intensity and intermittent activity in nature. The length of a shift can vary from several seconds to over two minutes, with players being active for a total of 15-20 minutes of intermittent play, out of the 60 minutes total duration of a game (Snyder & Foster, 1994). Given the nature of the game, the stop-and-go nature of the 20-MST test would seem to be an ideal field test of aerobic power for ice-hockey (Bracko, 1998). In an earlier work, Leger, Seliger & Bassard (1979) confirmed the specificity of physiological responses of ice-hockey players by showing higher VO_2 max and lower lactate values when tested with and without equipment using a 20-m shuttle and 140-m oval course on ice *versus* a treadmill, respectively.

Since the refinement and validation of the 20-MST for over-ground use (Leger et al., 1988), the relationship between the actual and estimated VO_2 max responses while performing the MST on-ice appears not to have been established. In cognisance of the foregoing, the aim of this study was to investigate variations between the predicted indirect VO_2 max and the simultaneously measured direct VO_2 max values of ice-hockey players and figure skaters whilst performing the 20-MST on-ice.

METHODOLOGY

Subjects

The subjects possessed skills specific to ice-hockey and figure skating and were all participants on provincial level. The study group, which comprised 14 subjects, i.e. nine female figure skaters and five male ice-hockey players gave written informed consent (Table 1). In South Africa competitions in male ice-hockey are more common than female ice-hockey which is at developing stages, thus explaining the difference in the groups and number of subjects.

Table 1: Subjects' descriptive characteristics

Group	n	Age (years)	Stature (cm)	Mass (kg)
Ice-hockey	5	17.8±1.8	182±8.0	75.6±12.1
Figure skating	9	15.3+4.1	159.618.1	49,8±10.3

Procedures and Instrumentation

Both ice-hockey players and figure skaters performed a skating 20-MST (on-ice test) which rendered an indirect predicted VO_2 max value, while the skaters' direct VO_2 max was simultaneously measured by means of an *Aerosport* ™ portable gas analyzer, which each subject carried on their backs. Ice-hockey players wore their full kit and carried a stick during the test while figure skaters wore only standard skating costumes or a tracksuit. The gas analyzer was calibrated before each subject was tested. Calibration and warm-up time of the gas analyzer took approximately four minutes. All tests were administered during the afternoon and evening and were performed on a 30m X 60m ice-rink. Subjects were tested individually in random order. The ambient temperature ranged from 2°C to 9°C and the barometric pressure ranged from 660-680 mmHg. Temperature of the ice ranged from -5.5°C to -6.0°C. Ice conditions were normal, considering the fact that rough ice could possibly affect the scores obtained.

When subjects performed the 20-MST they were instructed to pace themselves with the sound signals from a pre-recorded tape and complete as many shuttles as possible. At each signal the subjects had to reach the line at the same time as the tone from the tape recorder. Although the 20-MST was designed to start at a particular level, with stages increasing by 0.5 km/h or 1 MET (3.5 ml O_2 kg/ min) every minute from a starting speed of 8.5 km/ h or 7 METS (Leger et al., 1988), this over-ground starting speed was found to be too slow for the skaters. After experimentation and feedback from the skaters, the test was commenced on level four for all skaters. Shuttle run performance over-ground has been described as the final running speed (Leger & Lambert, 1982) or 20-m shuttle attained (Paliczka et al., 1987; Ramsbottom et al., 1988). In this study the test was terminated when the subject stopped voluntarily and could not continue skating despite verbal encouragement, or when the subject failed to be within three meters of the 20-m line on the sound of the tone on three consecutive occasions. It was then assumed that the skater had reached his/her maximal skating speed. Indirect VO_2 max values were thus determined according to the highest level attained by the subjects during the skated 20-MST. The last stage number announced was used to predict VO_2 max from the norm tables (Leger et al., 1988). The criteria used for determining the direct VO_2 max (ml 0_2 /kg/min), as provided by the data printout from the *Aerosport* ™ portable gas analyzer, were a respiratory gas exchange ratio of >1.15 and an increase of less than 150 ml O_2 from the previous stage.

Statistical Analysis

Student t-tests were applied to indicate differences between sets of data with alpha set at a minimum of $p<0.05$ (Thomas & Nelson, 1996). Accordingly, comparisons were made contrasting the directly measured VO_2 max and the predicted indirect VO_2 max, within and between the groups of ice-hockey players and figure skaters, respectively.

RESULTS

The results of this study are graphically depicted in figures 1 and 2. Among figure skaters a highly significant difference ($p < 0.0001$) was found between the direct VO_2 max values (38.9± 3.5) and the indirect VO_2 max (80.6± 5.1 ml/ kg/ min). Among ice-hockey players a significant difference ($p < 0.01$) also existed between the direct VO_2 max values (43.7± 6.6) and the indirect $V0_2$ max (62.4± 4.6 ml/ kg/ min). Thus, for both figure skaters and ice-hockey players the on-ice skated 20-MST overestimated the skaters' actual (directly measured) VO_2 max, but more so for figure skaters.

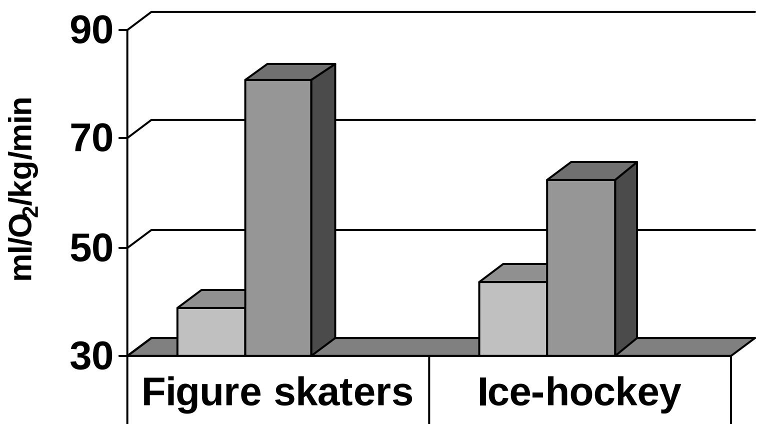

	Figure skaters	Ice-hockey
Direct	38.9	43.7
Indirect	80.6	62.4
Significance	p<0.0001	46.9

Figure 1: Direct vs. indirect on-ice VO_2 max within groups Figure skaters had a lower direct VO_2 max value than ice-hockey players (38.9± 3.5 vs. 43.7+ 6.6 ml/ kg/ min respectively), although this difference was not statistically significant ($p > 0.05$). Figure skaters, however, had a significantly greater indirect VO_2 max value ($p < 0.0001$) than ice-hockey players (80.6 ± 5.1 vs. 62.4+ 4.6 ml/kg/min), respectively. This further illustrates that on-ice skated 20-MST overestimates indirect VO_2 max values more in figure skaters than ice-hockey players in comparison to the directly measured VO_2 max (assessed by the *Aerosport* ™)

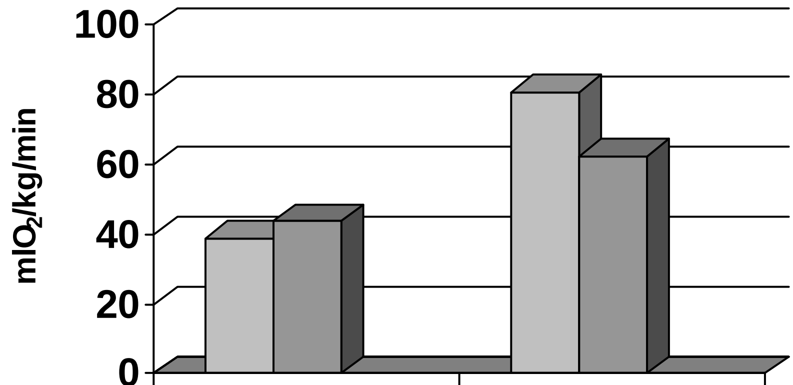

	Figure skaters	Ice-hockey
Direct	38.9	80.6
Indirect	43.7	62.4
Significance	$p>0.05$	$p<0.0001$

Figure 2: Direct vs. indirect on-ice max between groups

DISCUSSION

In this study ice-hockey players had a slightly higher direct VO_2 max value than the figure skaters. This could possibly be explained by the fact that ice-hockey players skated with full ice-hockey kit and a stick, which closely simulated a game situation and made the test more sport-specific, while figure skaters were wearing only standard skating costumes or tracksuits. Di Prampero, Cortili, Mognoni & Saibene (1976) stated that the energy expenditure per unit body weight and unit distance, increases with speed and increased air resistance and may lead to an increase in oxygen consumption ($V0_2$ max). For a particular speed, mechanical efficiency ratios have indicated a 4.8% additional energy cost of skating with ice-hockey equipment (Leger et al., 1979; Leger, 1981). This percentage is lower than the 10% of body weight in equipment (7.3 kg), which is normal in a sliding action where the vertical component of work is less than running (Leger et al., 1979). Men and women expend approximately the same energy while skating (Leger, 1981). The fact that the skaters in this study were wearing full ice-hockey kit and skated with their hockey sticks, would increase air resistance and thus ultimately their oxygen consumption.

The direct VO_2 max values of ice-hockey players (Table 2) and figure skaters (Table 3) in this study are lower than the VO_2 max values reported in the literature. Initially, ice-hockey players and figure skaters were described as having fairly unremarkable maximum values of aerobic power. Niinimaa (1982) showed that, when compared to a sedentary population of the same age, figure skaters have cardiovascular fitness levels, which are 50%-60% higher (Me Master, Liddle & Walsh, 1979), but when compared to endurance athletes (94 and 77 ml/kg/min in male and female cross-country skiers, respectively) the figure skaters had far lower values. Physical stress during free skating is approximated at 75% to 80% of the skater's maximal aerobic power. According to Kjaer & Larsson (1992) work intensity during simulated competitive figure skating corresponded to 89% of VO_2 max, and thus, high levels of aerobic power are required in elite figure skating. Mannix, Healy & Farber (1996) state that except for the highest ranking competitors, most of those aspiring to "attain greatness" in figure skating have average aerobic power. Rather than deducing that the aerobic capacities of subjects measured in this study are inferior, it is possible that their provincial competitive level, as opposed to elite standard, could have contributed to their lower VO_2 max values. It is even more likely, however, that these variations are due to the differing test modalities and protocols used to measure VO2 max in the studies cited, which included treadmill, over-ground running and cycle ergometry (Table 2 and 3).

Table 2: Aerobic capacity of ice-hockey players

Study	VO_2 max (ml/ kg/ min)	Modality
Snyder and Foster (1994)	53-57	Treadmill running
Montgomery (1988)	57.2	Running
Montgomery (1988)	55.5	Skating
Montgomery (1988)	53.4	Cycling
This study	43.7 ±6.6	Skating

Table 3: Aerobic capacity of figure skaters

Study	VO_2 max (ml/ kg/ min)	Modality
Niinimaa(1979)	48.9 ±4.5	Treadmill running
Kjaer and Lasson (1992)	54.7-68.8	Treadmill running
This study	38.9±3,5	Skating

The issue of test-specificity and the validity of laboratory (direct) *vs.* field (indirect) measurement of VO_2 max is integral to the purpose of this study. Although direct measurement is the single best measure of cardiorespiratory fitness or aerobic capacity, laboratory tests of VO_2 max involve complexities and require extensive equipment, are time consuming and are not cost effective. These maximal tests are also restricted to testing one subject at a time. In the absence of a portable ergospirometer, laboratory tests are often restricted to exercising on a treadmill or cycle ergometer with the subject required to wear a mask, which is then attached to a gas analyzer with the subject having to remain close to the equipment. Often, these are restricting factors for many people due to unfamiliarity and discomfort in the artificial conditions when compared to the actual sporting event. This often artificially affects the results obtained (Leger & Boucher, 1980; Ahmaidi, Collomp, Caillaud, & Prefaut, 1992; Grant et al., 1995). According to Bouchard, Shepard, Stephens, Sutton and Me Pherson. (1988) there is an intra-individual day to day variability of 4-6% in tests using ergometers, due to such factors as errors in gas analysis and calibration, equipment calibration and familiarization with the task. Reproducibility on the cycle ergometer and treadmill are similar, but bicycle VO_2 max values are 7-8% below those of a treadmill. For these reasons, a test without any respiratory equipment and required expertise is perceived as a real advantage (Leger, Seliger & Bassard, 1980; Boreham et al., 1990).

Hitherto, the majority of cardiovascular fitness tests among ice-skaters have been conducted on a treadmill and cycle ergometer, with very few actual skating tests having been performed (Snyder & Foster, 1994). Most tests specific to ice-hockey entail a mix of simulated laboratory and sport-specific field tests to measure variables related to anaerobic metabolism. Among these tests are the Sargent Anaerobic Skate Test (SAS_4o), which 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; the Reed Repeat Sprint Skate Test (RSS), which requires players to skate 55 m six times every 30 seconds; the Wingate test lengthened to 40 seconds (WAT_{40}); and a cycle ergometer test of six 15-second exercise: rest periods (RACE). Hockey & Howes (1979) have also compared skaters' heart rates and predicted caloric expenditure during a 12-minute skate test and a 12-minute over-ground running test. They found a correlation coefficient (r) of 0.6 between the 12-minute skate test and V02 max, while that between the 12-minute run test and the VO_2 max, r = 0.6.

The 20-MST (Leger et al., 1988) is a popular field test of aerobic power, and is relevant to sports such as soccer and hockey (Grant et al., 1995), where turning is a feature of the game. Ice-hockey and figure skating also require intermittent stopping, turning and changing direction, which should make the 20-MST an ideal aerobic test to apply to these sports. In this study, investigating the relationship between the actual and estimated VO_2 max responses while performing the MST on-ice, ice-hockey players had a slightly higher direct VO_2 max value than figure-skaters. In contrast, the figure skaters had a significantly greater indirect (predicted) VO_2 max value than ice-hockey players during the same 20-MST on-ice. Figure skaters had a longer total skating time during the on-ice 20-MST, reached higher levels than the ice-hockey players (level 19±1.4 vs. 13.8±1.3), and thus attained a higher indirect VO_2 max value. This finding is consistent with those reported by Kjaer & Larsson (1992), which indicated that figure skating is associated with high aerobic power. However, most of the work performed during on-ice workouts are above the anaerobic threshold, where progressive increases in blood lactate are observed (Mannix et al., 1996). A possible reason for figure skaters being able to skate to much higher levels during the on-ice skated 20-MST than ice-hockey players, could be due to the fact that figure skaters would seem to have a higher lactate tolerance. Thus, anaerobic power may also play an important role in accounting for the differences in on-ice MST scores as, after turning at the end of each shuttle, the subject has to accelerate to obtain the desired speed. This observation is consistent with that of Grant et al. (1995) in which subjects performed a running 20-MST. Alternatively, this difference could have been accentuated and attributed to the ice-hockey players wearing a full kit and carrying a stick during the test. This would have decreased their mechanical efficiency during skating (Leger et al., 1979), thus preventing the players from skating for longer periods of time to equal that of the figure skaters. Correspondingly, it was observed that figure skaters turned more economically than ice-hockey players did. This factor was particularly noticeable at higher speeds where turning technique is important,

Since the refinement and validation of the 20-MST for over-ground use (Leger et al., 1988), the relationship between the actual and estimated VO_2 max responses while performing the MST on-ice has remained unclear. In this study, a significantly higher indirect (estimated) *vs.* simultaneously measured direct VO_2 max value was found among both figure skaters and ice-hockey players, whilst performing an on-ice MST. Thus, for both figure skaters and ice-hockey players the on-ice skated 20-MST overestimated the skaters' actual (directly measured) VO_2 max, but this overestimation was greater in figure skaters. This illustrates that the on-ice skated 20-MST would tend to be more of a physiologically taxing maximal test and thus more accurately in predicting indirect VO_2 max for equipment-wearing ice-hockey players than for figure skaters. Alternatively, the on-ice skated 20-MST in its current format is not appropriate as a maximal aerobic power test for figure skaters.

CONCLUSIONS AND RECOMMENDATIONS

The most important conclusions that can be drawn from this study are that, in its over-ground format, the 20-MST performed on ice greatly over-estimates the VO_2 max of both figure skaters and ice-hockey players, but this over-estimation is greater in figure skaters. It is apparent that the 20-MST requires modification for use on ice. Possible modifications currently being investigated are increasing the distance skated within the time intervals of each shuttle, or decreasing the time intervals between the signal emitted from the tape recorder while the distance skated remains unchanged. These modifications might enhance the predictive validity of the on-ice 20-MST in estimating VO_2 max in provincial ice-hockey players and figure skaters.

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APPENDIX B

INFORMED CONSENT / PARENTAL CONSENT

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FACULTY OF HUMANITIES

Dept Biokinetics, Sport and Leisure Sciences
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INFORMED CONSENT / PARENTAL CONSENT (For subjects under 18 years of age)

I ____
(Full Name of Participant or Parent),

have been informed of the procedures, requirements, benefits and potential risks to participate in / for my child to participate in a research project on the development of a fitness test **(20 Metre Shuttle Skate Test)** for ice-sports. I understand that the project involves measuring oxygen consumption while running and skating a distance of 20 metres on the ground and on-ice repeatedly, on separate occasions until fatigued.

I therefore declare that I willingly cooperate / agree to my child's cooperation in the said project at own risk and will not withhold any information that may be of importance for the researchers and my / my child's safety. I am aware that I / my child may withdraw from the project at any time if I so wish.

I hereby also grant the researchers permission to use the results for publication and/or presentation purposes, with anonymity being ensured.

___________________________ **Tel**: ____________________________

Signature of Participant

___________________________ **Tel**: ____________________________

Signature of Parent (For subjects under 18 years of age)

____

Signature of Witness (Researcher)

Date: ________________________

APPENDIX C

MODIFIED (SKATING) 20 MST- PREDICTED VO_2 MAX

MODIFIED (SKATING) 20MST – PREDICTED VO_2 MAX

Time required for 20m	Velocity (km/h)	Level	Shuttle	VO_2 max	Time required for 20m	Velocity (km/h)	Level	Shuttle	VO_2 max	Time required for 20m	Velocity (km/h)	Level	Shuttle	VO_2 max	Time required for 20m	Velocity (km/h)	Level	Shuttle	VO_2 max
6.0	12	4	2	26.8	4.6	15.7	10	2	47.4	3.9	18.5	15	2	64.6	3.4	21.2	19	2	78.3
6.0	12	4	4	27.6	4.6	15.7	10	4	48.0	3.9	18.5	15	4	65.1	3.4	21.2	19	4	78.8
6.0	12	4	6	28.3	4.6	15.7	10	6	48.7	3.9	18.5	15	6	65.6	3.4	21.2	19	6	79.2
6.0	12	4	9	29.5	4.6	15.7	10	8	49.3	3.9	18.5	15	8	66.2	3.4	21.2	19	8	79.7
					4.6	15.7	10	11	50.2	3.9	18.5	15	10	66.7	3.4	21.2	19	10	80.2
5.7	12.6	5	2	30.2						3.9	18.5	15	13	67.5	3.4	21.2	19	12	80.7
5.7	12.6	5	4	31.0	4.4	16.4	11	2	50.8						3.4	21.2	19	15	81.2
5.7	12.6	5	6	31.8	4.4	16.4	11	4	51.4	3.8	18.9	16	2	68.0					
5.7	12.6	5	9	32.9	4.4	16.4	11	6	51.9	3.8	18.9	16	4	68.5	3.3	21.8	20	2	81.8
					4.4	16.4	11	8	52.5	3.8	18.9	16	6	69.0	3.3	21.8	20	4	82.2
5.5	13.1	6	2	33.6	4.4	16.4	11	10	53.1	3.8	18.9	16	8	69.5	3.3	21.8	20	6	82.6
5.5	13.1	6	4	34.3	4.4	16.4	11	12	53.7	3.8	18.9	16	10	69.9	3.3	21.8	20	8	83.0
5.5	13.1	6	6	35.0						3.8	18.9	16	12	70.5	3.3	21.8	20	10	83.5
5.5	13.1	6	8	35.7	4.3	16.7	12	2	54.3	3.8	18.9	16	14	70.9	3.3	21.8	20	12	83.9
5.5	13.1	6	10	36.4	4.3	16.7	12	4	54.8						3.3	21.8	20	14	84.3
					4.3	16.7	12	6	55.4	3.6	20.0	17	2	71.4	3.3	21.8	20	16	84.8
5.2	13.8	7	2	37.1	4.3	16.7	12	8	56.0	3.6	20.0	17	4	71.9					
5.2	13.8	7	4	37.8	4.3	16.7	12	10	56.5	3.6	20.0	17	6	72.4	3.2	22.5	21	2	85.2
5.2	13.8	7	6	38.5	4.3	16.7	12	12	57.1	3.6	20.0	17	8	72.9	3.2	22.5	21	4	85.6
5.2	13.8	7	8	39.2						3.6	20.0	17	10	73.4	3.2	22.5	21	6	86.1
5.2	13.8	7	10	39.9	4.1	17.6	13	2	57.6	3.6	20.0	17	12	73.9	3.2	22.5	21	8	86.5
					4.1	17.6	13	4	58.2	3.6	20.0	17	14	74.4	3.2	22.5	21	10	86.9
5.0	14.4	8	2	40.5	4.1	17.6	13	6	58.7						3.2	22.5	21	12	87.4
5.0	14.4	8	4	41.1	4.1	17.6	13	8	59.3	3.5	20.6	18	2	74.8	3.2	22.5	21	14	87.8
5.0	14.4	8	6	41.8	4.1	17.6	13	10	59.8	3.5	20.6	18	4	75.3	3.2	22.5	21	16	88.2
5.0	14.4	8	8	42.4	4.1	17.6	13	13	60.6	3.5	20.6	18	6	75.8					
5.0	14.4	8	11	43.3						3.5	20.6	18	8	76.2					
					4.0	18	14	2	61.1	3.5	20.6	18	10	76.7					
4.8	15.0	9	2	43.9	4.0	18	14	4	61.7	3.5	20.6	18	12	77.2					
4.8	15.0	9	4	44.5	4.0	18	14	6	62.2	3.5	20.6	18	15	77.9					
4.8	15.0	9	6	45.2	4.0	18	14	8	62.7										
4.8	15.0	9	8	45.8	4.0	18	14	10	63.2										
4.8	15.0	9	11	46.8	4.0	18	14	13	64.0										