

# Applied Physiology of Ice Hockey

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## Summary

Today's elite hockey players are physically bigger and have improved levels of physiological fitness when compared with their predecessors. Correspondingly, previous ice hockey studies that have become widely referenced may have little relevance to current players and the way the game is presently played.

A great need exists to apply exercise science to the game of ice hockey. Although much has been written about the physiology of ice hockey, there is little information based on well controlled studies. Particularly, there is a paucity of knowledge concerning optimal training schedules, training specificity, recovery profiles and seasonal detraining. Moreover, the reports that do exist have attempted to make comparisons across all levels of skill and talent. Thus, fundamental questions remain as to actual physiological exercise response and specialised training programmes for ice hockey players, particularly at the elite level.

There is a demand for new properly designed experiments to find answers pertaining to the appropriate training methods for today's ice hockey players. Future research directions should consider the relationships between performance and such variables as neuromuscular skills, strength, power, peripheral adaptations, travel, hydration, detraining and sport-specific training programmes. Incidence and severity of injury among ice hockey players in relation to fatigue and fitness must also be investigated. Much of the information currently used in ice hockey will remain speculative and anecdotal until these studies are conducted.

It has been stated that ice hockey is the fastest game in the world played on 2 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.<sup>[1,2]</sup> Due to the nature of the game, the physiology of ice hockey is complex and provides a number of provocative questions for the athlete, coach, trainer and sport scientist.

At the professional level, the game is characterised by intense bouts of play lasting 45 to 60 seconds, and seldom exceeding 90 seconds. The game length 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 3 hours.<sup>[3]</sup> However, some players may receive as much as 35 minutes playing time during a game.

Ice hockey as a sport is metabolically unique. Ice hockey is physically demanding, requiring finely trained aerobic and anaerobic energy path-

ways. The sport demands not only intense glycolytic activity related to bursts of intense muscular activity, but also exceptional aerobic power and endurance.<sup>[4-6]</sup> Moreover, with ice hockey the involvement of the anaerobic system may be dependent on the efficiency of the aerobic system.<sup>[1,2,7,8]</sup>

Besides well-developed aerobic and anaerobic energy pathways, the nature of the game also requires a large, lean body mass and exceptional muscular strength.<sup>[9]</sup> 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 prevent injury and offset premature fatigue to maintain performance.

The physiology of ice hockey has been reviewed twice during the 1980s. Shephard<sup>[10]</sup> reviewed the factors which limit ice hockey performance, and, in a comprehensive review, Montgomery<sup>[5]</sup> addressed most aspects of hockey physiology. In addition, specific aspects of ice hockey player characteristics have appeared in the literature.<sup>[9,11]</sup> Unfortunately, since Montgomery's<sup>[5]</sup> review, new information on the physiology of ice hockey has been sparse. The current review addresses the ap-

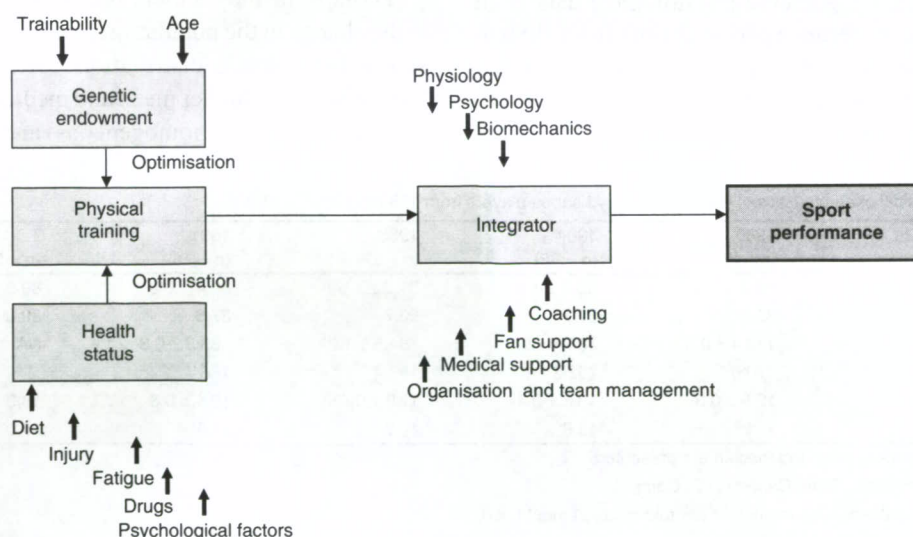


Fig. 1. The integration of factors which relate to successful athletic performance at the elite level.

plied physiology of ice hockey, particularly at the elite level, provides a critical review of previous research and recommends future directions with regard to research into hockey physiology.

1. Physiological Profiles

Most professional hockey players have spent years developing their skill and physical performance. Although superior performance is easily recognisable, it is somewhat more difficult to quantify those attributes or characteristics that produce performance excellence.<sup>[12]</sup> Confounding the ability to identify the characteristics of an elite athlete is the fact that successful performance is probably multivariate. Genetic endowment, physiological fitness, skill level, biomechanics, psychological factors, environment and coaching all enter into the equation for elite performance.<sup>[4,12-14]</sup> Figure 1 depicts many of the variables leading to successful performance in ice hockey.

Identification of the physiological attributes which are indigenous to a particular athlete in a given sport helps in player recruitment,<sup>[15]</sup> helps in identifying strengths and weaknesses in the athlete subpopulation<sup>[4,16]</sup> and leads to the development of sport-specific training and testing.<sup>[17-19]</sup>

Cox et al.<sup>[20]</sup> gathered physiological data from NHL teams covering a period of time from 1980 to 1991. Data were obtained on 170 players from 5 NHL teams over this 11-year time frame. As well, data from 55 players recruited for Team Canada in

the 1991 Canada Cup were supplied by Wenger (personal communication). Table I provides data on the physical characteristics of these NHL players. Body mass and height progressively increased between the years 1980 and 1991. In 1980, approximately 40% of the players weighed less than 85kg and 71% were shorter than 180cm in height. In contrast, by 1991 only 26% of the players weighed less than 85kg and 85% were taller than 180cm. During this same period, relative body fat remained constant at 13%. Grip strength and aerobic power are presented in table II. Grip strength and maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ) also progressively increased over the 11 years.

Figure 2 presents the  $\text{VO}_{2\text{max}}$  frequency distribution curves for 1980, 1984, 1988 and 1991 among NHL players. This same increased pattern holds true for body mass, height and grip strength. Data from Team Canada 1991, which contained some of the NHL's most skilled players, demonstrated that these athletes were bigger and had greater levels of  $\text{VO}_{2\text{max}}$  than the 1991 NHL regulars.  $\text{VO}_{2\text{max}}$ , body mass, height and grip strength had a distinct homogeneous distribution with little skewness, while relative body fat was positively skewed for Team Canada.

Perhaps the most salient feature of this data set is the change in the population distribution of these scores. For example, distribution scores for  $\text{VO}_{2\text{max}}$  have shifted to a higher mean and median, and have become leptokurtic (homogeneous) and negatively

Table I. Physical characteristics of National Hockey League players from 1980 to 1991<sup>a</sup>

| Characteristic | 1980<br>(n = 38)  | 1984<br>(n = 38)        | 1988<br>(n = 23)        | 1991<br>(n = 75) | TC 1991 <sup>b</sup><br>(n = 55) |
|----------------|-------------------|-------------------------|-------------------------|------------------|----------------------------------|
| Body mass (kg) | 85.3 ± 1.1        | 88.2 ± 1.1              | 91.2 ± 1.5              | 88.4 ± 0.8       | 89.3 ± 0.8                       |
| median         | 85.6              | 87.7                    | 90.7                    | 87.8             | 89.0                             |
| Height (cm)    | 179.4 ± 0.8       | 183.4 ± 0.9             | 184.5 ± 1.2             | 185.5 ± 0.8      | NA                               |
| median         | 179.8             | 182.7                   | 185.4                   | 186.7            |                                  |
| % Body fat     | 12.6 ± 0.3        | 13.8 ± 0.4 <sup>c</sup> | 11.8 ± 0.4 <sup>c</sup> | 12.1 ± 0.3       | 14.0 ± 1.9 <sup>d</sup>          |
| median         | 12.3 <sup>d</sup> | 13.6                    | 10.7                    | 11.5             | 14.0                             |

a Mean, standard error and median are presented.  
b Players invited to Team Canada (TC) Camp.  
c Durnin and Womersley method of skinfold measurement used.  
d Skinfold formulae not reported.

Abbreviation: NA = not applicable.

**Table II.** Combined grip strength and maximum oxygen uptake ( $\text{VO}_{2\text{max}}$ ) scores for National Hockey League players from 1980 to 1991<sup>a</sup>

|                                       | 1980<br>(n = 38) | 1984<br>(n = 30) | 1988<br>(n = 23) | 1991<br>(n = 72) | TC 1991 <sup>b</sup><br>(n = 55) |
|---------------------------------------|------------------|------------------|------------------|------------------|----------------------------------|
| Combined grip strength (kg)           | 123.3 ± 1.9      | 131.9 ± 4.9      | 130.4 ± 2.5      | 130.9 ± 1.8      | 115.6 ± 1.5 <sup>c</sup>         |
| median                                | 122.5            | 130.5            | 126.0            | 128.5            | 113.0                            |
| $\text{VO}_{2\text{max}}$ (ml/kg/min) | 54 ± 1.1         | 54.4 ± 0.8       | 57.8 ± 1.2       | 60.2 ± 0.6       | 62.4 ± 0.5                       |
| median                                | 53.0             | 54.1             | 58.0             | 60.6             | 62.8                             |

a In 1980, 40% of players had combined grip strength scores of <120kg; by 1991, only 20% were below this mark.

b Players invited to Team Canada (TC) Camp.

c Employed hydraulic dynamometer vs spring loaded dynamometer.

skewed. In contrast, the 1980 population distribution had a lower mean and median, was positively skewed and fitted a mesokurtic profile (wide range). Such changes in player characteristics suggest that training methods have changed and, as a result, more players have higher fitness levels. It also follows that player selection has become more consistent in regard to the physical characteristics needed to play professional ice hockey. In fact, beginning in 1993 the NHL adopted centralised physiological testing for all NHL entry draft players.<sup>[34]</sup>

In 1984, several NHL teams implemented a variety of rigorous conditioning programmes that were based upon proven scientific methods specifically designed to improve the central cardiorespiratory

systems. These programmes were in sharp contrast to traditional NHL training methods. Besides the shift in fitness score distribution, another remarkable feature of the data reported by Cox et al.<sup>[20]</sup> was the incremental improvement in  $\text{VO}_{2\text{max}}$  for these players. For example, in 1980 58% of the players examined had a  $\text{VO}_{2\text{max}}$  less than 55 ml/kg/min, in contrast to only 15% in 1991. These improvements in aerobic power occurred independently of an increase in body mass, which would indicate that the change in conditioning methods has been effective in improving those physiological components associated with aerobic power. Moreover, the most talented players, albeit by empirical observation, have the best physiological profile.

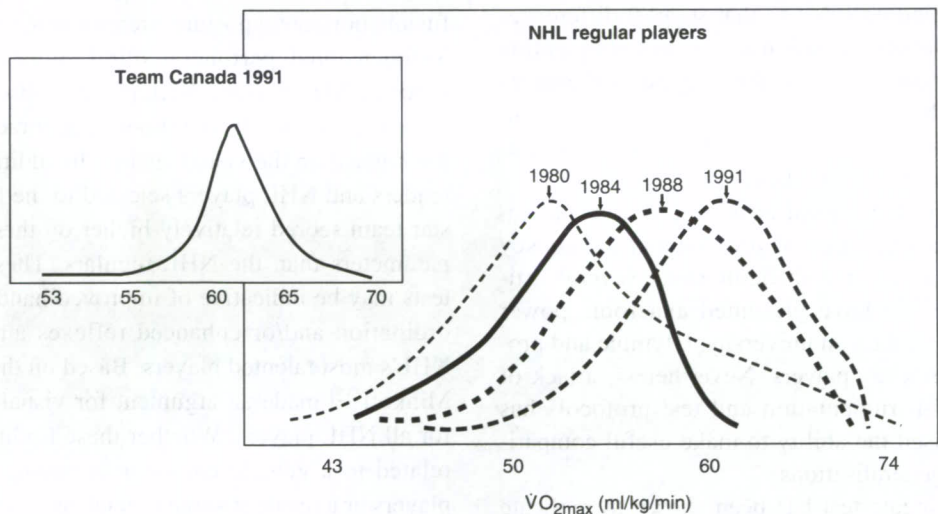


**Fig. 2.** Frequency distributions for maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ) among National Hockey League (NHL) players for the years 1980, 1984, 1988 and 1991, and for Team Canada 1991.

Previous reports have suggested that there are specific physiological requirements for each hockey position. That is, forwards, defencemen and goal tenders can be identified by specific physiological profiles.<sup>[8,21,22-24]</sup> With the exception of higher scores for hamstring and back flexibility for goal tenders and a tendency towards body mass homogeneity among defensemen, data on 180 ice hockey players over the last 6 years from our laboratory<sup>[3]</sup> show a weak relationship between select physiological parameters and position. Similar results have been reported by Agre et al.,<sup>[25,26]</sup> and by Quinney<sup>[11]</sup> in a comprehensive review of ice hockey player physical characteristics.

Cox et al.<sup>[4]</sup> monitored a training programme based on results from physiological testing of 10 NHL players. Five NHL forwards, 3 defencemen and 2 goal tenders complied with the programme for 3 consecutive years. Although physiological differences in body composition, strength measures and aerobic power existed among positions upon programme initiation, as the training programme progressed the 10 players (independent of position) not only significantly improved their fitness levels, but became closely matched in physiology. Regardless of the roles forwards, defencemen and goal tenders play, it is unlikely that previous findings<sup>[4,8,21,27]</sup> that suggest differences in fitness level by position are due to some position self-selection process. Rather, any past differences observed by position most likely reflect the training emphasis imposed by coaches and trainers, as well as by the players themselves.

Defining the typical anaerobic power and capacity characteristics of professional ice hockey players has been a difficult task. Several articles<sup>[4,21,22,24,28]</sup> have presented anaerobic power and capacity data on university, Olympic and professional hockey players. Nevertheless, a lack of standard instrumentation and test protocols has compromised the ability to make useful comparisons and generalisations.

The Wingate test has been shown to replicate fatigue curves generated with anaerobic on-ice skating tests for ice hockey players<sup>[29,30]</sup> and relate

to performance in speed skating.<sup>[18]</sup> Watson and Sargeant<sup>[31]</sup> have questioned the task-specificity of the Wingate assessment, however, even though their research showed good correlation ( $r = 0.73$ ) between on-ice anaerobic capacity tests and the Wingate protocol.

Our laboratory has conducted 181 anaerobic power and capacity tests on 118 different NHL players for the last 4 years utilising a modified Wingate protocol. The tests were performed on a Monark cycle ergometer (Ergomedic Model #814E) designed specifically to evaluate anaerobic power and capacity. The cycle ergometer was interfaced with a laptop computer and generated data calculated from one-quarter flywheel demarcations. Tension was adjusted to 80 g/kg of body-weight, and the test duration was set at 45 seconds to simulate a typical shift on the ice. Scores by position are presented in table III. Defencemen, forwards and goal tenders were, on average, identical in anaerobic power and capacity.

Although neuromuscular skills, such as agility, balance and mechanical efficiency are considered important in ice hockey,<sup>[30]</sup> controlled studies on these variables for ice hockey are lacking. Minkoff<sup>[32]</sup> studied visual speed and span, eye fusion, horizontal posture, stereoscopic vision and 3-dimensional peripheral blind spots among a group of NHL players. NHL players who were adept at face-off ability and shooting accuracy scored the highest on the visual testing. In addition, goal tenders and NHL players selected to the NHL all-star team scored relatively higher on these visual parameters than the NHL regulars. These visual tests may be indicative of improved hand-eye coordination and/or enhanced reflexes among the NHL's most talented players. Based on these data, Minkoff<sup>[32]</sup> made an argument for visual training for all NHL players. Whether these findings were related to a genetic endowment among specific players or a result of some specialised visual training and/or skill development remains unclear and needs further research.

**Table III.** Anaerobic power, capacity and fatigue index scores for 118<sup>a</sup> National Hockey League players grouped by position<sup>b</sup>

|                                        | Defence positions | Forwards    | Goal tenders |
|----------------------------------------|-------------------|-------------|--------------|
| Total tests <sup>a</sup>               | 57                | 105         | 19           |
| Anaerobic power <sup>c</sup> (W/kg)    | 12.3 ± 0.10       | 12.3 ± 0.08 | 11.9 ± 0.20  |
| [range]                                | [10.0-14.6]       | [10.5-14.0] | [10.1-13.8]  |
| Anaerobic capacity <sup>d</sup> (W/kg) | 8.5 ± 0.08        | 8.6 ± 0.60  | 8.3 ± 0.18   |
| [range]                                | [7.1-10.6]        | [6.6-11.8]  | [7.4-10.7]   |
| Fatigue index <sup>e</sup> (%)         | 52.5 ± 0.94       | 52.1 ± 0.72 | 52.7 ± 2.00  |
| [range]                                | [35.0-67.0]       | [21.0-69.0] | [25.0-66.0]  |

a 181 Wingate tests were conducted on 118 different National Hockey League players over 4 years.

b Mean, standard error and median are presented.

c Anaerobic power =  $\left( \frac{\text{total rev (5 sec)} \times \text{circumference (m)} \times \text{resistance (kp)}}{\text{time (5 sec)}} \right) / \text{body mass.}$

d Anaerobic capacity =  $\left( \frac{\text{total rev (45 sec)} \times \text{circumference (m)} \times \text{resistance (kp)}}{\text{time (45 sec)}} \right) / \text{body mass.}$

e Fatigue index =  $\left( \frac{\text{peak power} - \text{minimum power}}{\text{peak power}} \right) \times 100$

2. Physiological Testing of Elite Hockey Players

In addition to defining physical characteristics and profiling a hockey player's physiology, athlete testing can serve many important functions for a player, team and organisation.<sup>[4,19]</sup> As with all sports, for the athletes and team to benefit from scientific testing the assessments must: (i) be specific to the sport, meaningful and applicable to training development;<sup>[17]</sup> (ii) use measures that are valid and reproducible; and (iii) conducted on a regular schedule.<sup>[19]</sup>

Specifically, athlete testing can help to: identify performance capabilities; identify physiological potential; identify specific types of injuries that can be reduced or eliminated; identify specific training regimens; and quantify physiologically the response to a training programme. These programmes then can be monitored continuously and adjusted to meet individual needs.

Although it is possible that elite hockey players have a genetic physiological predisposition,<sup>[13,33]</sup> the ability to potentiate 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 programmes can help offset the rigours of travel during a greater than 95- to 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 a 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 an athlete is ready to return while minimising the risk of injury recurrence.

There are no international standards for the physiological assessment of elite hockey players. Gledhill and Jamnik<sup>[34]</sup> have suggested sport-specific laboratory protocols for hockey players, and Bouchard et al.<sup>[35]</sup> and Rhodes and Twist<sup>[30]</sup> have recommended protocols for on-ice testing.

Gledhill and Jamnik,<sup>[34]</sup> working with exercise physiologists associated with several NHL teams, have constructed a test battery for hockey players. These assessments include: (i) standing height; (ii) body mass; (iii) subcutaneous skinfold measurements (chest, triceps, biceps, subscapular,

suprailiac, abdominal, front thigh, medial calf); (iv) anaerobic power and capacity [Wingate cycle protocol (30 sec)], strength and muscular endurance [grip strength, benchpress repetitions (200lb), curl-ups (continuous to a 100 maximum over 4 min)]; (vi) flexibility (Wells and Dillon sit and reach<sup>[101]</sup>); and (vii) aerobic power assessed with direct gas analysis during cycle ergometer exercise.

In the absence of a skating treadmill, a cycle ergometer is perhaps the most task-specific laboratory device related to skating. In recent years, the development of electronic cycle ergometers has improved the ability to measure  $\text{VO}_{2\text{max}}$ . The ability to ramp the work intensity of the ergometer continuously and in very small increments eliminates the problems of quick, large jumps in workloads that were previously associated with the traditional manual cycle ergometers. Manual cycle ergometers limit performance due to the energy required to overcome the inertia of the incremental loading. The new electronic technology has improved the accuracy of  $\text{VO}_{2\text{max}}$  measurements, thus enabling a better and more precise knowledge of the aerobic power of ice hockey players. Moreover, these find-

ings should lead to precise specialised training programmes.

On-ice testing of ice hockey players can be highly task-specific, but may suffer from problems of reliability.<sup>[19]</sup> Nevertheless, the ice surface can be a good venue to test aerobic power, anaerobic power and capacity. Rhodes and Twist<sup>[30]</sup> have recommended an aerobic skating test (fig. 3) and the Reed Repeat Sprint Skate (RSS) anaerobic power and capacity test developed by Reed et al.<sup>[36]</sup> (fig. 4). Bouchard et al.<sup>[35]</sup> have suggested, for the testing of anaerobic capacity among ice hockey players, the Lariviere and Godbout<sup>[37]</sup> protocol. In this latter assessment, a hockey player must skate at maximum speed 6 times backwards and forwards (total 12 skates) a distance of 18.3m per repetition. The time to complete the course would be an indication of anaerobic capacity. In youth hockey players, depending on the age group, scores for this test range from a 97 to 44 seconds. No norms have been published for elite hockey players. Another research opportunity exists to establish on-ice normative data for elite hockey players using this protocol.

In addition to the core test battery for hockey players that Gledhill and Jamnik<sup>[34]</sup> have sug-

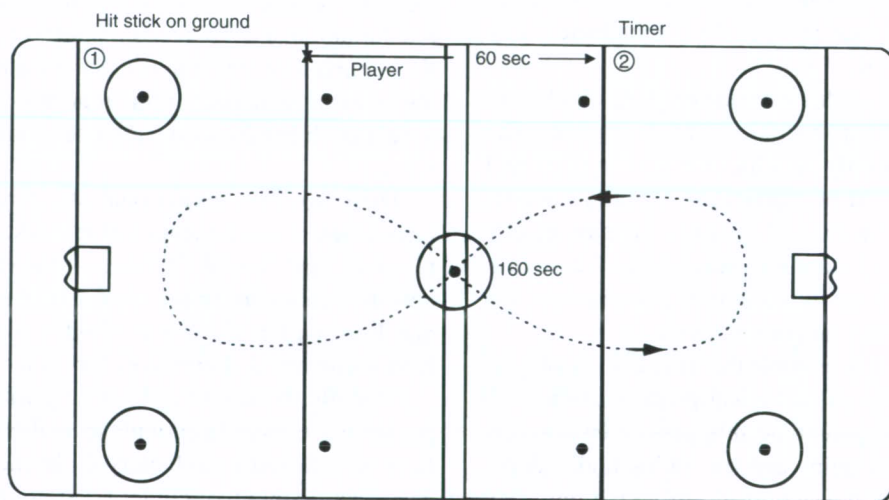


**Fig. 3.** The aerobic power skate involves a constant paced skate, completing 40 laps in as short as time as possible. Players begin at the centre ice and have a test administrator count and time the laps.

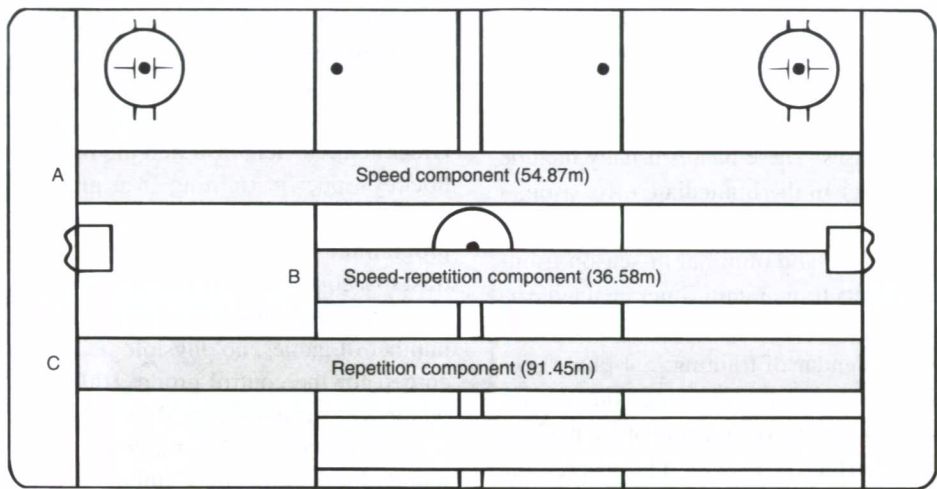


**Fig. 4.** The Reed Repeat Sprint Skate (RSS) consists of 6 bursts of maximal velocity skating (91.45m), with repeats started every 30 sec. Anaerobic power is indicated by the time to skate 1 complete length of the ice. Anaerobic capacity is assessed by the total time to skate the 6 repetitions.

gested, in our own laboratory we measure the individual lactate threshold (LT). Furthermore, we assess changes in the LT on a regular basis throughout the season.<sup>[3]</sup> The basis of this testing assumes that: (i)  $\text{VO}_{2\text{max}}$  is an indicator of central adaptation and LT is an index of peripheral muscular adaptation;<sup>[38-41]</sup> (ii) LT provides a highly specific and accurate baseline to construct individualised training programmes,<sup>[40]</sup> as well as a baseline to evaluate detraining and rehabilitation programmes; and (iii) LT will be more influenced by specificity of training, that is, proper and specific training leads to a right-shifted lactate curve.<sup>[42,43]</sup>

Table IV presents the lactate threshold data compared with  $\text{VO}_{2\text{max}}$  values for 24 American Hockey League (AHL) and NHL professional hockey players. LT on average occurred at 82% of  $\text{VO}_{2\text{max}}$ , and ranged from 73 to 92% among the 24

players. The classic curvilinear rise, of 1 mmol of lactate per litre with increasing work rate,<sup>[41]</sup> for this determination occurred on average within a 4-beat heart rate (HR) range. These data illustrate the difficulty when prescribing a training programme that is based solely on HR for elite hockey players. Such a small increment in HR would make the precision of the training programme almost impossible without determination of the individual LT.

3. Ice Hockey Training

Since 1984 there has been an increased emphasis on physical training among NHL teams. However, most programmes have evolved by trial and error, with techniques borrowed from other sports, or based upon information from the general fitness literature. Few examples exist of NHL teams using

**Table IV.** The lactate threshold (LT) for 24 National Hockey League players as it relates to watts at LT, percentage of maximal heart rate ( $\text{HR}_{\text{max}}$ ) at LT, and percentage of maximal oxygen uptake ( $\text{VO}_{2\text{max}}$ ) at LT

|                | Watts at LT | % $\text{HR}_{\text{max}}$ | % $\text{VO}_{2\text{max}}$ |
|----------------|-------------|----------------------------|-----------------------------|
| Mean           | 352.7       | 89.5                       | 82.5                        |
| Standard error | $\pm 9.9$   | $\pm 0.9$                  | $\pm 0.85$                  |
| Median         | 348.0       | 90.5                       | 82.0                        |
| (range)        | (228-440)   | (77-96)                    | (73-92)                     |

scientific data from physiological testing to design specific training programmes that relate to how ice hockey is played.

Typically, hockey players train over the calendar year in 3 or 4 phases. These phases usually include some type of taper in the immediate off-season, a pre-season combination aerobic and resistance training programme and minimal in-season training which attempts to maintain fitness gained earlier.<sup>[11]</sup> Recently, Rhodes and Twist<sup>[30]</sup> introduced a 'year-round calendar of training: a 4-phase programme' that is designed to challenge the physiological systems specific to the game of ice hockey. Studies on the effectiveness of this programme have yet to be published.

Training specificity is imperative for successful performance of the elite athlete.<sup>[17,44]</sup> Great differences exist between training for health and general fitness for the population at large and sport-specific training to improve performance (fig. 5). Professional ice-hockey training programmes should be designed on the basis of relevant objective physiological evaluations.<sup>[19,45]</sup> As much as possible the programmes should be task-specific to match the sport's energy demands,<sup>[2,46,47]</sup> improve fitness<sup>[48,49]</sup> and to offset the fatigue and staleness

encountered over a long season compounded by travel requirements.

Contrary to popular belief among players and coaches, players do not play themselves into shape. Greer et al.<sup>[50]</sup> demonstrated the importance of ice hockey-specific training in a group of Bantam players. The players entered into a specific training programme improved skating performance in contrast to a control group which was only involved in game play. Although both groups played an equal number of games, no physiological gains were recorded for the control group. Unfortunately, time on the ice was not reported for each player.

Even though several training studies have been reported<sup>[5]</sup> for university, junior, Olympic and age group hockey players, no controlled training studies have been reported at the professional level. Moreover, previous training experimentation has primarily been focused on training designed to enhance  $\text{VO}_{2\text{max}}$ . Quinney<sup>[51]</sup> and Cox et al.<sup>[4]</sup> have shown improvements in  $\text{VO}_{2\text{max}}$  among NHL players. However, little information exists related to training programmes and the consequences in the areas of lactate curve shifts, endurance, muscular strength, as well as anaerobic power and capacity. Once  $\text{VO}_{2\text{max}}$  has been attained, will measures of peripheral adaptation be more critical for each ice hockey player? Science and hockey await the answers to this question.

Based on individual lactate curves and a 4 mmol/L lactate training threshold, a programme was designed by our laboratory for an NHL team with the intention of maintaining aerobic power and peripheral adaptations over a season (fig. 6). The basis of this programme was the concept that exercise at LT is considered optimal in terms of the stimulus needed for muscle adaptation.<sup>[43]</sup> Each NHL player was given a cycle ergometer interval training programme at an exercise intensity designed to elicit a blood lactate value of 4 mmol/L in an effort to offset detraining over the course of a season. The training session frequency was prescribed based on minutes of ice time during game situations. Players whose averaged ice time was less than 8 minutes were asked to train 4 times per

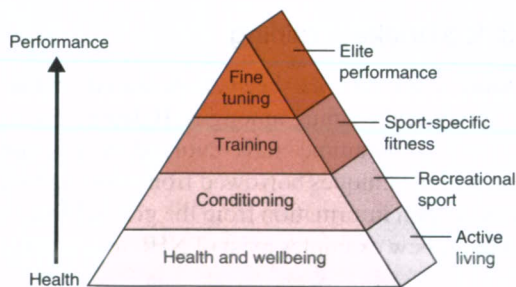


**Fig. 5.** The base of the triangle represents the population at large and depicts the general approach needed to gain health and well-being through daily physical activity. Regular daily activities such as gardening or walking have been shown to relate to health and quality of life. The apex of the triangle denotes that small fraction of the population who perform sport at the elite level. Sport-specific training is needed to gain sport-specific fitness.<sup>[102]</sup>

| Programme A - Conditioning |                       |
|----------------------------|-----------------------|
| Time (min)                 | Pedal speed (rev/min) |
| 4:00                       | 80                    |
| 1:00                       | 100                   |
| 4:00                       | 80                    |
| 1:00                       | 100                   |
| 4:00                       | 80                    |
| 1:00                       | 100                   |
| 4:00                       | 80                    |
| 1:00                       | 100                   |
| 4:00                       | 80                    |
| 1:00                       | 100                   |
| 4:00                       | 80                    |
| 1:00                       | 100                   |
| Total = 30 min             |                       |

Fig. 6. An example of a cycle ergometer training programme for ice hockey players. Work rate was prescribed at lactate threshold for each player.

week. Players who averaged 8 to 22 minutes of ice time were prescribed a training frequency of 3 times per week. Individuals who played more than 22 min per game on a regular basis were asked to train twice a week. Unfortunately, once the competitive season began, player compliance waned. The demands of travel schedule and playing minutes superseded programme adherence.<sup>[3]</sup>

The lactate and HR values observed during the baseline LT submaximal test can be used to serially evaluate the fitness level of each player over the course of the season. As presented in figure 7, a person's fitness level can be classified on a continuum from high to low. We have defined a significant change in lactate accumulation as  $\pm 0.5$  mmol/L and an HR of  $\pm 5$  beats/min. A player who accumulates less lactate and has a lower HR, for the same work rate, would be considered to have improved their fitness level. Alternatively, the player who demonstrates an increase in lactate accumulation and a higher HR would be considered detrained. It should be appreciated, however, that such information should be viewed in conjunction with additional input from the coaches, trainers and players before any informed decision can be reached.

4. Detraining

Historically, in the late part of the season, professional ice hockey players complain of 'heavy legs'. Coaches and trainers have traditionally considered this complaint to be due to overtraining, the rigours of travel and a greater than 80 game schedule. Complaints of 'heavy legs' may, however, be more related to detraining as opposed to overtraining.

Green et al.,<sup>[8]</sup> Quinney et al.<sup>[28]</sup> and Daub et al.<sup>[48]</sup> have suggested that on-ice practice and game play provide an insufficient physiological challenge to maintain or improve fitness among hockey players. To test this hypothesis in the NHL, our laboratory assessed the on-ice performance demands of 1 NHL team. 14 NHL games were monitored, and ice time was recorded for each player. The monitoring showed that, on average, ice time was less than 16 min per player. Moreover, during the 14 games, ice times ranged from 3 to a maximum of 25 minutes for any given player.

Subsequent to the 14 games, 3 players were telemetered for HR intensity during another game situation, and 4 other players were telemetered during 2 on-ice practice sessions. The head coach subjectively ranked 1 on-ice practice as 'hard' and the other 'light'. Telemetry results were compared with data from each player's laboratory assessments, and are presented in tables V and VI. For the 3 players telemetered in a subsequent game, ice time ranged from 14.1 to 31.2 min. The percentage of time at or above threshold heart rate (THR, heart rate at LT) ranged from 8.5 to 19.1%. The most

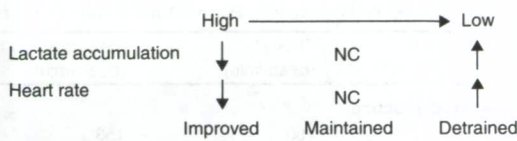


Fig. 7. Lactate accumulation and submaximal heart rate (HR) changes, as a reflection of fitness level, in response to steady rate cycle exercise as measured periodically throughout the season. An increase (↑) or decrease (↓) corresponds to a change in blood lactate of  $>0.5$  mM or a change in HR of  $>5$  beats/min during standardised submaximal exercise; NC denotes no change.

**Table V.** Heart rate (HR) telemetry data for 3 National Hockey League players monitored during a regular season game. The HR recordings are compared with laboratory data for lactate threshold HR (THR) and maximal HR (HR<sub>max</sub>)

| Player | THR<br>(beats/min) | Mean game HR<br>(beats/min) | Actual playing time<br>(min) | Game time <sup>a</sup><br>(min) | % THR | % Time at 75%<br>of HR <sub>max</sub> |
|--------|--------------------|-----------------------------|------------------------------|---------------------------------|-------|---------------------------------------|
| 1      | 163                | 132                         | 21.2                         | 135                             | 12.9  | 12.2                                  |
| 2      | 155                | 126                         | 31.2                         | 135                             | 19.1  | 20.6                                  |
| 3      | 170                | 128                         | 14.1                         | 135                             | 8.5   | 30                                    |

a Game time includes time-outs for penalties, television commercials or any stoppage in play. Between-period time has been excluded.

time any player was above THR for the entire game was 6 minutes. The mean game HR ranged from 126 beats/min to 132 beats/min for the players. Such data point out the need for appropriate training programmes far beyond the game situation. Exercise intensities of this amount are not sufficient to maintain an adequate fitness level and will lead to detraining.

The 3 players telemetered in the ‘hard’ practice reached THR or greater from 9 to 33% of the practice time. For the 2 players monitored during the ‘light’ practice, THR or greater was 0% for 1 player and 9% of the practice time for the other. Extrapolating this data over a season of hockey would certainly support the hypothesis that games and practices, when not supplemented with properly constructed training programmes, would lead to detraining.

In a follow-up experiment, Cox<sup>[3]</sup> observed blood lactate levels from a fixed work rate based on individualised LT. The observations were made 4 times over the NHL season, with 16 players. Initially, pre-season lactate curves were established as described by Thoden.<sup>[41]</sup> Individual submaximal

work rates were chosen to elicit approximately 4 mmol/L of lactate calculated from the pre-season lactate curves. Subsequently, after the first third of the season, lactate levels were measured during a 5-min steady-rate cycle ergometer protocol. The same protocol was repeated in the second and last third of the season.

Figure 8 shows the constant rise in lactate for the given work rate over the season. Repeated measures ANOVA (analysis of variance) demonstrated a significant difference between lactate levels at the first third of the season compared with those from the last third, with no associated change in HR. The percentage for winning games for the first third was 61% and the last third 36%. Such data suggest that a significant detraining may occur in many players over the course of the season. Minkoff<sup>[32]</sup> also showed a relationship between an NHL team’s winning percentage and decreases in VO<sub>2max</sub> in the second half of the season. Such observations further suggest that aerobic and anaerobic systems may be compromised without a properly constructed training programme.

**Table VI.** Heart rate (HR) telemetry data for 4 National Hockey League players. Players 1, 2 and 3 were monitored during a ‘hard’ practice (as determined by the head coach). Players 1 and 4 were monitored in a ‘light’ practice

| Player                         | THR<br>(beats/min) | Mean practice HR<br>(beats/min) | Practice time<br>(min) | % THR | % Time at 75%<br>of HR <sub>max</sub> |
|--------------------------------|--------------------|---------------------------------|------------------------|-------|---------------------------------------|
| <b>On-ice ‘hard’ practice</b>  |                    |                                 |                        |       |                                       |
| 1                              | 163                | 153                             | 65                     | 33    | 49.8                                  |
| 2                              | 170                | 160                             | 65                     | 30    | 66                                    |
| 3                              | 145                | 140                             | 45                     | 9     | 25.5                                  |
| <b>On-ice ‘light’ practice</b> |                    |                                 |                        |       |                                       |
| 1                              | 163                | 121                             | 60                     | 9     | 25.5                                  |
| 4                              | 170                | 121                             | 60                     | 0     | 17.5                                  |

Abbreviations: HR<sub>max</sub> = maximal heart rate; THR = heart rate at lactate threshold.

A question often asked of exercise scientists by professional hockey coaches and trainers in late season is whether to rest or train players, particularly those receiving more than average ice time. This question is based on the premise that ice hockey players are fatigued due to the consequences of overtraining. Sport scientists have not addressed this question specifically to ice hockey. However, Shepley et al.,<sup>[52]</sup> in a well designed study, looked at this question in elite middle distance runners. After 8 weeks of intense training, 9 runners were randomly assigned to 1 of 3 different taper regimens: high intensity, low volume; low intensity, moderate volume; rest only. The study included a cross-over design so that all 9 runners eventually completed each taper format. The high intensity, low volume taper was most effective in improving performance, increasing muscle glycogen, total blood volume and red cell volume. Unfortunately, lactate curves were not part of the protocol. However, since no changes in  $\text{VO}_{2\text{max}}$  were observed, but improvement in endurance performance was noted, it is likely that the LT was delayed. Professional ice hockey needs similar research.

#### 4.1 Travel Effects

Pace and Carron<sup>[53]</sup> investigated travel and home advantage in the NHL. Although there was a distinct home advantage (58.3% winning percentage), travel in itself could not explain winning percentage variance. Moreover, the main effect of travel across time zones had no impact on winning or losing. O'Connor and Morgan,<sup>[54]</sup> in an extensive literature review of athletic performance following multiple time zone travel, concluded that, due to inadequate research designs and lack of controlled studies, no definitive answers exist in this area of human performance research. More recently, Hill et al.<sup>[55]</sup> conducted 3 pilot studies that evaluated jet lag and sports performance. Small decrements were demonstrated in grip strength, and in anaerobic power and capacity following rapid transmeridian travel. However, these small physiological disadvantages quickly disappeared

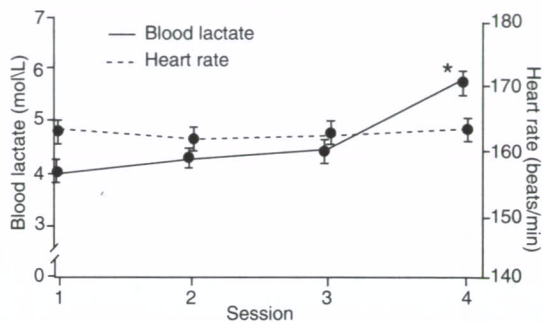


**Fig. 8.** For 16 National Hockey League (NHL) players, lactate accumulation in response to a steady rate cycle exercise increased at each of 4 testing sessions which spanned the regular NHL season. \*  $p < 0.001$ .

within 3 to 4 days following destination arrival. Since most of the findings by Hill et al.<sup>[55]</sup> were among nonathletes, and the travel was between the United States and Europe, or the United States and Asia, the relevance to North American hockey is questionable. Thus, the supposition that travel within the NHL season offsets performance and upsets a player's physiology or cognitive skills remains unanswered and requires further research.

#### 5. Dehydration

For several years there have been self-reports by ice hockey players that it is not uncommon to lose anywhere from 2 to 5 kg of bodyweight over the course of a game, representing from 3 to 10% of bodyweight. If correct, such reports are bothersome and could have dire consequences for performance. During exercise, a greater than 2% loss of bodyweight inhibits temperature regulation and impairs physiological function.<sup>[56]</sup> Compulsory fluid intake should be mandated by the coaches or trainers as negative fluid balance is not obvious to the athlete. Most importantly, several hours of rehydration are needed for the body to return to a state of homeostasis following significant dehydration.<sup>[56]</sup>

Surprisingly, only 1 article broaches the question of temperature regulation in ice hockey.<sup>[57]</sup> Using data from the time motion analysis of ice hockey play reported by Green et al.,<sup>[58]</sup> Mac-

Dougall,<sup>[57]</sup> utilising concepts of energy thermodynamics, extrapolated that during a single period of ice hockey a player could conceivably generate approximately 1250kJ (300 kcal) of excess heat. Since heat is dissipated primarily from the head, neck and shoulders during exercise, heat loss is further compromised by the uniform and protective equipment ice hockey players wear. In particular, protective padding and headgear impair heat loss. The potential for increased heat production, fluid loss, compensatory vasoconstriction, as well as other biochemical factors which may decrease plasma volume could conceivably affect cardiac stability.<sup>[2]</sup>

Cox<sup>[3]</sup> measured with HR telemetry a defenceman during the course of a hockey game in the AHL. This player was randomly selected from a group of defencemen who played on a regular basis. Results of this case study are presented in figure 9. Playing time was 21.2 min, mean period HR for the first, second and third periods were 126, 128 and 149 beats/min, respectively. Although fluid replacement was *ad libitum*, this player lost 4.5kg during the game. The cardiac drift experienced by this player was most likely a reflection of decreased plasma volume and a shift in circulating blood volume.<sup>[59-61]</sup> These circumstances can be further confounded for the ice hockey player if they enter the game hypohydrated.<sup>[62]</sup>

The thermal load that hockey imposes [thermal load = exercise intensity (internal) plus ambient temperature, uniform and equipment (external)]<sup>[63]</sup> requires constant fluid replacement. Although the question of what is the ideal fluid replacement beverage during exercise is unresolved,<sup>[64]</sup> Wheeler<sup>[56]</sup> has recommended a citrus-flavoured dilute electrolyte solution. In the meantime ice hockey players should be encouraged to replenish fluid during a game and not simply rinse out their mouths and promptly expectorate.

## 6. Glycogen Depletion

In the mid to late 1970s a number of studies suggested that ice hockey players' muscle glycogen stores depleted by the end of a game.<sup>[65-69]</sup>

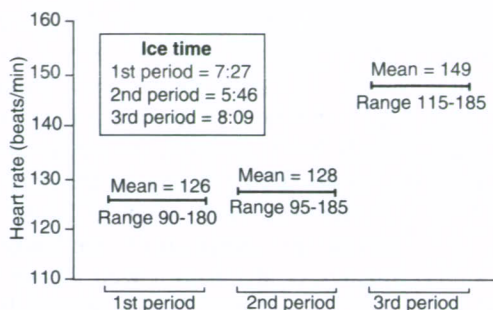


**Fig. 9.** Case study of a professional ice hockey player during a game situation. Heart rate (HR) rise in the third period was associated with a 4.5kg loss of body mass during the game. The maximal HR of the player (from laboratory assessment) was 180 beats/min, and the HR at the lactate threshold was 163 beats/min.

Such reports have motivated some NHL teams to promote ingestion of copious amounts of high caloric carbohydrate concentrated beverages. Unfortunately, it is unclear whether any of these original studies made adjustments for player fitness levels,<sup>[2,70]</sup> nutritional status,<sup>[71-75]</sup> hypohydration<sup>[62]</sup> or weight loss and dehydration.<sup>[57]</sup> Moreover, a number of questions remain as to the validity and reliability of muscle biopsy sampling.<sup>[76-78]</sup>

The majority of these studies that are related to glycogen stores have used ice hockey players below the NHL level. In addition, 1 of the widely referenced studies<sup>[68]</sup> used skating intervention protocols dissimilar to the game situation. For example, Green<sup>[68]</sup> employed ten 1-minute work intervals at 120% of  $\text{VO}_{2\text{max}}$  with a recovery period of 5 min following each exercise bout for a group of collegiate hockey players. For another group of college hockey players, a continuous skate of 60 min performed at 55% of  $\text{VO}_{2\text{max}}$  was used. Even with these skating manipulations, muscle biopsy samples showed decrements but not total depletion of glycogen. Intuitively, it is difficult to imagine glycogen depletion over the course of an NHL game when the ice time average is less than 16 minutes of play for most players. Moreover, a majority of game play is well below LT. The dogma of glycogen depletion among ice hockey players

demands further investigation through appropriately designed controlled studies.

## 7. Lactate Accumulation

A few previous reports<sup>[58,66-68]</sup> have documented lactate accumulation between shifts and following games among college and amateur players. Lactate levels reported ranged from a low of 2.9 mmol/L to a high of 11 mmol/L. It remains unclear whether any of these studies accounted for fitness level, weight loss or dehydration. Presently, no definitive study on game lactate levels has been conducted at the elite hockey level.

Nevertheless, some NHL teams have implemented post game lactate clearance protocols. These protocols consist of each player riding a cycle ergometer for at least 20 minutes at approximately 130W, following a game. Acceptance of a nonindividualised '1 workload fits all' approach for the purpose of enhancing lactate clearance is questionable.

Lactate accumulation depends on fitness level, state of training, active muscle mass, muscle fibre composition, nutritional status, blood flow and fatigue.<sup>[47,79,80]</sup> These same variables may affect recovery time and lactate clearance.<sup>[81,82]</sup> Previous studies, using primarily nonathlete populations, have reported optimal workloads for lactate removal during active recovery ranging anywhere from 28 to 68% of  $\dot{V}O_{2\max}$ . These results depend on the individual and the type of active recovery employed.<sup>[83-85]</sup>

There seems to be no question that some type of active recovery following exercise which promotes lactate accumulation is superior to a passive recovery.<sup>[86]</sup> However, there may be several critical factors to consider, such as the duration and intensity of the exercise performed, proper recovery intervals and appropriate recovery time, as well as the individuality of the athlete. In a recent study, Signorile et al.<sup>[86]</sup> demonstrated enhanced performance among power athletes with very short active recovery periods. Unfortunately, lactate clearance was not measured, leaving the question of why performance improved unanswered. On the other

hand, Watson and Hanley<sup>[81]</sup> showed enhanced lactate clearance among ice hockey players following bench stepping or ice skating with an increased duration of active recovery, but performance remained unaffected.

The concept of post game active recovery within the NHL is, thus far, based on anecdotal information and needs further research to be justified. The possibility of compromising some athletes with this approach exists, particularly if there is post game weight loss associated with dehydration.

## 8. Ice Hockey Injuries

For the most part, injuries in ice hockey are minor.<sup>[87-93]</sup> However, the incidence and severity of injuries in ice hockey is increasing.<sup>[90,94,95]</sup> Possible explanations for this change in injury statistics include: (i) the popularity of the game and the subsequent increase in participants;<sup>[96]</sup> (ii) the increase in the speed of the game, with a concomitant increase in the size of the players;<sup>[95]</sup> (iii) the extended length of the season; (iv) the lack of proper training; (v) the inconsistency in rule enforcement.

80% of injuries in ice hockey are caused by trauma, the remaining 20% through overuse.<sup>[90]</sup> Most injuries occur in the third period,<sup>[87]</sup> and fewest in the first period. The lowest incidence is in the neutral zone<sup>[91]</sup> and in play away from the puck. Trauma injuries usually fall into 2 broad classifications: (1) lacerations and contusions; (ii) ligamentous injuries and fractures. The former type of injury is most commonly caused by a puck or stick, whereas the latter is caused through physical contact.<sup>[87,88,91]</sup>

In a recent review,<sup>[95]</sup> which included injury data from 21 NHL teams, the Canadian Amateur Hockey Association, the UdSSR National Hockey Team and several other European hockey federations, data showed that ice hockey players are predisposed to lower and upper extremity injuries. Knee injuries were the most prevalent, followed by shoulder, groin and back injuries. More games were missed due to knee injuries than any other type of injury. Facial and eye injuries have been declining for years due to rule and equipment

changes, while injuries to the knee, shoulder and spine have increased, particularly since 1980. At the elite level, a player can expect some form of injury for every 7 hours of play.

## 9. Physiological Testing and Injury

The probability that an ice hockey 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.<sup>[6,89,95]</sup> Human performance assessments provide the basis for both preventive 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 programmes 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. This important fact must be recognised by all those concerned with returning a previously injured athlete to competition. For example, if a joint injury removes a player from competition and training for longer than 5 days,<sup>[97]</sup> the player should be evaluated not only for strength, time to peak torque, speed and specificity of the movement pattern, but also for cardiorespiratory reserve. These values must then 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.

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.<sup>[98-100]</sup> 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.

## 10. Conclusions

Training programmes and fitness characteristics of elite hockey players have changed dramatically over the last 10 to 15 years. The demands of ice hockey are such that players must maintain a high level of sport-specific fitness throughout the season. To maintain seasonal fitness goals, ice hockey players must supplement game play with scientifically constructed training programmes.

Many areas of research need to be further addressed to provide additional information to advance our understanding of ice hockey physiology. Human performance research in the areas of agility, balance, reaction time and neuromuscular skills need to be conducted for ice hockey. As well, travel and associated performance consequences await well designed studies. Thermoregulation may be a bigger problem for ice hockey players than previously recognised. Previous studies that suggested glycogen depletion and significant levels of lactate accumulation among ice hockey players need to be revisited. Studies on the strength characteristics of ice hockey players are lacking. Consequences of detraining and fatigue in relation to injury incidence needs to be closely examined.

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