Physiological Characteristics and Performance of NHL Entry Draft Players

by

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Table of Contents

Page

Abstract

This study examined the relationship between the physical fitness of National Hockey League (NHL) entry draft players and performance in the NHL. Physiological profiles were compared by level (NHL vs non-NHL) and position (forwards vs defense). The fitness level was determined by an assessment of body composition, anaerobic fitness, strength, power, muscular endurance, flexibility, and aerobic fitness. Subjects were 422 male hockey players, consisting of NHL entry draft (n = 310), minor league professional (n = 59) and NHL professional (n = 53) players. Results revealed that when drafted, physiological profiles of players who reach the NHL were significantly different from non-NHL players. Players that eventually made the NHL tended to be heavier and had higher peak power (W), mean power (W), VO_2max (L/min), grip strength and leg power. The fitness variables in the test battery had low predictive power to identify players who played in the NHL. Physiological profiles of forwards were significantly different from defense. Defense were taller, heavier, and fatter than forwards. Defense had higher peak power (W), grip strength and leg power compared to forwards. The forwards were higher in VO_2max when expressed relative to body weight. NHL entry draft players were lower in upper body strength than minor league professionals and NHL players.

Résumé

La présente étude visait à examiner la relation entre le niveau de condition physique des joueurs du repêchage de la LNH et leur performance dans la Ligue Nationale de Hockey (LNH). Les profils physiologiques ont été comparés par niveau (LNH vs non-LNH) et par position (attaquants vs défenseurs). Le niveau de condition physique a été déterminé par une évaluation de la morphologie, condition anaérobique, force, puissance, endurance musculaire, flexibilité, et condition aérobique. Le groupe de sujets comptait 422 joueurs de hockey masculin et était composé de joueurs du repêchage (n = 310), professionnels des ligues mineures (n = 59) et de professionnels de la LNH (n = 53). Les résultats ont révelé qu'au moment du repêchage, les profils physiologiques des joueurs qui atteignent la LNH étaient significativement différents de ceux des joueurs qui n'atteignent pas la LNH. Les joueurs qui éventuellement atteignaient la LNH avaient tendance à être plus lourds et étaient supérieurs en puissance maximale (W), puissance moyenne (W), VO_2max (L/min), force de poigne et en puissance des jambes. Les variables de condition physique dans la batterie de tests ont eu un faible pouvoir de prédiction pour identifier les joueurs qui ont évolué dans la LNH. Les profils physiologiques des attaquants étaient significativement différents de ceux des défenseurs: les défenseurs étaient plus grands, plus lourds et ils avaient un pourcentage de graisse plus élevé que celui des attaquants. Les défenseurs étaient supérieurs en puissance maximale (W), force de poigne et en puissance des jambes en comparaison avec les attaquants. Pour leur part, les attaquants étaient supérieurs en VO_2max exprimé en relation avec le poids. Les joueurs sélectionnés lors du repêchage avaient une force du

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List of Tables

List of Figures

Chapter I

Introduction

Ice hockey is an intense sport that requires many specific skills and physical abilities that will enable a player to perform under extreme conditions. Hockey is a stop-and-start, intermittent sport characterized by fast, explosive skating with sudden changes in direction (Twist and Rhodes, 1993b). The sport requires players to have great dexterity in order to fulfill the precision aspects of the game (passing, shooting, stick handling). In addition, players need good physiological attributes in order to fulfill the intense physical demands of the sport. Hockey requires players to exert high levels of power when they perform explosive skating starts, sudden direction changes, and shooting at speeds that can exceed 140 km/h. (Twist and Rhodes, 1993b). Ice hockey is also a contact sport that can create collisions of high impact. Bodychecking is another important part of the game. A collision may arise while both players are skating at maximal velocity. Players may also collide into boards and posts.

At elite levels, teams now benefit from knowledge that can help them to predict performance. Bouchard (1986) stated that the major factor determining the athlete's potential to excel in his sport is genetic endowment, which includes not only anthropometric characteristics, inherited cardiovascular traits, and muscle fiber-type proportions but also the capacity to improve with training. Players and coaches have realized the benefits of off-ice conditioning and it has become a standard practice among most hockey players and teams (Twist and Rhodes, 1993b). This has contributed in making today's elite hockey players physically bigger with improved levels of physiological fitness compared with their predecessors (Cox et al., 1995). In order to monitor progress and assess physiological fitness level, most elite teams now submit their players to a battery of field and laboratory tests.

Fitness assessments usually monitor the following elements: body composition, musculoskeletal fitness, anaerobic fitness and aerobic fitness. Body composition pertains to the amount of fat on the body. Musculoskeletal fitness refers to the muscular strength, power and endurance. It also pertains to flexibility of key areas of the body. Anaerobic fitness refers to the ability to work at a very high level for a relatively short period of time (5 - 45s). Aerobic fitness (VO_2max) reflects the endurance capability of the players' heart, lungs and muscles (Gledhill and Jamnik, 1994).

A hockey game contains elements that put high demands on the body. To cope with this factor, professional players strive to enhance their body's capacities. Superior skill and physical performance have been developed with the use of extensive and specific training programs (Cox et al., 1995). Cox et al. (1993), gathered data from National Hockey League (NHL) teams from 1980 to 1991. They showed a significant increase in body mass and height. A significant increase was also shown for grip strength and VO_2max during those 11 years. In addition, that study revealed that VO_2max, and body mass values from Team Canada 1991, which contains NHL's most skilled players, were higher than for NHL regulars.

1.1 Nature and Scope of the Problem

In recent years, researchers have described physiological demands of the sport according to ice hockey positions. It has been shown that physiological demands are different from one position to another. Twist and Rhodes (1993a) have stated that the goaltender position is characterized by quick, explosive movements that are short in duration and interspersed with periods of rest and submaximal activity. The aerobic system is used for recovery between these bouts of action. Forwards also use the aerobic system for recovery between their high intensity shifts, and to supply energy for sub-maximal efforts. Compared to forwards, defensemen are on the ice for more total time per game (Paterson, 1979). They have a shorter recovery period of time between shifts and higher off-ice heart rates than forwards (Paterson, 1979). Defensemen rely more on the aerobic system since they receive shorter recovery time between shifts (Twist, 1997).

Researchers have compared the physiological profiles for forwards, defensemen, and goaltenders. (Agre et al., 1988; Montgomery & Dallaire, 1986; Rhodes et al., 1986; Twist and Rhodes, 1993a; Wygand et al., 1987). VO_2max, Wingate, hand grip, and abdominal test scores were the variables examined.

Many elite ice hockey teams have been described by exercise physiologists in terms of fitness level. However, few studies have examined the link between the success of players in major hockey leagues and their overall fitness level described by specific physiological variables. There is little information in the scientific literature that refers to players' fitness data when comparing successful versus unsuccessful individuals in terms of playing time in the major leagues.

1.2 Significance of the Study

The study of physiological fitness is essential in evaluating the strengths and weaknesses of athletes in relation to their sport. It provides information about the players' progress within their training program as well as allows them to obtain a better understanding of their body's physical capacities and limitations (MacDougall and Wenger, 1991). Since hockey is a sport in which technical, tactical and psychological factors contribute to an athlete's performance, physiological testing alone will not enable a researcher to predict performance. However, the literature has shown that today's players are bigger, faster, and have better physiological fitness than those who played in earlier years (Cox et al., 1995; Montgomery, 1988).

Many studies have described the physiological characteristics of elite hockey players. The fitness levels of these players have also been assessed thoroughly. It is now possible to describe elite hockey players in terms of body composition, aerobic endurance, anaerobic power and endurance, muscle strength and endurance, and flexibility. It is unclear, however, whether there is a link between the players' fitness level when they are drafted and their performance in professional leagues. A comparison between players who eventually reach the NHL and players who do not reach that level might reveal trends in the physiological patterns that would enable sport scientists and coaches to identify key components in the physiological assessment of these players. Once completed, this analysis may provide helpful information on teams' criteria for selection of college and junior players. Hence, it may provide professional teams with an additional tool in the selection process.

1.3 Statement of the Problem

The purpose of this study was to examine the relationship between the fitness level of NHL entry draft players and their performance level in the NHL as well as the differences in physiological profiles of players according to level and position. The fitness level was determined by an assessment of body composition, musculoskeletal fitness, anaerobic fitness, aerobic fitness and flexibility. The performance level was determined by the number of NHL games played by a subject divided by the potential number of games played by a subject's team.

1.4 Hypotheses

1. The fitness profile of NHL players who play games at the NHL level will be significantly different from the players who do not make the NHL.
2. The number of games played at the NHL level can be predicted from fitness variables.
3. The physiological profile will be significantly different for forwards and defense.
4. NHL draft players will be significantly lower in upper body strength than minor league professionals and NHL professionals.

1.5 Operational Definitions

1. Absolute bench press: Total number of repetitions performed with 150 lbs.
2. Relative bench press: Number of repetitions multiplied by 150 and divided by body weight (lbs).
3. Peak power: Maximal power output (5s) during an all-out 45s test. Values are expressed in Watts and in Watts/kg.
4. Mean power: Average power output during an all-out 45s test. Values are expressed in Watts and in Watts/kg.

5. Minimum power: Minimal power output during an all-out 45s test. Values are expressed in Watts and in Watts/kg.

6. VO_2max: Maximum oxygen consumption during the aerobic evaluation. Values are expressed in L/min and in ml/kg• min.

7. Test duration: Time required to complete the aerobic evaluation.

8. Final workload: Workload achieved at the end of the aerobic evaluation.

9. NHL success ratio: Number of NHL games played by a subject divided by the total number of games played by the subject's team between October 1, 1994 and December 31, 1997.

1.6 Limitations

1. The physiological assessments over the four year period may have varied from year to year or among laboratories.

2. Laboratory equipment for assessment may have changed in different years.

1.7 Delimitations

1. Subjects were NHL entry draft players from 1994, 1995, 1996.

2. Subjects were male hockey players of junior and college levels.

3. NHL entry draft players ranged in age from 17 to 20 years.

4. Minor league professionals and NHL professionals ranged in age from 18 to 33 years.

5 Only forwards and defensemen were studied.

Chapter II

Review of Literature

2.1 Physiological Profile of the Ice Hockey Player

Vickers (1990) developed a knowledge-structures approach to help hockey coaches and scientists identify and evaluate the skills and abilities needed for successful performance. From approximately 400 skills, abilities, and concepts, Vickers identified five building blocks in the knowledge structure of ice hockey: background knowledge, philosophy of the game, physiological training, psychomotor skills, and psychological concepts. This review is concerned with only the physiological components.

Physiological assessment of the hockey player can be used to identify: (a) strengths and weaknesses of the individual, (b) physiological potential, (c) injuries, (d) when the player is ready to return to action following an injury, and (e) responses to a training regiment (Cox et al., 1995). Physiological testing not only provides precise information to develop potential but offers a motivational basis for training and allows for the establishment of objective measurable goals. A testing program can also be used as an educational process by which the athlete gains a better understanding of the physiological demands of the sport (MacDougall and Wenger, 1991).

Beginning in 1993, the NHL initiated physiological testing for entry draft players. The sport specific test battery for hockey players (Gledhill and Jamnik, 1994) included assessment of:

- Physical characteristics
- Aerobic power

• Anaerobic power and capacity (Wingate test)

• Strength and muscular endurance

• Flexibility

Some data pertaining to each of these measurements will be presented in the following sections.

2.2 Physical Characteristics and Added Mass

At the elite level, players range in age from 20 to 35 years with team averages in the mid-20's. The body mass, stature and fatness of elite players have previously been described (Chovanova, 1976b; Cox et al., 1995; Montgomery, 1988; Rhodes et al., 1986; Smith et al., 1981; Twist and Rhodes, 1993a). Over the last 20 years, body mass and height have progressively increased. In general, players are about 5 cm taller and carry an extra mass of 5 kg. Team averages in the NHL now exceed 185 cm for height and 90 kg for mass.

Cox et al. (1993) compared physiological data from 170 players on 5 NHL teams between 1980 and 1991. In 1980, 40% of the players weighed less than 85 kg and 71% were shorter than 180 cm in height. By 1991, only 26% of the players weighed less than 85 kg while 85% were taller than 180 cm. During this same period, the body fat content remained constant at 13% (Cox et al., 1995).

Within a team, the defense are taller and heavier than forwards (Agre et al., 1988; Green and Houston, 1975; Montgomery and Dallaire, 1986; Quinney, 1990; Smith et al., 1982; Twist and Rhodes, 1993a, 1993b).

The body composition of hockey players is usually estimated from skinfold thickness. Mean adipose levels range from 10 – 14% (Cox et al., 1995; Montgomery, 1988). Some of the variability can be attributed to the different equations used to estimate % body fat. Since hockey is a contact game, fat mass may offer some protection during collisions with boards and opponents. Fat mass may also be beneficial when body checking as it will add to the inertial mass.

Hockey players carry excess mass in the form of adipose tissue and equipment. The effect of added mass on skating performance has been examined with the Repeat Sprint Skate (RSS) test (Montgomery, 1982). Using a weighted vest, added mass was secured to the waist and shoulders in a manner not to impede skating movements. Added mass caused a significantly slower performance on both the speed and anaerobic endurance components of the RSS 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 challenged at a slower velocity and also reduces the time that a player can maintain the pace. Elite players should be encouraged to decrease body fat mass and to wear as light a uniform as possible without sacrificing protection.

The effect of experimental alterations in skate weight on performance in the RSS test has been investigated (Chomay et al., 1982). During the added skate weight conditions, there was a significant increase in time resulting in slower performance on both the speed and anaerobic endurance components of the RSS test. When purchasing skates and other protection equipment, players should use mass as an important selection criterion.

While hockey equipment serves to protect the player, it also increases energy expenditure. The effect of equipment weight (7.3 kg) on VO_2max and skating performance was examined during a 20 m shuttle skating test (Leger et al., 1979). Hockey players performed the test with and without equipment. While VO_2max was similar in both trials, the duration of the test was reduced by 20%. Final skating speed decreased by 7 m•min^{-1} (2.9%) when performing the test wearing hockey equipment. Calculation of mechanical efficiency ratios indicated a 4.8% additional energy cost of skating when wearing hockey equipment.

2.3 Aerobic Endurance

Table 1 summarizes the VO_2max results for elite players at the university, junior, national, and professional levels using cycle ergometer, treadmill and skating protocols. On the cycle ergometer, team means for both forwards and defense ranged from 52 to 62 ml/kg•min with one exception. One of the highest team means to be reported were the data on 55 players recruited for Team Canada in the 1991 Canada Cup. For this elite group, VO_2max averaged 62.4 ml/kg•min. On the treadmill, team means ranged from 52 to 66 ml/kg•min (Table 1). Measurement of VO_2max utilizing skating protocols has only been performed with university players. Hockey players appear to have the same VO_2max when tested on-ice and on the treadmill (Lariviere, 1972; Leger et al., 1979, Riby, 1993; Simard, 1975).

As the mean weight of the hockey team increases, the VO_2max expressed as ml/kg•min decreases. Within a team, positional comparisons support this trend. The defense are usually taller and heavier than the forwards so it is expected that the defense will have a lower VO_2max (ml/kg•min). There also appears to be an upward shift in aerobic endurance. Cox et al. (1993) examined VO_2max data from 170 players on 5 NHL teams between 1980 and 1991. In 1980, 58% of the players had a VO_2max less than 55 ml/kg•min. In contrast, only 15% were below this value in 1991. The improvements in aerobic power were independent of an increase in body mass, suggesting that conditioning methods had been effective in improving aerobic power (Cox et al., 1995).

2.4 Anaerobic Power and Endurance

Anaerobic power and endurance are important attributes for a hockey player. Cycling tests are generally preferred over other ergometers when evaluating hockey players. Research has indicated that the patterns of glycogen depletion and recruitment of muscles when cycling are similar to those used in skating (Geijsel, 1979; 1980; Green et al., 1978).

Laboratory test results with a cycling test have been compared with on-ice maximal skating performance using the RSS test (Gamble and Montgomery, 1986; Montgomery et al., 1990). Correlation coefficients of $r = -0.87$ for peak power on the cycling test and speed index on the RSS test, and $r = -0.78$ between mean power on the cycling test and total time for the RSS test provide support for the establishment of validity. The cycling test discriminated among hockey players at three levels - varsity, junior varsity and non-varsity players.

The most common test to assess anaerobic qualities in hockey players has been the Wingate test. Table 2 summarizes some results for the Wingate tests. Caution is warranted when comparing results across studies due to: (a) lack of standardization with respect to the type of cycle ergometer, (b) variance in test duration from 30 to 60 s, (c) variance in loading from 70 to 100 $g\bullet kg^{-1}$ of body mass, (d) stabilization of the ergometer, and (e) the presence or lack of toe clips on the pedals.

When peak power and mean power are expressed relative to body mass, forwards and defense have similar scores. Because the defense tend to be heavier than the forwards, their absolute scores are higher on cycle ergometer tests.

NHL players have significantly higher power outputs (W and $W\bullet kg^{-1}$) than minor league players. Using games played at the NHL level to establish two groups, peak power, mean power and minimum power on a 45 s Wingate test were able to discriminate between NHL players and minor league players (Montgomery et al., 1998). Figure 1 compares the results for the NHL players with minor league players over three seasons.

There is some dispute about what constitutes an anaerobic capacity test (Goslin and Graham, 1985). Jacobs et al. (1982) concluded that a 30 s Wingate test is too short in duration to quantify glycolytic anaerobic capacity. Bouchard et al. (1982) recommended that an anaerobic capacity test requires a maximal effort for 60 to 90 s. Hence, Table 2 uses mean power as the label rather than anaerobic capacity. Blood lactate levels for the 30 s Wingate test are high with mean values of 15.1, 14.9 and 14.9 $mmol\bullet L^{-1}$ reported for forwards, defense, and goalies, respectively (Twist and Rhodes, 1993a). These values suggest that hockey players have good anaerobic lactate capacity even though the test duration was shorter than recommended for an anaerobic capacity test. Finnish national team players performed two 60 s all-out cycling tests separated by a 3-minute recovery period. Blood lactate concentration increased from 13.8 following test 1 to 17.6 $mmol\bullet L^{-1}$ following test 2.

Another anaerobic test that has been used to assess hockey players has been a treadmill run at 8.0 mph (12.8 km•hr^{-1}) and 20% grade. A pre- to post-season comparison demonstrated that a season of hockey improves anaerobic fitness with treadmill run time increasing from 64.3 s to 74.8 s (Green and Houston, 1975). Maximal blood lactate following the test increased from 11.9 to 13.3 mmol•L^{-1}. University and junior hockey players have similar anaerobic run times and peak blood lactates (Houston and Green, 1976).

2.5 Muscle Strength and Endurance

Muscular strength is one of the factors that discriminates between professional and amateur players (Reed et al., 1979). A comparison of 54 professional and 94 junior players on 11 strength measures revealed that the professional players were significantly stronger on six of the tests.

A hand grip test is frequently used to measure grip and forearm strength, since they are important aspects that contribute to shot velocity. Elite hockey players have high values compared with other athletic teams (Chovanova, 1976a). Table 3 summarizes mean values from some elite teams. Professional players have higher hand grip strength than university or junior players. Forwards and defensemen have higher values than goaltenders. As players at the elite level become bigger and stronger, grip strength increases. In 1980, 40% of the players had combined grip strength scores less than 120 kg whereas only 20% were below this standard by 1991 (Cox et al., 1995). There is also a trend for right grip strength scores to be higher than left grip scores which is unrelated to shooting "handedness" (Reed et al., 1979).

Upper body strength and endurance of hockey players is assessed using the bench press test. The average strength for one professional team was 98.1 ± 18.3 kg which was 13% greater than their body mass (Montgomery and Dallaire, 1986). Primarily for safety reasons, most teams now measure the number of repetitions with 150 pounds instead of the 1 RM (maximum weight lifted with one repetition).

Data from Twist and Rhodes (1993a) on the number of bench press repetitions with 200 pounds indicate that the forwards (12.0 ± 3.0 reps) and defense (14.0 ± 3.3 reps) are stronger than goaltenders (4.3 ± 2.1 reps). Defensemen were stronger than forwards on the 1 RM bench press test when expressed as an absolute score, however when the results were adjusted for differences in body weight, the scores were similar (Montgomery and Dallaire, 1986).

Abdominal muscular endurance of hockey players is commonly assessed with curl-ups at a rate of 25 repetitions per minute with a maximum of 100 repetitions (Quinney et al., 1984). Professional hockey players (n = 117) averaged 49.7 ± 23.7 reps with scores ranging from 15 to 100. Only 11% of the players were able to achieve 100 repetitions. Table 4 summarizes mean values from some elite teams.

2.6 Flexibility

Flexibility aids the hockey player in the execution of skills, in the performance of explosive skating movements by extending the range of motion, and by decreasing injuries. While flexibility is important for hockey players, few data exist for comparison purposes. Trunk flexion is measured by many teams and is included as part of the fitness assessment protocol for NHL entry draft players. Positional comparisons indicate that goaltenders have the best flexibility (Montgomery and Dallaire, 1986, Rhodes et al., 1986). Forwards and defense have similar scores for trunk flexion, trunk extension and shoulder extension.

Many hockey players experience significant injuries that can be detected as musculoskeletal and/or flexibility abnormalities. Agre et al. (1988) identified specific deficits in 37% of professional players (n = 27) that had gone unnoticed in these players. Poor flexibility in the groin and hamstring muscles and tightness in the low back extensor muscles may be predisposing factors leading to injury.

The flexibility of hockey players has been compared to other university athletes (basketball, baseball, football, shot put and discus throwers, swimming, and wrestling) on 10 joint actions (Song, 1979). Except for the swimmers, hockey players exceeded the other teams on wrist, hip, knee and ankle flexibility. The hockey players had lower values for neck rotation, shoulder movements, elbow radial-ulnar actions, trunk extension-flexibility and lateral flexion.

Table 1. Maximum Oxygen Uptake of Elite Teams.

Group	n	Weight	VO2max	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	Leger et al. (1979)
Swedish national	24	75.8	57.0	Forsberg et al. (1974)
Junior	18	76.4	56.4	Green & Houston (1975)
Finnish national	13	77.3	61.5	Rusko et al. (1978)
University	19	77.4	58.9	Green et al. (1978)
University	19	77.6	58.9	Green et al. (1979)
NHL goalies	4	77.7	53.1	Agre et al. (1988)
Junior	9	78.7	55.4	Green et al. (1979)
Swedish national 1971	24	78.1	56.3	Wilson & Hedberg (1976)
Junior	44	78.2	55.4	Houston & Green (1976)
University	11	79.5	56.4	Montgomery (1982)
NHL goalies 1985-86	8	79.2	49.1	Rhodes et al. (1986)
Swedish national 1966	24	80.0	53.6	Wilson & Hedberg (1976)
University	9	80.9	56.3	Hutchinson et al. (1979)
Swedish professional (DIF)	22	81.4	62.4	Tegelman et al. (1992)
Swedish professional (SSK)	21	82.4	65.8	Tegelman et al. (1992)
NHL forwards	15	86.1	54.2	Agre et al. (1988)
Professional		86.4	53.6	Wilmore (1979)
NHL forwards	26	87.0	56.3	Cox et al (1988)
NHL forwards 1985-86	27	87.1	57.4	Rhodes et al. (1986)
NHL defense	8	88.5	52.2	Agre et al. (1988)
NHL defense	21	91.0	53.4	Cox et al (1988)
NHL defense 1985-86	40	90.3	54.8	Rhodes et al. (1986)
Junior and varsity	8	94.1	58.4	Watson & Hanley (1986)
Cycle ergometer				
Quebec Nordiques 1972-1973	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)
NHL goalies 1985-1986	8	79.2	44.1	Rhodes et al. (1986)
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)
Professional	38	82.3	43.5	Romet et al. (1978)
Junior	9	82.4	52.6	Green et al. (1979)
NHL players 1980	38	85.3	54.0	Cox et al. (1993)
Montreal Canadiens 1982-1983	29	86.8	51.9	Montgomery & Dallaire (1986)
NHL forwards 1985-1986	27	87.1	53.3	Rhodes et al. (1986)
NHL players 1984	38	88.2	54.4	Cox et al. (1993)
NHL players 1991	75	88.4	60.2	Cox et al. (1993)
Team Canada (1991)	55	89.3	62.4	Cox et al. (1993)
NHL players	22	90.0	51.4	Cox et al (1988)
NHL defense 1985-1986	40	90.3	51.6	Rhodes et al. (1986)
NHL players 1988	23	91.2	57.8	Cox et al. (1993)
Professional players	28		54.2	Wygand et al. (1987)

Group	n	Weight	VO2max	Reference
Skating				
University	10	72.8	62.1	Leger 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)

Table 2. Wingate Test Results (W•kg-1) of Elite Hockey Teams (Mean ± SD)

Group	n	Peak Power	Mean Power	Reference
Forwards				
Canadian Olympic team 1980	15	11.7 ± 1.0	9.6 ±0.6	Smith et al. (1982)
NHL players	40	12.0 ± 1.2	9.1 ± 5.5[b]	Cox et al. (1988)
Montreal Canadiens	6	10.3 ± 0.4	8.7 ± 0.7	Montgomery & Dallaire (1986)
NHL players	??	10.6	9.1	Quinney et al. (1982)
NHL players	??	13.4 ± 1.2	10.3 ± 1.3	Twist & Rhodes (1993a)
NHL players	42	12.0	9.1	Rhodes et al. (1987)
NHL players	105	12.3 ± 0.1	8.6 ± 0.6[b]	Cox et al. (1993)
Defense				
Canadian Olympic team 1980	6	11.5 ± 0.4	9.6 ± 0.9	Smith et al. (1982)
NHL players	27	12.0 ± 1.5	9.5 ± 1.0[b]	Cox et al. (1988)
Montreal Canadiens	12	9.8 ± 1.1	8.2 ± 0.3	Montgomery & Dallaire (1986)
NHL players	??	10.4	8.6	Quinney et al. (1982)
NHL players	??	13.1 ± 1.5	10.2 ± 0.9	Twist & Rhodes (1993a)
NHL players	30	12.1	9.5	Rhodes et al. (1987)
NHL players	57	12.3 ± 0.1	8.5 ± 0.1	Cox et al. (1993)
Goalies				
NHL players	8	11.4 ± 1.1	8.6 ± 5.2[b]	Cox et al. (1988)
Montreal Canadiens	3	10.6 ± 1.0	8.3 ± 0.1	Montgomery & Dallaire (1986)
NHL players	??	10.6	8.2	Quinney et al. (1982)
NHL players	??	12.7 ± 1.1	9.5 ± 1.6	Twist & Rhodes (1993a)
NHL players	8	11.4	8.6	Rhodes et al. (1987)
NHL players	19	11.9 ± 0.2	8.3 ± 0.2[b]	Cox et al. (1993)
Entire Team				
Montreal Canadiens 1981-82	27	9.9 ± 0.7	8.3 ± 0.3	Montgomery & Dallaire (1986)
Montreal Canadiens 1982-83	30	10.4 ± 1.1	8.7 ± 0.8	Montgomery & Dallaire (1986)
University and junior	24	10.1 ± 1.0	7.7 ± 1.0	Watson & Sargeant (1986)
University	17	11.5 ± 0.6	9.2 ± 0.5	Gamble (1986)
University	17	11.5 ± 0.8	9.0 ± 0.7	Brayne (1985)

Total of 24 subjects in the study by Quinney et al. (1982)
Total of 31 players in the study by Twist and Rhodes (1993a)
b 45 second test

Table 3. Hand Grip Values (kg) for some Elite Teams

Group	n	Right + Left Grip	Reference
Czechoslovakian elite	11	115.7	Chovanova (1976a)
Canadian Olympic team	23	130.1	Smith et al. (1982)
NHL defense 1985-86	27	135.7	Cox et al. (1988)
NHL forwards 1985-86	40	132.0	Cox et al. (1988)
NHL goaltenders 1985-86	8	110.2	Cox et al. (1988)
Edmonton 1980-81	20	123.2	Smith et al. (1981)
University	17	107.7	Song & Reid (1979)
Professional	52	116.2	Gauthier et al. (1979)
Junior	87	113.9	Gauthier et al. (1979)
Midget (mean 16 years)	18	102.4	Lariviere et al. (1976)
University	18	64.5 ± 6.4[a]	Romet et al. (1978)
Team Canada 1974	36	71.0 ± 8.2[a]	Romet et al. (1978)
Montreal Canadiens 1981-82	27	66.6 ± 5.8[a]	Montgomery & Dallaire (1986)
Montreal Canadiens 1982-83	30	67.6 ± 7.8[a]	Montgomery & Dallaire (1986)
NHL forwards	31	142.4 ± 8.6	Twist & Rhodes (1993a)
NHL defensemen		138.1 ± 9.4	Twist & Rhodes (1993a)
NHL goaltenders		121.5 ± 8.4	Twist & Rhodes (1993a)
NHL players 1980	38	123.3 ± 1.9	Cox et al. (1993)
NHL players 1984	30	131.9 ± 4.9	Cox et al. (1993)
NHL players 1988	23	130.4 ± 2.5	Cox et al. (1993)
NHL players 1991	72	130.9 ± 1.8	Cox et al. (1993)
Team Canada (1991)	55	115.6 ± 1.5[b]	Cox et al. (1993)

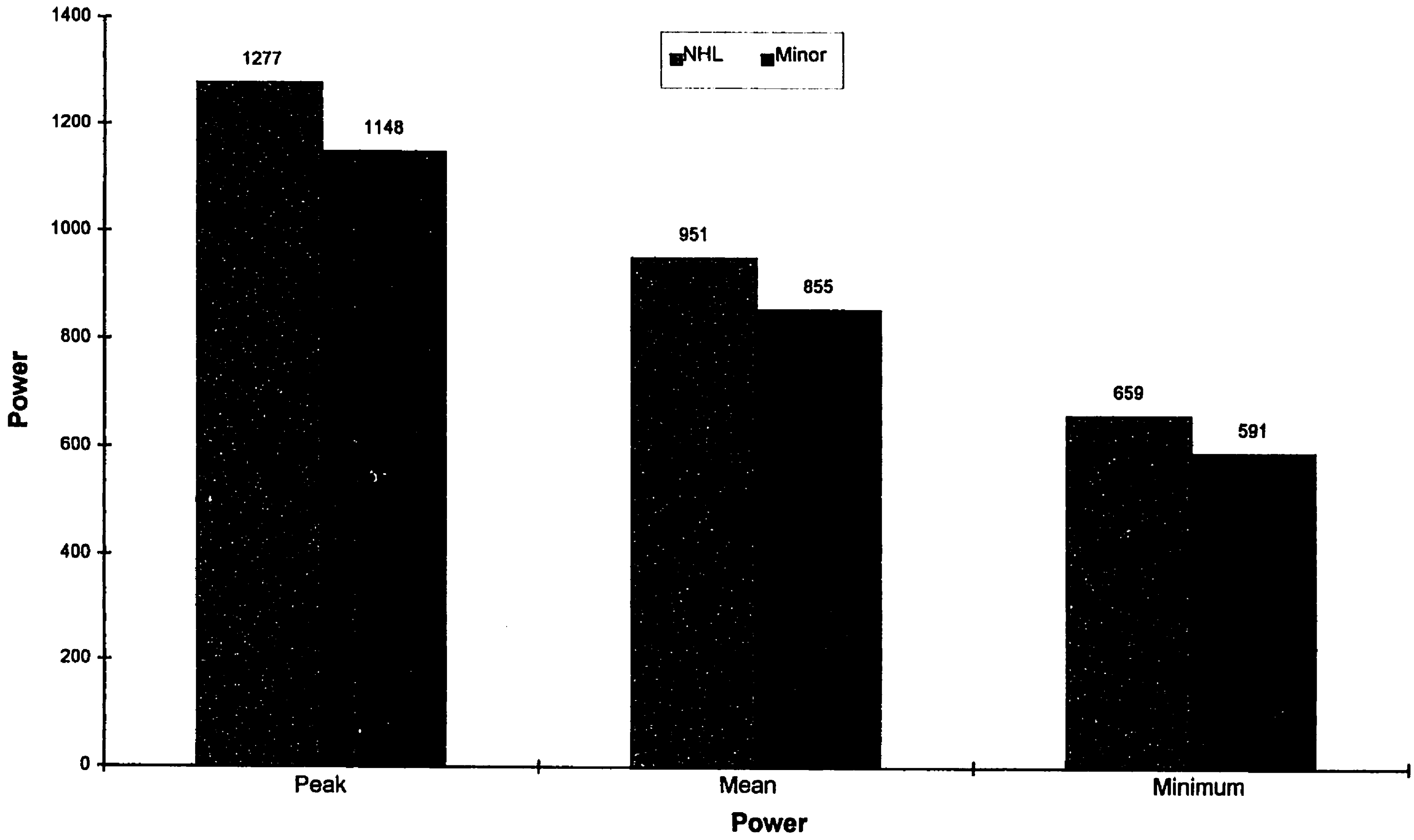
a Dominant Hand
b Hydraulic dynamometer vs spring loaded dynamometer

Table 4. Abdominal Endurance (mean ± SD) of Elite Hockey Teams

Level	n	Repetitions	Reference
Feet Unsupported			
Professional	117	49.7 ± 23.7	Quinney et al. (1984)
NHL defense	27	43.7 ± 15.1	Rhodes et al. (1986)
NHL forwards	40	38.5 ± 15.1	Rhodes et al. (1986)
NHL goaltenders	8	37.5 ± 13.3	Rhodes et al. (1986)
Feet Stabilized			
Montreal Canadiens 1981-82	27	54.2 ± 26.9	Montgomery & Dallaire (1986)
Montreal Canadiens 1982-83	30	70.8 ± 22.5	Montgomery & Dallaire (1986)
NHL forwards	31[a]	59.0 ± 21.0	Twist & Rhodes (1993a)
NHL defensemen		72.0 ± 16.0	Twist & Rhodes (1993a)
NHL goaltenders		58.0 ± 8.2	Twist & Rhodes (1993a)

a Total number of subjects

Figure 1. Wingate Results for Professional Players



Chapter III

Methods

Physiological assessment of the subjects was divided into five components. The following tests were conducted in this order: 1) body composition, 2) anaerobic fitness, 3) strength, power and muscular endurance, 4) flexibility, 5) aerobic fitness. The description of each test is outlined in "Detailed Fitness and Medical Assessment Protocols for NHL Entry Draft Players" (Gledhill and Jamnik, 1994).

3.1 Selection of Subjects

The subjects for this study were 422 male hockey players. They were NHL entry draft (n = 310), minor league professional (n = 59) and NHL professional (n = 53) players ranging from 17 - 33 years in age.

3.2 Body Composition

Standing height was determined with a measuring tape and set square. The subjects were without footwear, heels together with the backs of the feet touching the wall. The body was fully erect, the shoulders relaxed and the arms stretched downwards. To make the measurement, a set square was aligned to the top cf the head with the player standing against a flat wall. The measure was rounded to the nearest cm from the highest point on the top of the head. Body weight was obtained on a calibrated beam-type balance and recorded to the nearest 0.1 kg. The subjects were without footwear and wore minimal clothing (shorts & T-shirt).

Skinfold fat measurements were obtained with the use of skinfold calipers. All of the following measurements were made on the right side of the body with the exception of the abdominal skinfold, which was made on the left side. Six measurements were taken: chest, triceps, subscapular, suprailiac, abdomen and front thigh.

The chest measurement required the subjects to stand in a normal erect position, left arm hanging by the side and right resting on the appraiser's shoulder. The skinfold was raised above and slightly to the right of the right nipple at an angle of 45° to the horizontal. To get the triceps measurement, the caliper was applied one centimeter from the thumb and index finger raising a vertical fold at the marked mid-acromial-radial line on the posterior surface of the arm. The subscapular measurement required the caliper to be applied one centimeter distally from the left thumb and index finger raising a fold beneath the inferior angle of the scapula in a direction running obliquely downward at an angle of about 45° from the horizontal (Gledhill and Jamnik, 1994).

The suprailiac measurement was taken 3 cm above the iliac crest with the fold running parallel to the crest. The fold was taken at the midline of the body. The abdomen fat was measured with the caliper applied one centimeter inferior to the left thumb and index finger grasping a vertical fold on the left side which is raised 5 cm lateral to, and at the level of the midpoint of the navel. Finally, for the front thigh measurement, the caliper was applied one centimeter distally to the left thumb and index finger raising a fold on the anterior of the right thigh along the axis of the femur when the leg is flexed at an angle of 90 degrees at the knee by placing the foot on a box. The mid-thigh position for this measure was estimated at half-distance between the inguinal crease and anterior patella (Gledhill and Jamnik, 1994).

The Yuhasz formula was used to obtained the percentage of body fat.

$$\% \text{ fat} = [(\Sigma \text{ of six skinfolds}) \times .097] + 3.64$$

3.3 Anaerobic Fitness

This part of the physiological assessment was measured with a Wingate cycle ergometer test (30 s). The computerized version of the Wingate protocol utilizes a photocell counter to record the revolutions of the flywheel.

The subjects sat on a cycle ergometer with one leg slightly bent while it was in the "down" position. The feet were secured in the pedals with stirrups. The subjects were then allowed to warm-up at a low resistance for two minutes. The resistance applied to the flywheel was 0.090 kp/kg body weight.

The test started by having subjects pedal at a progressively quicker cadence so that by the time the designated workload was reached, they were pedaling at their maximal velocity. The subjects pedaled at their maximal capacity against the designated workload for 30 seconds. Revolutions were recorded for each five second period. The power output was calculated for the peak five second period, the mean for the 30 second test and the minimum power for the lowest five second period.

Calculations:

$$\text{Power Output } (\text{kpm} \bullet \text{min}^{-1}) = \frac{\text{revolutions} \times \text{resistance (kg) distance (m)}}{\text{time (s)}}$$

The score was expressed in Watts and Watts/kg

$$\text{Watts} = \frac{\text{kpm} \bullet \text{min}^{-1}}{6.123} \qquad \text{Watts/kg} = \frac{\text{Watts}}{\text{body weight (kg)}}$$

The following values were recorded for anaerobic fitness; peak power output, mean power output, minimum power output and the fatigue index which was obtained by the following formula:

$$\text{Fatigue index} = \frac{\text{peak power - minimum power}}{\text{peak power}} \times 100$$

3.4 Muscular Strength, Power and Endurance

These physiological attributes were measured with tests of Grip Strength, Vertical Jump, Bench Press Repetitions and Curl-ups.

The **Grip Strength Test** required the subjects to use a hand grip dynamometer previously adjusted to their hand size. The subjects then squeezed the dynamometer as forcefully as possible with the arm fully extended. The test was conducted with both hands and the test score recorded as the sum of the values for the right and left hand.

The **Vertical Jump Test** was conducted against a wall-mounted tape measure. The subjects stood flat-footed with their shoulders 90 degrees to the wall with fingers outstretched on the arm closest to the wall. They reached as high as possible over their head to register a first marking. The subjects then jumped as high as possible and touched the wall with the arm closest to the wall to register a second marking. The first marking was subtracted from the second one to provide the jump score. During the test, subjects were not allowed to turn their bodies and their fingers had to remain outstretched.

Leg power was calculated as follows:

$$\text{Power (ft-lb/sec)} = 4 \times \text{weight(lb)} \times [\text{jump height (ft)}]^{-2}$$

The **Bench Press Repetition Test** was conducted using a standard padded bench with 150 lb of free weights (including the barbell) in time with a metronome. Repeated 150 lb bench presses were performed at a rate of 25 per minute in time with a metronome set at 50 so that each click signaled a movement either up or down. The subjects lied with their back on the bench and gripped the barbell with thumbs approximately shoulder width apart. The buttocks remained on the bench with the feet on the floor. The start position of the bar required subjects to have their arms straight and the elbows locked. The subjects lowered the bar to the chest at approximately the axillary line and the bar was pushed to full extension of the arms. The number of consecutive repetitions completed was recorded until the subjects fell behind the cadence.

The **Curl-Up Test** was used to assess abdominal muscle endurance of the subjects. They were required to lie in a supine position, knees bent at an angle of 90°, heels in contact with the floor, arms crossed over the chest with each arm on the opposite shoulder. The feet were not stabilized. A metronome was set at 50 so that each signal involved a movement either up or down at a rate of 25 curl-ups per minute.

The initial phase of the curl-up involved a "flattening out" of the lower back region (i.e. posterior pelvic tilting) by active contraction of the abdominal muscles. This was followed by a slow "curling up" of the upper spine far enough so that the elbows made contact with the thighs. The heels remained in contact with the floor. On the return, the subjects' shoulder blades contacted the mat placed on the ground. The movement was performed in a well-controlled manner so that the time to perform the lifting and lowering stages of the curl-up were the same.

The subjects performed, without pausing, the maximum number of curl-up repetitions possible to a limit of 100. The test was terminated for one of the following reasons: participants appeared to be experiencing unusual discomfort, were unable to maintain the required cadence, were unable to maintain proper technique, or 100 repetitions were performed.

3.5 Flexibility

Trunk flexion was assessed with the Sit and Reach Test. The subjects sat without shoes and legs fully extended with the soles of the feet placed flat against the two horizontal crossboards of the flexometer. The flexometer was adjusted to a height at which the balls of the feet rested against the upper crossboards. The inner edge of the soles was placed 2 cm from the edge of the scale. Keeping the knees fully extended and the arms evenly stretched with palms down, the subjects bent and reached forward (without jerking), pushing the sliding marker along the scale with the fingertips as far forward as possible. The position of flexion was held for two seconds. The measurement were recorded in centimeters. To avoid negative numbers, the bottom of the feet was equivalent to a score of 25.4.

3.6 Aerobic Fitness

Aerobic fitness was assessed by measuring the amount of oxygen utilized during a maximal cycle ergometer exercise employing volume determination and analysis of expired air. In addition, heart rate was monitored continuously.

A heart rate monitoring device (Sport Tester®) was placed around the subject's chest. A head set was then secured on their head. A mouthpiece was connected to a hose which sent the expired air into a chamber for gas analysis. The subjects were allowed time to become accustomed to pedaling the cycle ergometer with the mouthpiece in place. A metronome was set so that subjects cycled at 60 revolutions per minute for the first three workloads. After the first three workloads, the metronome was set so that subjects cycled at 70 revolutions per minute:

Work level	Time (min)	Resistance (kp)	Watts
1	0 - 2	2.5	147
2	2 - 4	3.5	206
3	4 - 6	4.5	265
4	6 - 7	5.0	343
5	7 - 8	5.5	377
6	8 - 9	6.0	412
7	9 - 10	6.5	446

Heart rate was recorded at the maximal workload that was reached. VO_2 was also measured every 30 seconds until the final stage of the test. The VO_2max results were expressed in both absolute (liters/min) and relative (ml/kg•min) values.

The time to exhaustion and the final workload achieved in Watts were recorded. The end point was determined by volitional exhaustion or the appraiser stopping subjects because they could no longer maintain the required revolutions per minute (rpm).

Subjects were allowed to stand up and pedal near the end of the test and were encouraged to do so until they absolutely could not maintain the required rpm any longer.

3.7 Statistical Analysis

Descriptive statistics (means and standard deviations) were calculated for the following variables: age, height, weight, sum of skinfolds, fat percentage, hand grip, vertical jump, leg power, absolute bench press, relative bench press, curl-ups, sit and reach, peak absolute power, peak relative power, mean absolute power, mean relative power, minimum absolute power, minimum relative power, absolute VO_2max, relative VO_2max, test duration, final work load and NHL success ratio.

Hypothesis 1 (difference in fitness profiles of entry draft players classified as NHL and non-NHL) was examined using a multi-factor analysis of variance (MANOVA).

Hypothesis 2 (games played in the NHL can be predicted from fitness variables) was examined using a regression analysis.

Hypothesis 3 (fitness profiles will be different for forwards and defense) was examined using a MANOVA.

Hypothesis 4 (NHL draft players will be lower in upper body strength than professionals) was examined using a one factor ANOVA.

Chapter IV

Results

4.1 Physical Characteristics

The physical characteristics of the 310 entry draft subjects are shown in Table 5. These subjects were the players who were ranked for selection in the 1994, 1995 and 1996 NHL entry drafts. The group was sub-divided into NHL and non-NHL players. Only 69 players appeared in at least one game between Oct. 1, 1994 and Dec. 31, 1997. Table 6 examines the NHL players relative to the year of the draft. The 1994 cohort averaged 72.5 games with a success ratio of 28.8%. This is interpreted as these players appearing in 28.8% of the games that were played by their teams between 1994 and 1997. The 1995 cohort averaged 36.8 games with a success ratio of 18.7%. The 1996 cohort averaged 34 games with a success ratio of 27.8%.

The variables - height, weight, sum of skinfolds and percent fat were examined in a two-way ANOVA (Table 7). Differences were determined between NHL and non-NHL players as well as forwards and defense.

The mean height for the 310 players was 186.2 ± 4.9 cm. There was no significant difference in height between the NHL players and the non-NHL players. The defense (X= 188.1 cm) were significantly taller than the forwards (X= 185.0 cm). The mean weight was 86.4 ± 7.5 kg. NHL players (X= 89.4 kg) were significantly heavier than the non-NHL players (X= 85.6 kg). The defense (X= 88.8 kg) were significantly heavier than the forwards (X= 84.9 kg).

4.3 Aerobic Endurance, Strength, and Flexibility

The results of the aerobic cycling test, hand grip, vertical jump, curl-ups and flexibility tests are shown in Table 10. The two-way ANOVA results are summarized in Table 11. The absolute VO_2max for 308 players averaged 4.67 ± 0.65 L/min. NHL players (X= 4.85 L/min) had significantly higher VO_2max values when compared to non-NHL players (X= 4.65 L/min), however when expressed relative to body weight there was no difference with values of 54.6 and 54.3 ml/kg•min respectively. There was no significant difference in VO_2max between defense and forwards in absolute VO_2 (L/min), however forwards (X= 55.1 ml/kg•min) had significantly higher relative VO_2max values than defense (X= 52.4 ml/kg•min). The mean aerobic test duration for 302 players was 9.33 ± 1.76 min. NHL players (X= 9.78 min) had significantly longer tests than non-NHL players (X= 9.28 min). There was no significant difference in test duration between defensemen (9.26 min) and forwards (X= 9.38 min).

The hand grip score for 302 players averaged 123.5 ± 17.5 kg. NHL players (X= 127.7 kg) were significantly stronger than non-NHL players (X= 122.3 kg) while defensemen (X= 126.5 kg) were significantly stronger than forwards (X= 121.6 kg). The vertical jump for 299 players averaged 56.6 ± 7.2 cm. There was no significant difference in vertical jump when NHL players were compared to non-NHL players and when defense were compared to forwards. The leg power score for 295 players was 1033 ± 114 ft-lb/s. Leg power was calculated using vertical jump and body weight in the formula. Even though vertical jump scores were similar, differences in leg power were significant and can be attributed to body weight. Leg power was significantly higher for the NHL players than the non-NHL players and for the defense versus the forwards.

The mean number of curl ups for 306 players was 26.1 ± 14.9. There were no significant differences when comparing NHL players to non-NHL players. There was also no difference between the defense and forwards. The mean sit and reach score for 305 players was 38.0 ± 8.6 cm. There were no significant differences when comparing NHL players to non-NHL players and defensemen to forwards.

Table 10. Fitness Test Results (mean ± S.D.)

Variable	n	NHL players	n	Non-NHL players	n	Total
VO2 max (L/min)						
forwards	48	4.87 ± 0.58	139	4.60 ± 0.49	187	4.67 ± 0.53
defense	21	4.82 ± 0.52	100	4.73 ± 0.57	121	4.67 ± 0.81
total	69	4.85 ± 0.56	239	4.65 ± 0.53	308	4.67 ± 0.65
VO2 max(ml/kg•min)						
forwards	48	55.7 ± 6.8	139	54.9 ± 5.9	187	55.1 ± 6.1
defense	21	52.2 ± 4.8	100	53.5 ± 6.1	121	52.4 ± 8.9
total	69	54.6 ± 54.3	239	54.3 ± 6.0	308	54.1 ± 7.4
Test Duration (min)						
forwards	48	9.81 ± 1.86	137	9.23 ± 1.48	185	9.38 ± 1.57
defense	21	9.71 ± 1.92	96	9.35 ± 1.57	117	9.26 ± 2.02
total	69	9.78 ± 1.87	233	9.28 ± 1.49	302	9.33 ± 1.76
Hand grip (kg)						
forwards	48	126.4 ± 18.2	134	119.8 ± 17.3	182	121.6 ± 17.4
defense	20	130.6 ± 10.2	100	125.7 ± 18.3	120	126.5 ± 17.3
total	68	127.7 ± 16.3	234	122.3 ± 17.7	302	123.5 ± 17.5
Vertical Jump (cm)						
forwards	48	56.3 ± 6.9	136	56.7 ± 7.8	184	56.7 ± 7.5
defense	20	57.4 ± 7.7	95	56.1 ± 6.4	115	56.3 ± 6.7
total	68	56.7 ± 7.1	231	56.6 ± 7.2	299	56.6 ± 7.2
Leg Power (ft-lb/s)						
forwards	47	1049 ± 133	134	1006 ± 113	181	1017 ± 118
defense	19	1129 ± 99	95	1045 ± 100	114	1059 ± 104
total	66	1072 ± 128	229	1022 ± 108	295	1033 ± 114
Curl Ups (reps)						
forwards	47	28.6 ± 18.7	136	25.9 ± 15.1	183	26.6 ± 16.0
defense	21	19.8 ± 10.6	102	26.6 ± 13.4	123	25.4 ± 13.2
total	68	25.9 ± 17.0	238	26.2 ± 14.3	306	26.1 ± 14.9
Sit and Reach (cm)						
forwards	48	38.8 ± 8.5	135	37.2 ± 8.4	183	37.8 ± 8.4
defense	21	34.7 ± 9.9	101	39.0 ± 8.7	122	38.2 ± 9.1
total	69	37.5 ± 9.1	236	38.0 ± 8.9	305	38.0 ± 8.6

Table 11. ANOVA Results - Fitness Variables

Comparison	NHL vs Non-NHL		Forwards vs defense	
Variable	**F-ratio**	**P**	**F-ratio**	**P**
VO2 max (L/min)	7.47	0.01	2.10	0.15
VO2 max (ml/kg•min)	0.15	0.70	7.63	0.01
Test Duration (min)	5.21	0.02	0.29	0.59
Hand grip (kg)	4.96	0.03	6.56	0.01
Vertical Jump (cm)	0.03	0.88	0.54	0.47
Leg Power (ft-lb/s)	10.10	0.01	8.35	0.01
Curl Ups (reps)	0.03	0.87	0.43	0.51
Sit and Reach (cm)	0.27	0.60	0.15	0.70

4.4 NHL Success Ratio and Physiological Assessment

The 21 variables located in Table 12 were entered into a stepwise regression model to predict NHL success. The data for the 1996 entry draft was excluded since only 8 players had played games at the NHL level prior to Dec. 31, 1997. The regression performed on the subjects from 1994 and 1995 entry drafts and the ANOVA results are shown in Table 13. The regression equation explained only 5.4% of the variation. The equation included three variables - peak power, VO_2max and cycling test duration.

Table 12. Correlations between NHL Success Ratio and Physiological Assessment Variables (1994-1995)

Variable	Partial Correlation
Height	0.062
Weight	0.178
Sum of Skinfolds	-0.016
Body Fatness	-0.013
Hand grip	0.132
Vertical Jump	-0.055
Leg Power	0.101
Bench Press (absolute)	0.099
Bench Press (relative)	0.072
Curl Ups	0.100
Sit and Reach	0.014
Peak Power (absolute)	0.181
Peak Power (relative)	0.092
Mean Power (absolute)	0.164
Mean Power (relative)	0.072
Minimum Power (absolute)	0.137
Minimum Power (relative)	0.055
VO2 max (absolute)	0.180
VO2 max (relative)	0.069
Final Workload	-0.026
Cycling Test Duration	-0.007

Table 13. Results of the Stepwise Regression Analysis (1994-1995)

Variable	Coefficient	Standard Error	T	P(2 tail)
Constant	-27.54	11.5	-2.38	0.02
Peak Power	0.02	0.01	-1.91	0.06
VO2 max (absolute)	6.49	2.50	2.60	0.01
Cycling Test Duration	-1.26	0.83	-1.53	0.13

ANOVA Table

Source	Sum of squares	df	Mean Square	F-ratio	P
Regression	3750.5	3	1250.2	4.13	0.007
Residual	65654.8	217	302.5		

Multiple R = 0.232

R squared = 0.054

Standard error of the estimate = 17.39

The 21 variables located in Table 14 were entered into a stepwise regression model to predict NHL success. In this stepwise regression analysis, subjects from the 1994, 1995 and 1996 NHL entry drafts were used. This analysis is shown in Table 15. The regression equation explained only 10.0% of the variation. The equation included seven variables - height, weight, sum of skinfolds, vertical jump, peak power, relative VO_2max and final workload.

Table 14. Correlations between NHL Success Ratio and Physiological Assessment Variables (1994-1996)

Variable	Partial Correlation
Height	0.053
Weight	0.191
Sum of Skinfolds	-0.011
Body Fatness	-0.004
Hand grip	0.135
Vertical Jump	-0.075
Leg Power	0.102
Bench Press (absolute)	0.112
Bench Press (relative)	0.083
Curl Ups	0.058
Sit and Reach	-0.007
Peak Power (absolute)	0.142
Peak Power (relative)	0.037
Mean Power (absolute)	0.123
Mean Power (relative)	0.018
Minimum Power (absolute)	0.072
Minimum Power (relative)	0.011
VO2 max (absolute)	0.187
VO2 max (relative)	0.058
Final Workload	-0.021
Cycling Test Duration	0.048

Table 15. Results of the Stepwise Regression Analysis (1994-1996)

Variable	Coefficient	Standard Error	T	P(2 tail)
Constant	15.38	40.58	0.38	0.71
Height	-0.38	0.23	-1.63	0.10
Weight	0.86	0.20	4.35	0.01
Sum of Skinfolds	-0.20	0.07	-3.06	0.01
Vertical Jump	-0.81	0.35	-2.29	0.02
Peak Power	0.01	0.01	1.49	0.14
VO2 max (relative)	0.41	0.17	2.36	0.02
Final Workload	-0.04	0.02	-1.96	0.05

ANOVA Table

Source	Sum of squares	df	Mean Square	F-ratio	P
Regression	8012.5	7	1144.6	4.48	0.001
Residual	71727.0	281	255.3		

Multiple R = 0.317

R squared = 0.100

Standard error of the estimate = 15.98

4.5 Upper Body Strength

Hypothesis 4 compared the upper body strength of the NHL draft players to the strength of minor league professional and NHL players. The NHL subjects were players for the Montreal Canadiens in 1994, 1995 and 1996. The minor league professionals participated in the training camp of the Montreal Canadiens but played more games in the minor league than in the NHL in 1994, 1995 and 1996. The physical characteristics for this sample are presented in Table 16. The NHL players were older and heavier than the NHL draft players.

The bench press results for the three groups are shown in Table 17. The ANOVA results (Table 18) showed that the junior and college draft players were weaker, with 9.9 reps performed with 150 pounds, when compared to the NHL players who averaged 26.1 reps and to the minor league professionals who averaged 23.6 reps.

When the results were adjusted for body weight, the NHL draft players still remained weaker than the NHL players and the minor league professionals. The NHL draft players averaged 7.8 lbs per lb of body weight compared to 19.6 lbs per lb of body weight for NHL professionals and 17.8 for the minor league professionals.

The ANOVA results (Table 19) also showed that forwards and defense were similar in strength when expressed relative to body weight. The P value was 0.06. The interaction of group and position was significant for the bench press. For the NHL professionals and the NHL draft players, the defense were stronger than the forwards. For the minor league players, the forwards were stronger than the defense. The latter finding was attributed to a sample that may not reflect the usual pattern.

Table 16. Characteristics of Subjects (mean ± S.D.)

Variable	Minor Pro	NHL
Sample Size		
Forwards	42	35
Defense	19	19
Total	61	54
Age (yrs)		
Forwards	22.3 ± 2.1	25.5 ± 3.4
Defense	20.8 ± 1.4	25.3 ± 2.4
Total	21.8 ± 2.0	25.3 ± 3.1
Height (cm)		
Forwards	183.8 ± 6.1	183.0 ± 4.9
Defense	187.1 ± 3.9	186.5 ± 5.6
Total	184.9 ± 5.7	184.4 ± 5.4
Weight (kg)		
Forwards	88.2 ± 8.8	89.2 ± 6.2
Defense	92.9 ± 6.6	94.5 ± 7.8
Total	89.6 ± 8.4	91.0 ± 7.2
Sum of Skinfolds (mm)		
Forwards	85.0 ± 20.2	79.6 ± 15.4
Defense	96.0 ± 20.8	82.3 ± 22.1
Total	88.5 ± 20.8	80.8 ± 17.9
Body Fatness (%)		
Forwards	10.7 ± 1.7	10.2 ± 1.3
Defense	11.6 ± 1.8	10.3 ± 1.9
Total	11.0 ± 1.8	10.3 ± 1.5

Table 17. Physical Strength of Subjects (mean ± SD)

Variable	Draft Players	Minor Pro	NHL
Sample Size			
Forwards	173	40	34
Defense	115	19	25
Total	288	59	53
Reps with 150 lbs.			
Forwards	9.8 ± 5.5*	25.2 ± 9.3	24.9 ± 5.3
Defense	10.1 ± 5.6*	20.1 ± 4.6	27.5 ± 5.5
Total	9.9 ± 5.5*	23.6 ± 8.4	26.1 ± 5.5
Reps/lb. body weight			
Forwards	7.8 ± 4.2*	19.2 ± 6.2	19.1 ± 4.1
Defense	7.7 ± 4.2*	14.9 ± 3.7	20.2 ± 4.2
Total	7.8 ± 4.1*	17.8 ± 5.9	19.6 ± 4.2

* = $p < .001$ compared with minor pro and NHL values

Table 18. ANOVA Results for Bench Press (repetitions)

Source	Sum of Squares	df	Mean Square	F-ratio	P
Groups (G)	15754.4	2	7877.2	221.2	0.01
Position (P)	21.9	1	21.9	0.6	0.43
(G) X (P)	437.7	2	218.9	6.1	0.01
Error	14032.2	394	35.6		

Table 19. ANOVA Results for Bench Press (relative to body weight)

Source	Sum of Squares	df	Mean Square	F-ratio	P
Groups (G)	8359.4	2	4179.6	217.7	0.01
Position (P)	65.0	1	65.0	3.4	0.06
(G) X (P)	235.9	2	117.9	6.1	0.01
Error	7565.6	394	19.2		

Chapter V

Discussion

Beginning in 1993, the NHL initiated physiological and medical testing for entry draft players. Exercise physiology laboratories that have received accreditation from the Canadian Association of Applied Exercise Physiology are contacted by the NHL head office and requested to test potential NHL players from junior and university teams within their district. The purpose of the physiological and medical assessment is to identify strengths and weaknesses of the individual and to document injuries that may influence future performance. The hockey test battery (Gledhill and Jamnik, 1994) includes assessment of physical characteristics, anaerobic power and capacity, aerobic endurance, flexibility, muscular endurance and upper body strength. Our results are discussed relative to these variables.

5.1 Physical Characteristics

In this study of 310 NHL draft players, the defense were taller, heavier and fatter than the forwards. This is in agreement with studies of junior, university, and professional players (Agre et al., 1988; Green and Houston, 1975; Montgomery and Dallaire, 1986; Quinney, 1990; Smith et al., 1982; Twist and Rhodes, 1993a, 1993b).

Cox et al. (1993) compared physiological data from 170 players on 5 NHL teams between 1980 and 1991. Body mass and height progressively increased over this 11-year time span. In 1980, 40% of the players weighed less than 85 kg and 71% were shorter than 180 cm in height. By 1991, only 26% of the players weighed less than 85 kg while

85% were taller than 180 cm. During this same period, the body fat content remained constant at 13% (Cox et al., 1995). At the time of the physiological testing, the NHL draft picks were 17.8 years, 186.2 cm, 86.4 kg, and 9.8% fat. Although younger than the professional players, the NHL draft selections from 1994 to 1996 in this study were taller. The median height of the NHL professionals was 179.8 cm in 1980, 182.7 cm in 1984, 185.4 cm in 1988 and 186.7 cm in 1991 (Cox et al., 1995). The younger NHL draft selections were 2 – 4 kg lower in body mass than the professionals whom had a median mass of 87.7 kg in 1984, 90.7 kg in 1988, and 87.8 kg in 1991. Some of the differences in weight can be attributed to body fatness since the NHL draft selections were lower in percent body fat.

5.2 Anaerobic Power and Capacity

Since the patterns of glycogen depletion and recruitment of muscles when cycling are similar to those used in skating (Geijsel, 1979; 1980; Green et al., 1978), cycling tests are preferred over other ergometers when evaluating hockey players. The most common test to assess anaerobic qualities in hockey players has been the Wingate test. This test has been shown to replicate fatigue curves generated with anaerobic on-ice skating tests for ice hockey players (Cox et al., 1995). Table 2 summarized results from 10 studies that used the Wingate test to examine anaerobic power and capacity of hockey players. Factors such as type of ergometer, duration of test, flywheel resistance, stabilization of the ergometer, and presence or lack of toe clips on the pedals vary among studies. As such, caution is necessary when comparing results.

When expressed relative to body weight, the peak power for the NHL draft selections was 12.52 ± 1.67 W/kg. There were no significant differences between NHL players and non-NHL players in peak, mean and minimum power. Similarly, there were no differences in peak, mean and minimum power between forwards and defense. For the NHL draft selections, peak power was similar to that reported for the 1980 Canadian Olympic team (Smith et al., 1982) and NHL players (Cox et al., 1988; Quinney et al., 1982; Twist & Rhodes, 1993a; Rhodes et al., 1987; Cox et al., 1993). The peak power was higher than that reported for junior and university players (Brayne, 1985; Gamble, 1986; Watson & Sargeant, 1986).

For the NHL draft selections, mean power averaged 9.98 ± 1.47 W/kg. Mean power was higher than that reported for junior and university players (Brayne, 1985; Gamble, 1986; Watson & Sargeant, 1986) and NHL players (Cox et al., 1988; Cox et al., 1993; Montgomery & Dallaire, 1986; Quinney et al., 1982; Rhodes et al., 1987; Smith et al., 1982). Only the mean power results reported by Twist & Rhodes (1993a) were higher with values of 10.2 and 10.3 W/kg for professional defense and forwards, respectively. Although younger, the NHL draft selections have similar Wingate test results when compared to their professional counterparts.

5.3 Aerobic Endurance

Table 1 summarized results from 19 studies that used the treadmill, 15 studies that used a cycle ergometer to measure VO_2max of hockey players in the laboratory. Four studies are reported in Table 1 that measured VO_2max while skating on ice. Hockey players have the same VO_2max when tested on-ice and on the treadmill (Lariviere, 1972; Leger et al., 1979, Riby, 1993; Simard, 1975).

On the cycle ergometer, team means for both forwards and defense ranged from 52 to 62 ml/kg•min with one exception (Table 1). As the mean weight of the hockey team increases, the VO_2max expressed as ml/kg•min tends to decrease. Within a team, positional comparisons support this trend. The defense are usually heavier than the forwards so it is expected that the defense will have a lower VO_2max (ml/kg•min). In this study, the forwards had a significantly higher VO_2max than the defense (55.1 vs 52.4 ml/kg•min).

There appears to be an upward shift in aerobic endurance. Cox et al. (1993) examined VO_2max data from 170 players on 5 NHL teams between 1980 and 1991. In 1980, 58% of the players had a VO_2max less than 55 ml/kg•min. In contrast, only 15% were below this value in 1991. The improvements in aerobic power were independent of an increase in body mass, suggesting that conditioning methods had been effective in improving aerobic power (Cox et al., 1995). For the total group in this study (n = 308), VO_2max averaged 54.1 ml/kg•min while body weight averaged 86.4 kg. There was no significant difference in VO_2max (ml/kg•min) between the non-NHL and NHL draft players.

5.4 Flexibility

While flexibility is important for hockey players, few data exist for comparison purposes. Trunk flexion is measured by many teams and is included as part of the fitness assessment protocol for NHL entry draft players. Positional comparisons indicate that goaltenders have the best flexibility (Montgomery and Dallaire, 1986, Rhodes et al., 1986). Forwards and defense have similar scores for trunk flexion.

In this study, the mean sit and reach score for 305 players was 38.0 ± 8.6 cm. There were no significant differences when comparing NHL players to non-NHL players and defensemen to forwards. In comparison, Twist & Rhodes (1993) reported trunk flexion scores of 45.0 and 44.2 cm for forwards and defense, respectively. The lower values for the NHL draft selections may be attributed to differences in age between the entry draft and professional players.

5.5 Muscular Endurance

Abdominal muscular endurance of hockey players is commonly assessed with curl-ups at a rate of 25 repetitions per minute with a maximum of 100 repetitions (Quinney et al., 1984). The protocol for the NHL draft selections required that the heels remain in contact with the floor and the feet not stabilized. Professional hockey players (n = 117) averaged 49.7 ± 23.7 reps with scores ranging from 15 to 100. Only 11% of the players were able to achieve 100 repetitions. Lower values were reported for NHL players by Rhodes et al. (1986) with mean values of 43.7 reps for defense (n = 27) and 38.5 reps for forwards (n = 40).

In this study, the mean curl-up score for 306 players was 26.1 ± 14.9 reps. There were no significant differences when comparing NHL players to non-NHL players and defensemen to forwards. The lower values by the NHL draft selections demonstrate that the abdominal muscles should receive more attention during their programs.

5.6 Upper Body Strength

Muscular strength is one of the factors that discriminates between professional and amateur players (Reed et al., 1979). A comparison of 54 professional and 94 junior players on 11 strength measures revealed that the professional players were significantly stronger on six of the tests. The results from this study confirm the strength differences between professional players and junior players.

The NHL draft selections averaged 9.9 reps vs 23.6 reps and 26.1 reps for the minor league and NHL professionals, respectively. Differences in body weight among the three groups did not account for the differences. When the results were adjusted for body weight, the NHL players still remained stronger than the NHL draft players. The NHL professionals averaged 19.6 lbs per lb of body weight compared to 17.8 for the minor league professionals and only 7.8 lbs per lb of body weight for the NHL draft players. Upper body strength is clearly one factor that discriminates the older NHL players from the younger draft selections.

5.7 Prediction of NHL Success

Identification of hockey talent by the head office for the National Hockey League and the 26 professional teams in the NHL is an expensive business. The National Hockey League funds a central scouting bureau whose mandate is to evaluate amateur prospects for the annual NHL entry draft. Players are assessed by scouts on 10 task requirements: (a) skating, (b) shooting/scoring, (c) positional play, (d) checking, (e) puck control, (f) passing, (g) hockey sense, (h) desire/attitude, (i) aggressiveness/toughness, and (j) size/strength. Renger (1994) asked 16 scouts to rank these task requirements and to assign relative importance to the tasks using a 100-point distribution. The task requirement of skating ranked first for both forwards and defensemen with relative weighting of 22.5 for the forwards and 20.5 for the defensemen. The results revealed that not all skills and tasks are of equal importance to forwards and defense. The task of shooting/scoring was weighted significantly higher for forwards than for defensemen. In contrast, checking, size/strength, and positional play were weighted more heavily for defensemen than for forwards. Thus the tasks necessary for success in professional hockey vary as a function of position.

When 21 variables from the physiological assessment battery for NHL draft selections (1994 and 1995) were entered into a stepwise regression model to predict NHL success, the best equation could only explain 5.4% of the variation. This equation contained three variables – peak power, VO_2max and cycling test duration. These variables represent specific aspects of anaerobic and aerobic fitness. As a single variable, VO_2max (L/min) had a correlation of 0.18 with the dependent variable NHL success ratio. Peak power (W) also had a correlation of 0.18 with NHL success ratio.

The definition of NHL success may have contributed to the low multiple R. The NHL success ratio was defined as the number of NHL games played by a subject divided by the total number of games played by the subject's team between October 1, 1994 and December 31, 1997. This restriction in range on the dependent measure permitted only 3½ years for the players drafted in 1994 and only 2½ years for the players drafted in 1995 to demonstrate their capability of playing in the NHL. By examining a longer time span, a higher multiple R would be obtained for the regression equation to predict NHL success.

Chapter VI

Summary, Conclusions and Recommendations

6.1 Summary

The present investigation examined the relationship between the fitness level of NHL entry draft players and their performance level in the NHL as well as the differences in physiological profiles of players according to level and position. The study also compared the upper body strength of NHL entry draft players to minor league and NHL professionals. The NHL entry draft players were evaluated on the following fitness components: body composition, anaerobic fitness, strength, power, muscular endurance, flexibility and aerobic fitness.

The sample for this study was 422 male hockey players ranging in age from 18 to 33 years. NHL entry draft players were submitted to a battery of tests. Anthropometry measures such as height, weight, sum of 6 skinfolds, and percentage of body fat were recorded. Anaerobic fitness was assessed with a 30s all-out cycling test. Muscular strength, power and endurance were assessed with bench press repetitions performed with 150 lbs, a grip strength test performed on a hand grip dynamometer, a curl-up test performed at a rate of 25 reps per minute (maximum score = 100 sit-ups), and a vertical jump test which required the subjects to jump as high as possible. Flexibility was measured with a sit and reach test requiring the subjects to reach as far forward as possible while seated. Finally, the aerobic evaluation was performed on a cycle ergometer with measurement of VO_2max.

The first hypothesis predicted a significant difference between the fitness profiles of players who played games at the NHL level and the fitness profiles of players who did not. When comparing the two groups for weight, the ANOVA revealed an F-ratio of 15.92 which was significant at the 0.01 level. When comparing peak and mean anaerobic power expressed in Watts, the ANOVA revealed F-ratios of 6.82 and 8.70 both being significant at the 0.01 level. Significant F-ratios were also revealed for the following variables: VO_2 max in L/min (F-ratio = 7.47; p = 0.01), cycle test duration (F-ratio = 5.21; p = 0.02), hand grip (F-ratio = 4.96; p = 0.03) and leg power (F-ratio = 10.10; p = 0.01). Both groups were similar in height, sum of skinfolds, and body fatness. Peak and mean power expressed in Watts were higher for the NHL players than the non-NHL players. When the results were expressed relative to body weight, there were no differences between NHL and non-NHL players for peak, mean, and minimum power. There were no significant differences between NHL and non-NHL players in VO_2 max (ml/kg•min), vertical jump, curl-ups, and sit and reach. In summary, NHL players were significantly heavier, had higher peak and mean power outputs (W), higher VO_2max (L/min), longer cycle test duration, higher hand grip and leg power scores (ft-lb/s).

The second hypothesis stated that the number of games played at the NHL level could be predicted from fitness variables. Two regression analyses were performed. The first one used a sample of subjects from the 1994 and 1995 NHL entry drafts. A stepwise regression analysis revealed a significant but low prediction effect. The multiple R value was 0.232 with 5.4 % of the variation explained by the regression equation. Peak power, VO_2max (L/min) and cycle test duration entered significantly into the regression equation. The second analysis used a sample of subjects from the 1994, 1995, and 1996 NHL entry drafts. The stepwise regression analysis revealed a significant but low prediction effect. Only 10 % of the variation was explained by the regression equation.

The regression analysis revealed a multiple R value of 0.317. Height, weight, sum of skinfolds, vertical jump, peak power, VO_2max (ml/kg•min) and final workload entered significantly into the equation.

The third hypothesis stated that the physiological profiles would be significantly different for forwards and defense. When comparing the two groups for height and weight, the ANOVA revealed F-ratios of 32.81 and 21.57 respectively, both being significant at the 0.01 level. The comparison for sum of skinfolds and for body fatness revealed F-ratios of 4.73 and 4.71 respectively both being significant at the 0.03 level. The ANOVA results also showed a significant F-ratio of 7.37 for peak power expressed in Watts. Finally, VO_2max expressed in ml/kg•min, hand grip and leg power were all significant at the 0.01 level with F-ratios of 7.63, 6.56 and 8.35 respectively. Therefore, the defense were significantly taller, heavier, and fatter than forwards. They also exerted higher absolute peak power values. Finally, the defense had significantly lower VO_2max relative to body weight but had higher hand grip and leg power scores.

The fourth hypothesis stated that NHL draft players would be significantly lower in upper body strength than minor league professionals and NHL professionals. When comparing the three groups for bench press, the ANOVA revealed that there was a significant difference among groups when values were expressed as total number of repetitions ($F = 221.2$; $p = 0.01$) and in relation to body weight ($F = 217.7$; $p = 0.01$). Tukey post hoc tests revealed that for both absolute and relative bench press, the NHL players and minor league players were stronger than the NHL draft players.

6.2 Conclusions

Within the delimitations and limitations of the present study, the following conclusions seem justified:

1. Physiological profiles of players who reach the NHL were significantly different from non-NHL players. When drafted, players that eventually made the NHL tended to be heavier and had higher peak power (W), mean power (W), VO_2max (L/min), grip strength and leg power.

2. The fitness variables in the test battery had low predictive power to identify players who played in the NHL.

3. Physiological profiles of forwards were significantly different from defense. Defense were taller, heavier, and fatter than forwards. Defense had higher peak power (W), grip strength and leg power compared to forwards. The forwards were higher in VO_2max when expressed relative to body weight.

4. NHL entry draft players were lower in upper body strength than minor league professionals and NHL players.

6.3 Recommendations

The restriction in range on the dependent measure (NHL success ratio) should be noted since NHL entry draft players from 1994 were only given a potential of 3 ½ years to reach the NHL since the data were examined using games played up to Dec. 31, 1997. For players who were drafted in 1995, there was only a 2 ½ year opportunity to demonstrate NHL success while the players drafted in 1996 only had 1 ½ years to demonstrate NHL success as defined in this study. It is recommended that future research examining this matter should be conducted over the next five years. This will allow the players who were subjects for this study a better chance of reaching the NHL. By examining a longer time span, possibly a higher multiple R from the regression equation to predict NHL success would be obtained. This study was a first attempt to predict future NHL players based on physiological variables obtained from the fitness assessment performed prior to the NHL draft.

References

Agre, J.C., Casal, D.C., Leon, A.S., McNally, M.C., Baxter, T.L. and Serfass, R.C. Professional ice hockey players: Physiologic, anthropometric, and musculoskeletal Characteristics. Archives in Physical and Medical Rehabilitation. 69:188-192, 1988.

Bouchard, C. Genetics of aerobic power and capacity. In: Malina & C. Bouchard (Eds.), Sport and human genetics. Champaign, Illinois: Human Kinetics, 1986.

Bouchard, C., Landry, F. and Leblanc, C. Quelques-unes des caracteristiques physiques et physiologiques des joueurs de hockey et leurs relation avec la performance. Mouvement. 9(1): 95-110, 1974.

Bouchard, C., Taylor, A.W. and Dulac, S. Testing maximal anaerobic power and capacity. In: MacDougall, J.D., Wenger, H.A. and Green, H.J. (eds): Physiological Testing of the Elite Athlete. Ithaca, NY: Mouvement, pp. 61-73, 1982.

Brayne, S.P. A comparison of on ice and laboratory tests of hockey fitness. Unpublished Master's thesis, McGill University, Montreal, 1985.

Chomay, J., Montgomery, D.L., Hoshizaki, T.B. and Brayne, S.P. The effect of added state weight on performance in an ice hockey fitness test. Canadian Journal of Applied Sport Sciences. 7(4): 240, 1982.

Chovanova, E. Somatotypes of ice hockey forwards, backs and goal-keepers. Acta Facultatis Rerum Naturalium Universitatis Comenianae Anthropologia. 23: 141-146, 1976a.

Chovanova, E. The physique of the Czechoslovak top ice-hockey players. Acta Facultatis Rerum Naturalium Universitatis Comenianae Anthropologia. 22:115-118, 1976b.

Cox, M.H., Rhodes, E.C., Thomas, S. and Quinney, A. Fitness testing of elite hockey players. Canadian Athletic Therapy Journal, Winter, 6-13, 1988.

Cox, M.H., Miles, D.S., Verde, T.J. and Levine, A.R. Physical and physiological characteristics of NHL players over the last decade. Medicine and Science in Sports and Exercise. 25(5): S169, 1993.

Cox, M.H., Miles, D.S., Verde, T.J. and Rhodes, E.C. Applied physiology of ice hockey. Sports Medicine. 19(3): 184-201, 1995.

Coyne, L. Cited by Marcotte, G. and Hermiston, R. Ice Hockey In: Taylor (ed) The Scientific Aspects of Sports Training, pp. 222-229. Charles C. Thomas, Springfield, Illinois, 1975.

Daub, W.B., Green, H.J., Houston, M.E., Thomson, J.A., Fraser, I.G. and Ranney, D.A. Specificity of physiologic adaptations resulting from ice-hockey training. Medicine and Science in Sports and Exercise. 15(4): 290-294, 1983.

Enos, E., Hoerner, E.F., Ryan, J. Sellers, W. and Smith, M. Recommendations for "pre and in-training" for United States World Hockey Team. AHAUS. May: 14-15, 1976.

Ferguson, R.J., Marcotte, G.G. and Montpetit, R.R. A maximal oxygen uptake test during ice skating. Medicine and Science in Sports. 1(4): 207-211, 1969.

Forsberg, A., Hubten, B., Wilson, G. and Karlsson, J. Ishockey idrottsfysiologi ratport no.14, Trygg-hansa forlagsverksamheten, 1974.

Gamble, F. A laboratory test of anaerobic endurance for ice hockey players. Master's thesis, McGill University, Montreal, 1986

Gamble, F. and Montgomery, D.L. A cycling test of anaerobic endurance for ice hockey players. Canadian Journal of Applied Sport Sciences. 11(3): 14P, 1986.

Gauthier, R., Cotton, C., Reed, A. and Hansen, H. A comparison of upper body and leg strength between professional and major junior A hockey ice hockey players. In: Terauds & Gros (Eds). Science in Skiing, Skating and Hockey, p.133-138, Academic Publishers, Del Mar, California, 1979.

Geisel, J.S.M. Training and testing in marathon speed skating. Journal of Sports Medicine and Physical Fitness. 19: 277-282, 1979.

Gledhill, N., and Jamnik, V. Detailed fitness and medical assessment protocols for NHL entry draft players. York University, Toronto, 1994.

Goslin, B.R. and Graham, T.E. A comparison of "anaerobic" components of O2 debt and the Wingate test. Canadian Journal of Applied Sport Sciences. 10: 134-140, 1985.

Green, H.J. Glycogen depletion patterns during continuous and intermittent ice skating. Medicine and Science in Sports. 10(3): 183-187, 1978.

Green, H.J. and Houston, M.E. Effect of a season of ice hockey on energy capacities and associated functions. Medicine and Science in Sports. 7(4): 299-303, 1975.

Green, H.J., Daub.B.D., Painter, D.C. and Thomson, J.A. Glycogen depletion patterns during ice hockey performance. Medicine and Science in Sports, 10(4): 289-293, 1978.

Green, H.J., Thomson, J.A., Daub, W.D. Houston, M.E. and Ranney, D.A. Fiber composition, fiber size and enzyme activities in vastus lateralis of elite athletes involved in high intensity exercise. European Journal of Applied Physiology and Occupational Physiology. 41(2): 109-117, 1979.

Hermiston, R. Ice Hockey In: Taylor (ed) The Scientific Aspects of Sports Training, pp. 222-229. Charles C. Thomas, Springfield, Illinois, 1975.

Houston, M.E. and Green, H.J. Physiological and anthropometric characteristics of elite Canadian ice hockey players. Journal of Sports Medicine and Physical Fitness. 16(3): 123-128, 1976.

Hutchinson, W.W., Maas, G.M. and Murdoch, A.J. Effect of dry land training on aerobic capacity of college hockey players. Journal of Sports Medicine and Physical Fitness. 19(3): 271-276, 1979.

Jacobs, I., Bar-Or, O., Karlsson, J., Dotan, R., Tesch, P., Kaiser, P. and Inbar, O. Changes in muscle metabolites in females with 30-s exhaustive exercise. Medicine and Science in Sports and Exercise. 14: 457-460, 1982.

Krotee, M.L., Alexander, J.F., Chien, I.H., LaPoint, J.D. and Brooks, H. The psychophysiological characteristics of university ice hockey players. In: Terauds & Gros (Eds). Science in Skiing, Skating and Hockey, p. 159-171, Academic Publishers, Del Mar, California, 1979.

Lariviere, G. Comparison of the efficiency of six different patterns of intermittent ice hockey skating. Ph.D. Thesis, Florida State University, Miami, 1972.

Lariviere, G., LaVallee, H. and Shephard, R.J. A simple skating test for ice hockey players. Canadian Journal of Applied Sport Sciences. 1: 223-228, 1976.

Léger, L. Seliger, V. and Brassard, L. Comparisons among VO_2max values for hockey for hockey players and runners. Canadian Journal of Applied Sport Sciences. 4(1): 18-21, 1979.

MacDougall, J.D. and Wenger, H.A. The purpose of physiological testing. In: MacDougall, J.D., Wenger, H.A. and Green, H.J. editors. Physiological Testing of the High-performance Athlete. Human Kinetics Publishers, Champaign, Illinois, pp.1-5, 1991.

Montgomery, D.L. The effect of added weight on ice hockey performance. The Physician and Sportsmedicine. 10(11): 91-99, 1982.

Montgomery, D.L. Physiology of ice hockey. Sports Medicine. 5: 99-126, 1988.

Montgomery, D.L. and Dallaire, J.A. Physiological characteristics of elite ice hockey players over two consecutive years. In: Broekhoft et al. (Eds). Sport and Elite Performers, p.133-141, Human Kinetics Publishers Inc., Champaign, Illinois, 1986.

Montgomery, D.L., Turcotte, R., Gamble, F.W. and Ladouceur, G. Validation of a cycling test of anaerobic endurance for ice hockey players. Sports Training, Medicine and Rehabilitation. 2: 11-22, 1990.

Montpetit, R.R., Binette, P. and Taylor, A.W. Glycogen depletion in a game-simulated hockey task. Canadian Journal of Applied Sport Sciences. 4(1): 43-45, 1979.

Paterson, D.H. Respiratory and cardiovascular aspects of intermittent exercise with regard to ice hockey. Canadian Journal of Applied Sport Sciences. 4(1): 22-28, 1979.

Quinney, H.A. Sport on ice. In: Reilly, T., Secher, R., Sevell, P., et al., editors. Physiology of Sports. London: E and FW sport. 311-336, 1990.

Quinney, H.A., Belcastro, A. and Steadward, R.D. Seasonal fitness variations and pre-playoff blood analysis in NHL players. Canadian Journal of Applied Sport Sciences. 7: 237, 1982.

Quinney, H.A., Smith, D.J. and Wenger, H.A. A field test for the assessment of abdominal muscular endurance in professional ice hockey players. The Journal of Orthopaedic and Sports Physical Therapy. 6(1): 30-33, 1984.

Reed, A., Hansen, H., Cotton, C. Gauthier, R., Jette, M. et al. Development and validation of an on-ice hockey fitness test. Canadian Journal of Applied Sport Sciences. 4(4): 245, 1979.

Renger, R. Identifying the task requirements essential to the success of a professional ice hockey player: A scout's perspective. Journal of Teaching in Physical Education. 13: 180-195, 1994.

Rhodes, E.C., Cox, M.H. and Quinney, H.A. Physiological monitoring of national hockey league regulars during the 1985-1986 season. Canadian Journal of Applied Sport Sciences. 11(3): 36P, 1986.

Rhodes, E.C., Cox, M.H. and Quinney, H.A. Comparison of national hockey league regular players on selected physiological parameters. Medicine and Science in Sports Exercise. 19(Suppl): S46, 1987.

Riby, S.G. Skating economy of ice players. Unpublished Master's thesis. McGill University, Montreal, 1993.

Romet, T.T., Goode, R.C., Watt, T. Allen, C., Schonberg, T., et al. Possible discriminating factors between amateur and professional hockey players in Canada. In: Landry & Orban (Eds). Ice hockey, Vol. 10, p.75-80, Symposia Specialists, Miami, 1978.

Rusko, H., Havu, M. and Karvinen Esko. Aerobic performance capacity in athletes. European Journal of Applied Physiology and Occupational Physiology. 38: 151-159, 1978

Seliger, V., Kostka, V., Grusova, D., Kovac, D., Machovcova, J., Pauer, M., Pribylova, A. and Urbankova, R. Energy expenditure and physical fitness of ice hockey players. Internationale Zeitshcrift fur Angewandte Physiologie. 30: 283-291, 1972.

Simard, P. Epreuve progressive et intermittente de consommation d'oxygene maximale chez les hockeyeurs lors du patinage sur glace. Master's thesis. Universite de Montreal, Montreal, 1975.

Smith, D.J., Quinney, H.A., Wenger, H.A., Steadward, R.D. and Sexsmith, J.R. Isokinetic torque outputs of professional and elite amateur ice hockey players. Journal of Orthopaedic and Sports Physical Therapy. 3(2): 42-47, 1981.

Smith, D.J., Quinney, H.A., Steadward, R.D. Wenger, H.A. and Sexsmith J.R. Physiological profiles of the Canadian Olympic Hockey Team (1980). Canadian Journal of Applied Sport Sciences. 7(2): 142-146, 1982.

Song, T.M.K. Flexibility of ice hockey players and comparison with other groups. In: Terauds & Gros (Eds). Science in Skiing, Skating and Hockey, p.117-225, Academic Publishers, Del Mar, California, 1979.

Song, T.M.K. and Reid, R. Relationship of lower limb flexibility, strength and anthropometric measures to skating speed. In: Terauds & Gros (Eds). Science in Skiing, Skating and Hockey, p.83-98, Academic Publishers, Del Mar, California, 1979.

Tegelman, R., Åberg, T., Poussette, Å. and Carlstrom, K. Effects of a diet regimen on pituitary and steroid hormones in male ice hockey players. International Journal of Sports Medicine. 13(5): 424-430, 1992.

Thoden, J.S. and Jetté, M. Aerobic and anaerobic activity patterns in junior and professional hockey. Mouvement (Special Hockey) 2: 145-153. 1975.

Twist, P. Complete Conditioning for Ice Hockey. Champaign, Illinois: Human Kinetics. 1997

Twist, P. and Rhodes, T. A Physiological analysis of ice hockey positions. National Strength and Conditioning Association Journal. 15(6): 44-46, 1993a.

Twist, P. and Rhodes, T. The bioenergetic and physiological demands of ice hockey. National Strength and Conditioning Association Journal. 15(5): 68-70, 1993b.

Vainikka, P., Rahkila, P. and Rusko H. Physical performance characteristics of the Finish national hockey team. In Komi (Ed.) Exercise and Sport Biology, p.158-165,Human Kinetics Publishers, Champaign, Illinois, 1982.

Vickers, J. Instructional design for teaching physical activities: A knowledge structures approach Human Kinetics Publishers, Champaign, Illinois, 1990.

Watson, R.C. and Hanley, R.D. Application of active recovery techniques for a simu lated ice hockey task. Canadian Journal of Applied Sport Sciences. 11(2): 82-87, 1986.

Watson, R.C. and Sargeant, T.L.C. Laboratory and on-ice test comparisons of anaerobic power of ice hockey players. Canadian Journal of Applied Sport Sciences. 11(4): 218-224, 1986.

Wilmore, J.A. The application of science to sport: Physiological profiles of male and female athletes. Canadian Journal of Applied Sport Sciences. 4(2): 103-115, 1979.

Wilson, G. and Hedberg, A. Physiology of ice-hockey: a report, Canadian Amateur Hockey Association, Ottawa, 1976.

Wygand, J.W., Luchsinger, E., Otto, R., Perez, H.R. and Kamimukai, C. Position related characteristics of professional ice hockey players. Medicine and Science in Sports and Exercise. 19(suppl): S46, 1987.