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Physiology of Ice Hockey

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Summary

Ice hockey is characterised by high intensity intermittent skating, rapid changes in velocity and duration, and frequent body contact. The typical player performs for 15 to 20 minutes of a 60-minute game. Each shift lasts from 30 to 80 seconds with 4 to 5 minutes of recovery between shifts. The intensity and duration of a particular shift determines the extent of the contribution from aerobic and anaerobic energy systems. The high intensity bursts require the hockey player to develop muscle strength, power, and anaerobic endurance. The length of the game and the need to recover quickly from each shift demands a good aerobic system.

Physical characteristics of elite players show that defensemen are taller and heavier than forwards probably due to positional demands. Hockey players are mesomorphic in structure. They are relatively lean since excess mass is detrimental to their skating per-

formance. There is a large interindividual variability in $\dot{V}O_2$ during skating. Both the aerobic and anaerobic energy systems are important during a hockey game. Peak heart rates during a shift on the ice exceed 90% of HR_{max} with average on-ice values of about 85% of HR_{max} . Blood lactate is elevated above resting values confirming the anaerobic nature of the game.

Glycogen depletion studies show a preferential utilisation of glycogen from the slow twitch fibres but also significant depletion from the fast twitch fibres. Elite hockey players display a muscle fibre composition similar to untrained individuals.

Physiological profiles of elite hockey teams reveal the importance of aerobic endurance, anaerobic power and endurance, muscular strength and skating speed. Training studies have attempted to improve specific components of hockey fitness. Using traditional laboratory tests, a season of hockey play shows gains in anaerobic endurance but no change in aerobic endurance. On-ice tests of hockey fitness have been recommended as an essential part of the hockey player's physiological profile.

Existing training procedures may develop chronic muscular fatigue in hockey players. Lactic acidosis is associated with the onset and persistence of muscle fatigue. Muscle force output remains impaired throughout the hockey player's typical cycle of practices and games. A supplementary programme of low-intensity cycling during the competitive phase of training was unsuccessful in altering $\dot{V}O_{2max}$. Strength decrements during the hockey season are attributed to a lack of a specifically designed strength maintenance programmes. On-ice and off-ice training programmes should focus on the elevation of aerobic endurance, anaerobic power and endurance, muscular strength and skating speed.

Ice hockey had its origin in Canada in the early 1800s. For the first century of existence Canada dominated international competition. Today the game is popular in North America and Europe with top teams coming from Canada, Czechoslovakia, Finland, Sweden, the USA, or the USSR. The increased interest during the last 2 decades in international competition has created opportunities for physiological evaluation of elite teams.

There is little data on female hockey players so no attempt will be made in this article to compare possible sex differences. Shephard (1981) reviewed the physiological factors limiting the ice hockey player. This review will attempt to characterise the elite hockey player from a physiological perspective and examine research on a variety of metabolic factors relating to performance.

1. Skating Mechanics

Ice skates evolved from a blade attached to a walking boot. There is evidence that the first skate blades were made in the Scandinavian countries. The shank or rib bones of elk, oxen and reindeer

were secured to the boot long before the discovery of iron.

Modern hockey skates are designed for protection as well as performance. Ice hockey skates differ from those of the speed skater in blade length, blade rocker, boot structure, and skate weight to match the performance needs of the skater. Since speed and agility are fundamental skills of a hockey player, recent innovations such as plastic brackets, lightweight blades, and moulded skates have improved performance.

The ice skating stride consists of 3 phases: (a) glide during single support; (b) propulsion during single support; and (c) propulsion during double support (Marino & Weese 1979). Propulsion begins approximately half-way through the single support phase and lasts until the end of the double support phase. When extending the knee joint in the skating thrust, the quadriceps develop the largest contractile forces (Halliwell 1978). The hamstrings and gastrocnemius muscle act to stabilise the knee during the weight shift and push off of the skating thrust. It has been suggested (Marino & Weese 1979) that technique modifications could minimise the duration of the glide phase and max-

imise propulsion. Technical modifications to the skate boot may also enhance the hockey player's ability to achieve greater forward impulse and possibly achieve a higher maximum skating velocity (Kirchner & Hoshizaki 1987b).

The ability to accelerate quickly characterises the elite hockey player. Skilled skaters are able to exceed a velocity of 8 m/sec after just 4 strides (Lariviere 1968). Forward propulsion of a hockey player is impeded by the frictional resistance of the ice, air resistance, drag, and contact from opponents. External power is equal to the product of the work per stroke and the stroke frequency. Many researchers (Halliwell 1978; Kirchner & Hoshizaki 1987a; Lariviere 1968, 1972; Marino & Weese 1979; Page 1975) have studied the technical aspects of the hockey skating stride.

There is some disagreement regarding the key factors that contribute to elite skating performance, especially when investigations using speed skaters are included in the comparison. For example, Marino (1983) concluded that the stride pattern associated with a high rate of acceleration during a skating start includes a high stride rate, significant forward lean at the point of touchdown of the recovery skate, short single support periods, and placement of the recovery foot below the hip of the recovery leg at the end of the single support period. Again, Marino (1977) reported that stride rate among hockey players was highly related to skating velocity ($r = 0.76$) but stride length was unrelated ($r = 0.05$). Two studies of elite speed skaters (de Boer et al. 1986; van Ingen Schenau 1985) show that speed skating performance was unrelated to stroke frequency. Differences in performance level were a result of differences in work per stroke. Faster skaters showed a better timing in push-off mechanics resulting in effective directed push-off perpendicular to the gliding direction of the skate (de Boer et al. 1986). Elite skaters were able to sustain the gliding phase for a longer time. With larger muscle power, they are able to extend their knees in a shorter push-off time. Elite skaters can perform more work per stroke (van Ingen Schenau et al. 1983). Speed skaters control their speed at different velocities mainly by changing stroke fre-

quency (van Ingen Schenau et al. 1985). In contrast, Marino (1984) states that increases in maximal horizontal velocity of hockey players during the ages 8 to 15 years are accompanied by increases in skating stride length with no significant changes in skating stride rate.

Hockey coaches teach the player to attempt full extension of the hip, knee and ankle in order to accelerate quickly. Page (1975) reported significant correlations between maximum skating velocity and knee extension at toe-off as well as knee flexion prior to propulsion. When ankle support is removed from the hockey boot by altering the skate design, the hockey player is able to achieve greater forward impulse during the heel-off to toe-off phase of the stride due to greater range of motion about the ankle (Kirchner & Hoshizaki 1987b).

High speed filming (100 frames/sec) of the first and sixth repetitions of the repeat sprint skate (RSS) test was used to examine the effect of fatigue on forward skating patterns (Hoshizaki et al. 1982). From film analysis, stride length, stride rate, skating velocity, single support time, and double support time were obtained. The decrease in skating velocity with fatigue was a result of a decrease in stride rate. With fatigue, there was a slower extension of the leg and a longer glide phase.

2. Physical Characteristics

Typical physical characteristics of the elite hockey player are summarised in table I. Data on age, height, weight and percentage body fat show that professional players in the National Hockey League (NHL) are taller and heavier than university and junior players. Within a team, defensemen are taller and heavier than forwards (Chovanova 1976; Green & Houston 1975; Houston & Green 1976; Montgomery & Dallaire 1986; Smith et al. 1982).

The body composition of hockey players has been assessed primarily by skinfold techniques. Team mean adipose levels appear to remain constant at about 10 to 12% (table I). When compared with elite athletes in endurance sports, most Canadian hockey players carry some excess fat weight.

Table 1. Physical characteristics of some elite teams (mean ± SD)

Nationality	Level	n	Age (y)	Height (cm)	Mass (kg)	Percentage fat	Sum of skinfolds (mm) ^a	Reference
Canadian	Junior	26			77.9 ± 6.0	9.0 ± 1.8	55.0 ± 15.5 (6)	Green & Houston (1975)
Canadian	Junior	94	18.5 ± 1.0		81.8 ± 7.2	13.6 ± 1.5		Gauthier et al. (1979)
Canadian	Junior	9	18.4 ± 0.7		78.7 ± 6.0	8.9 ± 0.9		Green et al. (1979b)
Canadian	Junior	24	18.2 ± 1.1	177.3 ± 5.4	77.0 ± 6.0	8.6 ± 3.1	49.8 (6)	Bouchard et al. (1974)
Canadian	University	18	21.0	178 ± 5.7	78.1 ± 6.0	10.5 ± 3.2		Romet et al. (1978)
Canadian	University	8	21.0	177.3	75.9	8.6		Green et al. (1976)
Canadian	University	17	20.4 ± 1.8	177.2 ± 7.4	77.1 ± 7.8			Song (1979)
Canadian	University	19	21.5 ± 1.1		77.6 ± 4.8	10.7 ± 2.6		Green et al. (1979)
Canadian	University	17	21.5 ± 2.0	183.2 ± 3.8	83.8 ± 5.9			Gamble & Montgomery (1986)
Canadian	University and junior	24	20.2 ± 1.6	183.1 ± 4.9	86.0 ± 6.4			Watson & Sargeant (1986)
Canadian	University and junior	48	19.0	177.8	78.8	10.1	69.5 (6)	Houston & Green (1976)
American	University	21	19.2		79.8	5.6		Krotee et al. (1979)
Czechoslovakian	Elite 1970	55	23.0	176.9 ± 4.5	78.0 ± 7.6			Chovanova & Zrubak (1972)
Czechoslovakian	Forwards	33		176.2 ± 4.3	76.4 ± 6.6			Chovanova (1976)
Czechoslovakian	Defense	16		178.2 ± 4.2	82.6 ± 7.4			Chovanova (1976)
Czechoslovakian	Goalies	6		174.4 ± 5.5	74.8 ± 8.9			Chovanova (1976)
Czechoslovakian	National 1971	13	24.4	179.3	81.8	13.1		Seliger et al. (1972)
Finnish	National	27	23.9 ± 2.6	179.9 ± 5.0	81.1 ± 6.0	13.0 ± 2.6		Vainikka et al. (1982)
Finnish	National 1973-74	13	22.5 ± 3.5	179 ± 5.0	77.3 ± 5.7			Rusko et al. (1978)
Canadian	Olympic 1980	23	22.1 ± 2.6	179.8 ± 5.3	81.1 ± 6.2	10.6 ± 0.5		Smith et al. (1982)
NHL	Quebec Nordiques 1972-73	12	25.3 ± 5.3	175.2 ± 5.0	75.9 ± 5.0	10.0 ± 4.3	46.5 (6)	Bouchard et al. (1974)
NHL	Professional players	12	21.5 ± 1.6		83.4 ± 4.5	10.5 ± 1.7		Green et al. (1979b)
NHL	Montreal Canadiens 1981-82	27	25.0 ± 4.2		85.9 ± 7.0	12.4 ± 1.9	90.2 ± 19.8 (6)	Montgomery & Dallaire (1986)
NHL	Montreal Canadiens 1982-83	30	24.6 ± 3.7		86.2 ± 8.0	9.7 ± 1.6	62.4 ± 16.4 (6)	Montgomery & Dallaire (1986)
NHL	Edmonton Oilers 1980	20	25.3 ± 4.0	182.5 ± 5.4	85.8 ± 6.7	11.4 ± 1.3		Smith et al. (1981)
NHL	Professional	54	24.9 ± 3.2		85.8 ± 6.1	14.2 ± 1.4		Gauthier et al. (1979)
NHL	Defensemen 1985-86	27	24.9 ± 4.6	186.4 ± 4.5	90.3 ± 4.3	10.0 ± 2.4	29.8 ± 5.3 (4)	Rhodes et al. (1986)
NHL	Forwards 1985-86	40	23.6 ± 2.6	183.2 ± 4.8	87.1 ± 5.6	11.7 ± 2.3	30.0 ± 5.4 (4)	Rhodes et al. (1986)
NHL	Goaltenders 1985-86	8	27.0 ± 4.5	174.1 ± 4.7	79.2 ± 3.9	15.8 ± 6.5	41.7 ± 11.6 (4)	Rhodes et al. (1986)
NHL & Team Canada 1974		38	27 ± 3.5	180 ± 7.1	82.3 ± 8.0	10.4 ± 4.3		Romet et al. (1978)

a Figures in parentheses indicate number of skinfold measurements taken.

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. Empirical observations as well as experimental data reveal greater leanness among players in the 1980s compared with 15 years ago (Enos et al. 1976).

Using the Heath-Carter modification to Sheldon's method of somatotyping, Chovanova and Zrubak (1972) characterised the elite Czechoslovakian hockey player ($n = 55$) as 2.57 in endomorphy, 5.73 in mesomorphy, and 1.88 in ectomorphy. The average somatotype of selected players of First League teams in Czechoslovakia was reported (Stepnicka 1972) as 2.44 in endomorphy, 5.88 in mesomorphy and 2.13 in ectomorphy. Compared with the somatotype of the Czechoslovakian population, successful hockey players show higher values on the mesomorphy component and lower values on the ectomorphy and endomorphy ratings (Chovanova 1979). Bouchard et al. (1974) reported similar profiles for a professional team, the Nordiques (2.1 - 5.4 - 1.8), and a Quebec junior team (2.1 - 5.2 - 2.0).

Forwards and defensemen have similar values for mesomorphy (5.77 and 5.78, respectively). Defensemen and goalies have a higher endomorphic component than forwards (Chovanova 1976).

Chovanova (1977) compared body dimensions of elite Czechoslovakian hockey players with skiers. Hockey players had significantly larger forearm length, hand length, arm circumference, thigh circumference, and calf circumference as well as shorter arms. Short leg length relative to height combined with a low centre of gravity assists elite hockey players to have good balance (Chovanova 1979).

3. Effect of Added Mass

Any increase in the mass carried by the hockey player increases frictional resistance during skating. At maximal skating speed, the stride consists of 82% single support and only 18% double support (Marino & Weese 1979). During single support, there is a propulsion phase and a glide phase. Since

the glide phase begins during the initial stages of single support time (Marino & Weese 1979) and because the coefficient of friction is low in skating, it may be argued that added body mass can be supported by the skates so that a moderate excess of fat may not be a decrement in skating.

A hockey player may carry excess mass in the form of fat weight or equipment weight. Montgomery (1982) investigated the effect of experimental alterations of mass on skating performance using the repeat sprint skate (RSS) test of hockey fitness. 11 hockey players were tested in mid-season in each of 4 conditions: (a) normal body mass; (b) 5% added body mass; (c) 10% added body mass; or (d) 15% added body mass. The mass was secured to the waist and shoulders of a weighted vest. It did not interfere with skating movements. Results are shown in table II.

Added mass caused a significantly slower performance on both the speed and anaerobic endurance components of the hockey fitness test. When carrying 5% excess mass, anaerobic endurance time increased by 4%. Since the players attempted to skate at maximum velocity in each of the four conditions, the drop-off scores were relative to the times produced for that specific condition. Excess body mass increases the energy required to skate at a particular velocity so that energy systems are taxed to maximum at a slower velocity. It also shortens the time that a player can maintain the pace. Elite players should be encouraged to decrease body fat mass and to wear as light a uniform as possible without sacrificing protection.

In a follow-up study, Chomay et al. (1982) investigated the effect of experimental alterations in skate weight on performance in the repeat sprint skate test. Subjects ($n = 11$) performed the repeat sprint skate test under 3 conditions: (a) with normal skate weight; (b) 227g of weight added to each skate; and (c) 555g of weight added to each skate. During the added skate weight conditions, there was a significant ($p < 0.05$) increase in performance time resulting in slower performance on both the speed and anaerobic endurance components of the hockey fitness test. When purchasing skates, players should use skate mass as an important selection criterion.

Table II. Repeat sprint skate test results for 4 conditions

Hockey test components	Normal body mass	Added mass		
		5%	10%	15%
Speed index (sec)	7.96	8.22	8.37	8.76
Anaerobic endurance (sec)	95.5	99.0	99.1	103.3
Drop-off (sec)	2.24	2.73	2.86	2.88
3-min recovery HR (beats/min)	50.5	52.6	51.5	53.3
5-min recovery HR (beats/min)	64.4	65.1	65.8	66.9

The effect of equipment weight on aerobic skating performance is evident from the results of Leger et al. (1979). Ten hockey players performed a 20m shuttle skating test to determine $\dot{V}O_{2max}$. While $\dot{V}O_{2max}$ was similar, with and without equipment, test duration was reduced from 6.4 to 5.1 minutes (20%). Final skating speed decreased by 7 m/min (2.9%). For a particular speed, the mechanical efficiency ratios indicated a 4.8% additional energy cost of skating with hockey equipment (7.3 kg).

4. Energetics of Skating

Ferguson et al. (1969) developed test procedures for measuring $\dot{V}O_{2max}$ while skating around a 140m oval course. Workloads consisted of skating 3 minutes at increasing velocities. Velocities of 350, 382, 401, 421 and 443 m/min were selected since they corresponded to 24, 22, 21, 20 and 19 seconds per lap. The velocities were chosen to increase the oxygen consumption by 300 ml/min. Test-retest correlation on 17 hockey players was 0.94 with values of 54.7 and 55.3 ml/kg/min obtained on test 1 and 2, respectively. The relationship between skating velocity (m/min) and $\dot{V}O_2$ (ml/kg/min) was linear between 350 and 443 m/min.

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

Efficiency = $\frac{\text{Velocity (m/min)}}{\dot{V}O_2 \text{ (ml/kg/min)}} \times 100$

The interindividual variability in $\dot{V}O_2$ ($\pm 15\%$) found during ice skating is considerably larger than the 5 to 7% difference between trained and untrained runners. Even though all of the subjects were trained skaters, considerable differences must have existed in the skill of skating. At a velocity of 382 m/min, the mean $\dot{V}O_2$ was 46.7 ml/kg/min (range, 40.1 to 54.7) [Ferguson et al. 1969]. Green (1979) has also observed a substantial interindividual difference in skating efficiency.

5. Energy Expenditure During a Game

Researchers have examined various methods of assessing the energy expenditure and/or exercise intensity during a hockey game.

5.1 Oxygen Uptake in a Model Game

Using existing equipment, it is not possible to measure oxygen consumption during an actual game for players would risk being body-checked while the gas collection apparatus was in place. As such, it is necessary to simulate a 'model' training game (Seliger et al. 1972). Players (n = 13) of the Czechoslovakian national team were studied during 1 shift averaging 1.17 minutes followed by 21 minutes of recovery. Energy expenditure was measured by indirect calorimetry and corrected for basal metabolic rate. Based on oxygen consumption during this one shift and the prolonged recovery period, 69% of the oxygen consumption was in the recovery period. Oxygen consumption during the shift averaged 32 ml/kg/min or 66% of $\dot{V}O_{2max}$ during the model game. Seliger et al. (1972) char-

acterised ice hockey as 'an activity showing mostly a submaximal metabolic rate with a great participation of anaerobic metabolism (69%), but simultaneously with high requirements for aerobic metabolism (31%).' These percentages are frequently quoted by other hockey investigators. During simulated play, the on-ice heart rate averaged only 152 beats/min, while pulmonary ventilation was 92 L/min. Based on other methods to estimate aerobic intensity, it appears that Seliger's protocol to simulate a model game underestimated aerobic intensity, or the on-ice gas collection apparatus may have restricted the player's movements. Green et al. (1976) estimated the on-ice energy requirements at 70 to 80% of $\dot{V}O_{2\max}$ in university players, while Paterson et al. (1977) estimated on-ice aerobic involvement in excess of 80% of $\dot{V}O_{2\max}$ in young boys.

5.2 Time-Motion Analysis

Seliger et al. (1972) estimated that players from the Czechoslovakian national team ($n = 13$) averaged 5160m (range, 4860 to 5620m) during a game. This paper cites a reference to Yokobori (1964) which states that top-performance players skate 6400 to 7200m per game.

Green et al. (1976) employed both heart rate telemetry and time-motion analysis to examine energy expenditure of university players. During 24 minutes of actual playing time, the players skated 5553m. From heart rate telemetry, energy expenditure was estimated at 70 to 80% of $\dot{V}O_{2\max}$. Using the oxygen cost-skating velocity relationship outlined by Ferguson et al. (1969), skating velocities between 50 and 400 m/min would be expected during game play. However, the university players averaged only 227 m/min. The authors concluded that even though skating velocity represents a major component of work intensity, its singular use would underestimate energy expenditure. Changing acceleration, frequent turning, shooting and checking are activities that add to exercise intensity but are not evident from velocity analysis.

In a study of 3 junior and 1 professional games, Thoden and Jette (1975) observed that hockey

players averaged 5 to 6 shifts of 70 to 80 seconds per period with 3 to 4 minutes of recovery on the bench between shifts. Within a shift, there were 5 to 7 bursts ranging in duration from 2.0 to 3.5 seconds. Total burst time per game averaged 4 to 6 minutes with players on the ice for 15 to 21 minutes per game. Forwards displayed more anaerobic activity than defensemen.

Based on their observations from time-motion analysis, Thoden and Jette (1975) recommended criteria to structure a test to evaluate the physical capacity to play hockey. These criteria are represented in the repeat sprint skate test designed by Reed et al. (1979a). Recommendations for the hockey fitness test were:

1. Maximal performances of the anaerobic type
2. Long enough to tax the anaerobic mechanism
3. Repeated efforts for as many bursts as a shift will involve
4. Assess physical capacity on the basis of one's ability to perform the final repeats at the same level of performance as the initial trial.

Green et al. (1978a) compared the performance of varsity forwards ($n = 5$) and defensemen ($n = 3$) using time-motion analysis. In general, the defensemen had a longer playing time (+33%), a greater number of shifts (+17%) and a longer playing time per shift (+21%) with less recovery time between shifts (-35%). Similar values were reported in another study by Green et al. (1976). Defensemen averaged only 61.6% of the skating velocity of forwards (Green et al. 1976).

Leger (1980) summarises data from time-motion analysis of 80 junior and 170 midget players. For junior players, the forwards and defensemen had similar (88.5 *versus* 84.9 seconds, respectively) playing time per shift. Since the defensemen spent less time on the bench between shifts, the ratio of bench time/on-ice time was higher for the forwards (2.3 ratio) than the defensemen (2.1 ratio).

Montgomery and Vartzbedian (1979) have described the characteristics of Old Timer hockey games. Compared with junior elite, college and professional players, the adult recreational players tend to stay on the ice much longer per shift. The

average shift time (excluding play stoppage) for the Old Timers was 139.1 seconds. The ratio between bench time and playing time was lower for the recreational players than junior, university and professional players because there are fewer players per team. The recreational teams tend to play with only enough players to form 2 forward lines whereas junior, college and professional teams utilise 3 or 4 forward lines. The Old Timer hockey players averaged 19 minutes of playing time during the 65 minutes of hockey. Paterson et al. (1977) reported that young ice hockey players also averaged 19 minutes of playing time in their games.

Data from time-motion studies of minor league, midget, junior, university and Old Timer play are summarised in table III. Such variables as bench/on-ice ratio and playing time per shift are a function of the level of play and the number of players per team.

If time-motion analysis of game play were studied today, different characteristics would probably be seen. Most elite teams now utilise 4 units with a playing time of about 40 seconds per shift. Skating velocity is higher with teams converting to a ‘flow’ system of movement which places greater emphasis on speed.

5.3 Heart Rate Telemetry

Heart rate has been used to estimate the aerobic demand of playing hockey. Using a linear relationship between heart rate and $\dot{V}O_2$, players are first assessed in the laboratory, where oxygen uptake can be measured then monitored during a hockey game. Wilson and Hedberg (1976) have shown that heart rate on the ice is slightly higher than heart rate obtained while running on the treadmill when oxygen demand is the same in both cases. However, when both heart rate and oxygen uptake are expressed as a percentage of maximum potential range, then there is very little difference between heart rate on the ice and heart rate on the treadmill.

Average on-ice intensity is estimated at 70 to 80% $\dot{V}O_{2max}$ (Paterson 1979). During a 60-minute stop-time game (2.25 hours), oxygen uptake exceeds 90% of $\dot{V}O_{2max}$ for approximately 30 min-

Table III. Time-motion analysis (mean ± SE) of game play

Time period	Players						
	5 university (forwards) ^a	3 university (defensemen) ^a	10 university ^b	80 junior ^c	170 midget ^c	12 Old Timer ^d	89 minor league ^e
Bench time between shifts (sec)	293 ± 16	189 ± 18	225 ± 25	329	147.5	276.3 ± 14.0	228
Ice time/shift (sec)				146.3	91.2	233.1	160
Bench/on-ice ratio	2.52	1.24	2.66	2.25	1.61	1.20	1.43
Playing time/game (sec)	1152 ± 54	1723 ± 97	1471 ± 84	1884	1032	1134	828
Shifts	20.2 ± 0.6	24.3 ± 0.7	17.4 ± 1.0	12.8	11.3	7.8 ± 0.6	9.0
Playing time/shift (sec)	57.9 ± 2.5	73.1 ± 4.7	85.4 ± 3.1	86.9		139.1 ± 10.5	94.9
Total stoppage time/shift (sec)	58.2	79.3	62.3	59.4		75.3 ± 8.8	
Play stops/shift (sec)	2.0 ± 0.1	2.6 ± 0.2	2.3 ± 1.0			3.5 ± 0.3	2.3
Time/play stoppage (sec)	29.1 ± 3.3	30.5 ± 4.1	27.1 ± 1.4			21.5	
Playing time between stoppage (sec)	29.5 ± 0.8	28.5 ± 0.3	39.7 ± 2.6			20.6 ± 1.3	41.9

a Data from Green et al. (1978a).
b Data from Green et al. (1976).
c Data from Leger (1980).
d Data from Montgomery & Vartzbedian (1979).
e Data from Paterson (1979).

utes. Heart rate telemetry, like other techniques that are used to assess aerobic demand of ice hockey, has limitations that should be recognised when interpreting the results. In hockey, heart rate may be influenced by conditions that do not elevate oxygen cost, such as: (a) the emotional nature of the game; (b) upper body static contractions; (c) intermittent nature of play; and (d) elevation of core temperature since hockey equipment may limit heat dissipation.

Table IV summarises the results of a number of studies using players from minor leagues, recreational ‘Old Timer’ players, and elite players. From these studies, it is clear that hockey represents an intense activity with peak heart rates in excess of 90% of maximum and average on-ice values about 85% of maximum

Many adults participate in non-contact, recreational hockey leagues. Their motives for playing hockey are usually associated with fun and the improvement and/or maintenance of physical fitness (Proulx & Soucie 1978). The effectiveness of such participation for cardiovascular fitness depends on

the frequency, duration and intensity of the activity.

Montgomery (1979) used both telemetry monitoring and time-motion analysis to assess the intensity and duration of play that characterises adult non-contact hockey. During the typical Old Timer game, players are on the ice for 27 minutes with the heart rate in excess of 70% intensity. Results from monitoring 12 forwards are shown in figure 1. The ratio of bench time to on-ice time is low (1.20) for this group compared with elite hockey players.

The heart rates of goaltenders (n = 9) have also been monitored during adult recreational games (Montgomery 1979). Average heart rate was 143 beats/min or 64% intensity.

5.4 Muscle Glycogen Depletion

Several laboratories have used the muscle biopsy technique to examine the demands that are placed on the muscle’s fuel storage. During high intensity intermittent exercise carbohydrate utilis-

Table IV. Summary of heart rate telemetry studies

Subjects	n	On-ice heart rates (beats/min)				Bench heart rates (beats/min)		Reference
		mean	% max	peak	% max	mean	% max	
Competitive (10 years)	14	182.4	92.3	190.7	96.5	135.3	68.4	Paterson et al. (1977)
Recreational (10 years)	14	187.7	94.7	198.1	99.9	141.0	71.1	Paterson et al. (1977)
Forwards (Old Timers)	12	160.8	84.6	173.0	94.4	126.3	56.9	Montgomery & Vartzbedian (1979)
Goaltenders (Old Timers)	9	143	64					Montgomery (1979)
Czechoslovakian Junior team	15	177						Seliger (1968)
Czechoslovakian National team	13	152 ^a	72.5					Seliger et al. (1972)
Anders Hedberg (3 international games)	1	178.3	78.3	191.6				Wilson & Hedberg (1976)
Competitive (10.7 years)	19	181		189		136		Paterson (1979)
Competitive (12.2 years)	28	187		198		148		
Competitive (14.4 years)	22	194		204		153		

a ‘Model game’.

ation is important. Muscle glycogen depletion has been associated with a decrease in physical performance. Because the vastus lateralis is active during intense intermittent skating, it is selected as the muscle for biopsy examinations. Muscle glycogen concentration (mmol/kg wet tissue) was 89.3 ± 13.6 for forwards ($n = 5$) and 85.0 ± 3.7 ($n = 3$) for defensemen prior to a hockey game (Green et al. 1978a). Muscle glycogen declined an average of 60% for both forwards and defensemen. Glycogen was utilised from type I, IIa, and IIb fibres with the greatest depletion from the type I fibres. Since a large amount of glycogen still remained in the type II fibres, it does not appear that glycogen depletion is the cause of fatigue.

The intermittent nature of hockey play and the

maintenance of low lactate levels are important factors in utilising plasma free fatty acids as an energy source. During a hockey game, there is a 2-fold increase in plasma free fatty acid levels, which provides a glycogen-sparing effect in the exercising muscles (Green et al. 1978a).

Green (1978) has also studied the glycogen depletion patterns from the vastus lateralis muscle during continuous and intermittent ice skating. Eight subjects performed intermittent skating consisting of 10 bouts of high intensity work corresponding to 120% of $\dot{V}O_{2max}$. Each bout consisted of 1 minute of skating followed by a 5-minute recovery period. This schedule was selected to represent the most extreme example of play during the actual hockey game. The continuous skating was

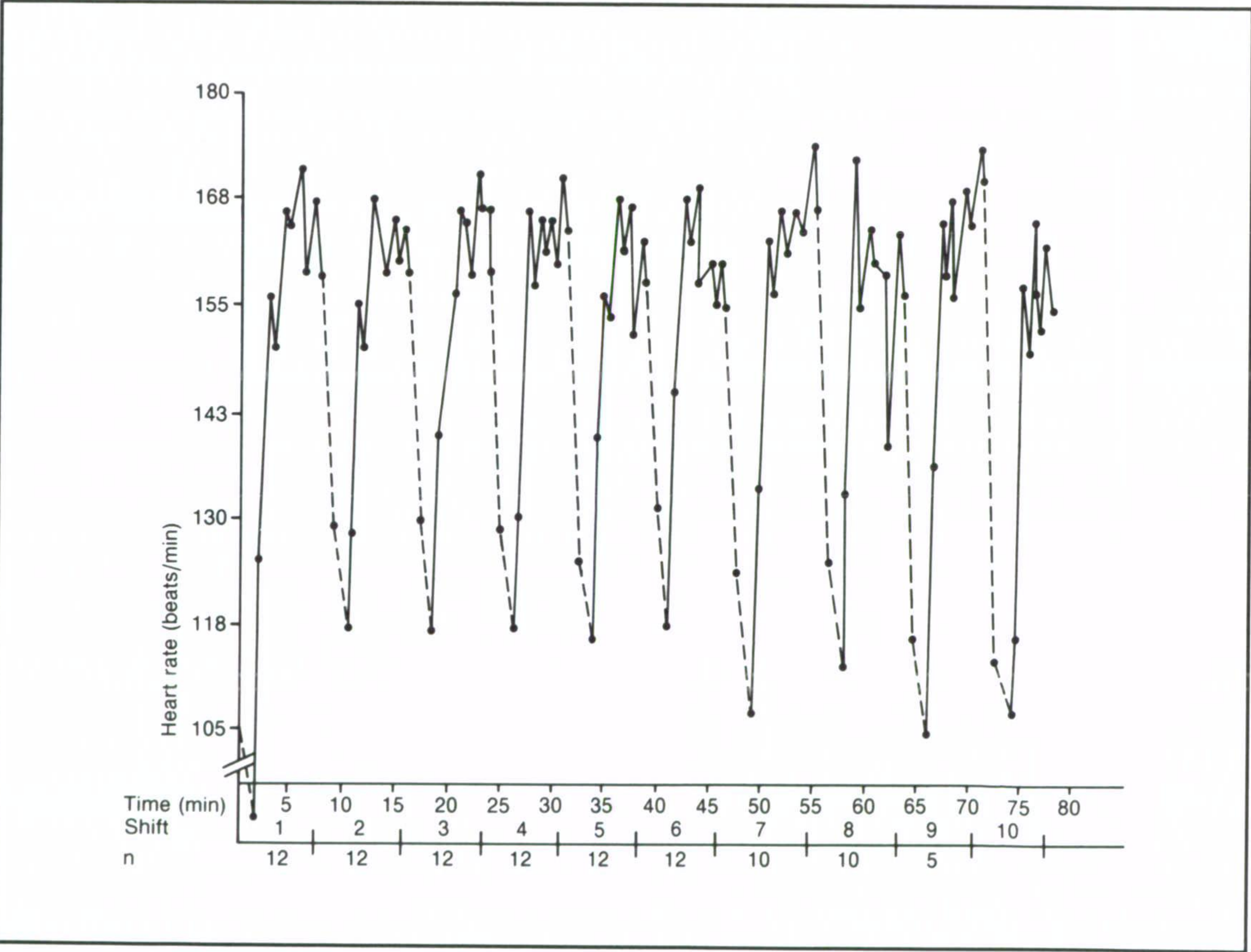


Fig. 1. Telemetry monitoring of heart rate ($n = 12$ forwards).

performed at 55% of $\dot{V}O_{2\max}$ for 60 minutes. Muscle biopsies were taken at the start of each skate and after 30 minutes (5 work bouts) and 60 minutes (10 work bouts).

During continuous skating, glycogen showed a 29% decline over the 60 minutes with a more pronounced glycogen loss from the type I fibres. During the intermittent condition, there was a 2-fold increase in depletion of muscle glycogen (70%) with a preferential loss from the type II fibres, particularly the type IIb fibres. Muscle lactate was 2.7 mmol/L after 60 minutes of continuous skating and 26.4 mmol/L after the intermittent high intensity skating. Either a high concentration of lactate or an excessive reduction of glycogen in type II fibres could reduce the muscle's potential to sustain work output (Tesch et al. 1978). Following intense efforts, recovery of the muscle to normal homeostatic conditions is a relatively slow process. The half-life for removal of lactate is estimated at 9.5 minutes (Sahlin et al. 1976).

Muscle biopsy studies using players from the Finnish national team (Luetsolo 1976) have demonstrated that the hockey player can have a high muscle glycogen concentration before the game. During 2 matches against the USSR team, muscle glycogen concentration was lowered from 53 to 33 g/kg of wet muscle tissue in game 1 and from 50 to 6 g/kg in game 2. During 2 matches against the USA team, pre- to postgame values were 46 to 20 g/kg in game 1 and 18 to 12 g/kg in game 2. In the game against the USA when the pregame muscle glycogen level was 18 g/kg, blood lactate and glucose values were lowest.

Glycogen depletion from the vastus lateralis has been examined in a game-simulated task (Montpetit et al. 1979). Pre- to post-task comparisons ($n = 8$, university players) were 1.98 to 0.88 g/100g of wet muscle tissue, respectively. There was a preferential glycogen utilisation by the slow twitch fibres but also significant depletion from the fast twitch fibres. Wilson and Hedberg (1976) reported that slow twitch fibres are depleted of glycogen by about 80% after a hockey match in comparison with pregame levels. The fast twitch fibres' supply of glycogen had not been challenged.

Many hockey leagues schedule games on consecutive days. Since there is a significant utilisation of muscle glycogen stores during a hockey game, this substrate may be reduced to the point where performance is impaired. To investigate this possibility, 3 hockey games, separated by 15 hours, were studied (Green et al. 1978b). Blood samples taken from 14 players prior to the games and after each period were analysed for glucose and lactate. Lactate averaged 4.9 and 4.7 mmol/L during games 1 and 2, respectively. The goaltender showed little elevation in blood lactate. During game 1, blood glucose at the end of each period was elevated above the resting value. During game 2, lower values were evident after each period. There was a progressive decline in blood glucose with the final value (90 ± 17.4 mg/dl) lower than the pregame value. Between positions, the forwards had lower values throughout game 2. The authors speculated that the depressed glucose levels in game 2 may have reflected elevated levels of plasma insulin causing increased uptake by the exercising muscles, or may have been due to reduced releases of hepatic glucose. The back-to-back games may have reduced both liver and muscle glycogen levels. Muscle biopsies from 2 players indicated that glycogen (56 mmol/kg) had not been repleted prior to game 2. The *ad libitum* diet of the 2 players between games contributed to the low glycogen level.

5.5 Lactate Accumulation

There is a large energy contribution from anaerobic glycolysis during a hockey game. Venous blood samples taken at the end of each period of play have been used as an indicator of the intensity of play. Green et al. (1976) found that values of blood lactate in Canadian university players were highest during the first and second periods (mean = 8.7 and 7.3 mmol/L, respectively) then declined during the third period (mean = 4.9 mmol/L). The forwards and defensemen had similar values despite markedly different skating velocities. The additional number of shifts played by the defensemen and the shorter recovery time between shifts probably accounted for the similar values. The goalten-

der had only a small elevation in lactate from the pregame value.

In a subsequent study, Green et al. (1978a) found lower lactate values which were attributed to shorter shift durations. Blood lactate values averaged 5.5 mmol/L for the forwards and 2.9 mmol/L for the defensemen. Although data are limited, it appears that European hockey is characterised by higher levels (9 to 11 mmol/L) of blood lactate (Wilson & Hedberg 1976). Both blood lactate concentration and heart rate vary according to the calibre of the opposing team (Forsberg et al. 1974).

Absolute values of lactate concentration of minor hockey players are lower than adult values. When the lactate values are expressed as a percentage of maximal concentration following a treadmill $\dot{V}O_{2\max}$ test, the lactate values of minor hockey players are similar to values reported for adult players (Paterson et al. 1977).

One explanation for the relatively low lactate values seen during a hockey game is that within a shift there are typically 2 to 3 play stoppages. Continuous play averages about 30 seconds (table III). This pause provides sufficient time for 60 to 65% of the phosphocreatine to be resynthesised and available for the next phase of the shift (Green 1979). Time-motion analysis reveals many changes in tempo. A typical shift is interspersed with short bursts of high intensity skating followed by longer periods of coasting. During a typical shift there is ample opportunity for substantial anaerobic glycolysis. Elite players have probably learned to optimise the high intensity bursts. Since hockey demands precise coordination of many muscle groups, excessive increases in lactate would interfere with the execution of hockey skills.

Ice hockey is not simply a lower limb activity. Upper body activity adds to the total energy expenditure. Battling for the puck in the corners, attempting to maintain position in the front of the net, shooting, and occasionally fighting are upper body activities that can elevate lactate in the exercising arms as well as alter blood flow to the legs. Green et al. (1979a) have shown that 4 bouts (60 seconds' duration) of intermittent exercise can elevate leg muscle lactate, decrease phosphocreatine,

and result in increased utilisation of muscle glycogen. This study implies that if a hockey shift involves excessive upper body activity combined with maximal skating activity, there may be a deterioration in performance in subsequent shifts.

Following high intensity skating that elevated blood lactate, bench-stepping during recovery was shown to enhance lactate removal over resting recovery. Skating during the recovery period was not significantly different from bench-stepping (Watson & Hanley 1986).

5.6 Implications for Shift Length

The study of hockey intensity has some implications regarding shift length. There are several physiological reasons why the coach should employ short shifts. First, the heart rate drops by an average of only 10 beats/min during on-ice play stoppage. Second, the overall intensity of play is very high during a shift on the ice. Third, short shifts reduce lactate buildup in the muscle by allowing time for restoring the ATP-CP stores.

Long shifts of high intensity result in accumulation of lactate in the muscle. Lactate removal is slow. If sufficient lactate is produced, the increase in muscle acidity causes metabolic and contractile disturbances that result in decreased work performance (Green 1979). High intensity, intermittent work (10 bouts of 60-second duration) also causes a rapid reduction in muscle glycogen particularly from fast twitch fibres (Thomson et al. 1979).

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

6. Muscle Fibre Type

It is well established that athletes who specialise in sprint type events have a predominance of fast twitch fibres in their leg muscles, while athletes involved in endurance type events display a predominance of slow twitch fibres. The requirements of ice hockey are a compromise between the 2 extremes. Since the game involves both high intensity skating at maximal velocity and requires distribution of energy over a time frame of 2 to 2.5 hours, it is not surprising to find a wide range of fibre composition among elite players. Within a group of 25 junior, university and professional players, slow twitch fibre composition of the vastus lateralis ranged from 20 to 71% (Green et al. 1979b).

Hockey players display a muscle fibre profile similar to the average untrained individual. Muscle biopsies from the vastus lateralis of 48 Canadian hockey players revealed no differences in the type I fibre distribution of university ($47.8 \pm 2.5\%$), junior ($50.2 \pm 2.9\%$) and professional ($50.1 \pm 3.2\%$) players (Green et al. 1977). There was no difference in the percentage of type I fibres between positions (goalkeepers, 47.4%; defensemen, 51.7%; and forwards, 48.1%).

European hockey players may have a higher percentage of slow twitch muscle fibres than Canadian players. The Finnish national team ($n = 13$) had $61 \pm 12\%$ slow twitch muscle fibres in the vastus lateralis (Rusko et al. 1978).

Muscle fibre composition has been examined at the start and end of a hockey season. Muscle biopsies from the vastus lateralis of elite hockey players revealed pre- and postseason values of 49.6% and 50.8% slow twitch fibres. In the fast twitch fibre subgroups, there was an increase (38.0 to 45.2) in the percentage of fast twitch a fibres and a decrease (12.2 to 3.9) in fast twitch b fibres from pre- to postseason (Green et al. 1979b). Prolonged endurance activity has been known to decrease the proportion of fast twitch b fibres and increase the proportion of fast twitch a fibres. This study also shows that hockey training can also bring about interconversions in the fast twitch metabolic profile.

Hockey training also causes a significant in-

crease in the size of the fast twitch a (22%) and fast twitch b (28%) fibres. There was no change in the area of the slow twitch fibres (Green et al. 1979b). The authors acknowledge in this cross-sectional study that differences between groups may have accounted for some of the changes and not necessarily hockey training.

7. Anaerobic Power and Endurance

Anaerobic power and endurance are important attributes for a hockey player. Tests that have been administered to assess anaerobic capabilities of hockey players include the Margaria stair running test (Green & Houston 1975; Vainikka et al. 1982), treadmill run to exhaustion with speed at 8.0 mph (12.8 km/h) and grade at 20% (Green et al. 1972; Houston & Green 1976), repeat 60-second all-out efforts on a cycle ergometer (Vainikka et al. 1982), Wingate 30-second supramaximal test (Montgomery & Dallaire 1986; Smith et al. 1982) and an intermittent cycle ergometer test (Gamble & Montgomery 1986).

Table V is a summary of anaerobic test results using the cycle ergometer. When the peak power and anaerobic endurance values are expressed relative to bodyweight, forwards and defensemen have similar scores. Because defensemen are heavier than forwards, their absolute scores on the cycle ergometer test are higher. Supramaximal tests on a cycle ergometer have been used to determine anaerobic power and anaerobic endurance of ice hockey players. When a single test is measured it is often unclear as to whether peak values have been elicited. Smith (1978) has demonstrated the importance of optimal load selection to maximise power output during an anaerobic test. It is probable that some of the differences seen in the anaerobic test results (table V) are due to load selection. The values for the Montreal Canadiens team appear low; however, the resistance setting was equivalent to 0.070 kp/kg bodyweight. Higher resistance has been recommended for achievement of peak and mean power outputs (Evans & Quinney 1981; LaVoie et al. 1984; Smith 1987). The mean anaerobic endurance score for the data from Watson and Sargeant

Table V. Anaerobic results (mean $\pm$ SD) of elite hockey teams

Reference	Group	n	Peak power (W/kg)	30-second anaerobic endurance (W/kg)
Smith et al. (1982)	Canadian Olympic forwards 1980	15	11.7 $\pm$ 1.0	9.6 $\pm$ 0.6
	Canadian Olympic defense 1980	6	11.5 $\pm$ 0.4	9.6 $\pm$ 0.9
Rhodes et al. (1986)	NHL defense	27	12.0 $\pm$ 1.5	9.5 $\pm$ 1.0
	NHL forwards	40	12.0 $\pm$ 1.2	9.1 $\pm$ 5.5
	NHL goaltenders	8	11.4 $\pm$ 1.1	8.6 $\pm$ 5.2
Montgomery & Dallaire (1986)	Montreal Canadiens – defensemen	12	9.8 $\pm$ 1.1	8.2 $\pm$ 0.3
	Montreal Canadiens – forwards	6	10.3 $\pm$ 0.4	8.7 $\pm$ 0.7
	Montreal Canadiens – goaltenders	3	10.6 $\pm$ 1.0	8.3 $\pm$ 0.1
	Montreal Canadiens 1981-82	27	9.9 $\pm$ 0.7	8.3 $\pm$ 0.3
	Montreal Canadiens 1982-83	30	10.4 $\pm$ 1.1	8.7 $\pm$ 0.8
Watson & Sargeant (1986)	University and junior	24	10.1 $\pm$ 1.0	7.7 $\pm$ 1.0
Gamble (1986)	University	17	11.5 $\pm$ 0.6	9.2 $\pm$ 0.5
Brayne (1985)	University	17	11.5 $\pm$ 0.8	9.0 $\pm$ 0.7

(1986) is lower because the test duration was 40 seconds compared with 30 seconds for the other tests.

An ice hockey shift is an intermittent activity that demands periodic bursts of maximal effort. The Wingate test is a single effort of 30 seconds' duration. Gamble and Montgomery (1986) developed an intermittent cycle ergometer test that is a measure of the anaerobic endurance of ice hockey players. The test consists of six 15-second repetitions with an exercise to recovery ratio of 1:1. Cycle test results have been compared with on-ice maximal skating performance using the repeat sprint skate test. Correlation coefficients of $r = -0.87$ for peak power/kg on the laboratory test and speed index on the repeat sprint skate test, and $r = -0.78$ for total power/kg on the lab test and total time on the ice test provided support to the establishment of validity. The test discriminated between varsity, junior varsity and non-varsity players. (The varsity team consists of the best players in the university, while the junior varsity team is the 'second' team. Non-varsity players were physical education students.)

Members ($n = 27$) of the Finnish National team (1978) have been subjected to two 60-second all-out efforts on a cycle ergometer. The tests were separated by a 3-minute recovery period. Power output was 383 and 326 J/kg on the first and sec-

ond tests, respectively. Defensemen had the highest mean value with the goaltenders having the lowest mean power output. The blood lactate concentration increased significantly from 13.8 to 17.6 mmol/L. These values reflect a good anaerobic lactate capacity in elite hockey players.

Using a treadmill test, Green and Houston (1975) found similar maximal lactate values for forwards and defensemen playing junior hockey (elite players between 16 and 20 years of age). A pre- to postseason comparison revealed an improvement in run time from 64.3 to 74.8 seconds. Maximal blood lactate concentration increased from 11.9 to 13.3 mmol/L. In another paper, Houston and Green (1976) reported treadmill run times of university and junior players. Despite the greater duration of the junior season, both teams were similar in the values that were obtained for blood lactate and anaerobic run time.

8. Aerobic Endurance

The physiological demands imposed during a hockey game are not confined to the anaerobic systems. Improving aerobic capacity reduces fatigue and improves player performance. In the 1970s professional players traditionally used the month of September to play themselves 'into shape' (Duda

1985). It is now expected that professional players come to training camp in good aerobic condition.

The aerobic endurance of hockey players has frequently been assessed on both a treadmill and a cycle ergometer. The few studies that have measured skating $\dot{V}O_{2\max}$ have used university hockey players (table VI). On the cycle ergometer, team means range from 52 to 58 ml/kg/min with one exception. On the treadmill, the means range from 54 to 62 ml/kg/min. Treadmill testing usually gives values that are 10% higher than the cycle ergometer.

It appears that the heavier the mean weight of the hockey team, the lower the mean $\dot{V}O_{2\max}$ (ml/kg/min). Within a team, positional comparisons support this trend. Defensemen are usually taller and heavier than forwards, so it is not surprising that the defensemen have lower $\dot{V}O_{2\max}$ (ml/kg/min) values (Green & Houston 1975; Houston & Green 1976; Montgomery & Dallaire 1986; Rhodes et al. 1986; Smith et al. 1982).

Canadian hockey players appear to have the same $\dot{V}O_{2\max}$ when tested on the ice and on the treadmill (Lariviere 1972; Leger et al. 1979; Simard 1975), although Scandinavian research (Wilson & Hedberg 1976) found a lower $\dot{V}O_{2\max}$ when skating.

The functional capacity of the cardiovascular system of young hockey players (age 10 years) is similar to elite adult players. A $\dot{V}O_{2\max}$ of 56.6 ml/kg/min has been reported for boys involved in a competitive league (Cunningham et al. 1976).

A correlation of 0.60 between a 12-minute skate test and $\dot{V}O_{2\max}$ was as high as the correlation between a 12-minute run test and $\dot{V}O_{2\max}$ for a team of Bantam All-Stars (Hockey & Howes 1979). The somewhat low correlation can be partially explained by the homogeneity of the group. Similar heart rates were obtained on the 12-minute skate test and run test. This group averaged 355 m/min during the skating test.

9. Specificity of On-Ice Versus Laboratory Tests

In the physiological evaluation of athletes, it is imperative that the testing protocol be specific to the demands of the sport. The cycle ergometer is

frequently used to evaluate the aerobic and anaerobic capabilities of hockey players in the laboratory setting. Some research has indicated that the glycogen depletion patterns and muscles used in cycling are similar to those used in skating (Geijsel 1979, 1980; Green et al. 1978a). Several studies (Brayne 1985; Daub et al. 1983; Leger et al. 1979; Watson & Sargeant 1986) have examined the specificity of on-ice testing *versus* laboratory testing of hockey players. Daub et al. (1983) examined the specificity of the metabolic and cardiorespiratory responses to training programmes and to varied testing modalities and protocols. Training-induced adaptations were determined during submaximal and maximal conditions while skating and cycling. Ice hockey training caused no change in $\dot{V}O_{2\max}$, $HR_{\max}$ or $\dot{V}_{E\max}$ during the maximal skating test. Hockey training reduced blood lactate, $\dot{V}_E/\dot{V}O_2$, and R during the submaximal skating test; however, these changes were not evident during maximal and submaximal cycling.

Another group of hockey players supplemented their training with 3 sessions per week of continuous cycling at 70% of $\dot{V}O_{2\max}$. Initial duration was 30 minutes and progressed to 45 minutes. Hockey practices or games averaged 6 days per week over the 14-week season. The hockey and cycling programmes resulted in adaptations similar to those observed during submaximal ice skating following hockey training. There was also a significant decrease in heart rate during the submaximal cycling test. The conclusions were that the adaptive response to training was specific to the type of work used in training and the type of ergometer used to evaluate training.

In an investigation of the specificity of the $\dot{V}O_{2\max}$ response, runners and hockey players were tested on ice and on the treadmill (Leger et al. 1979). Hockey players had the same $\dot{V}O_{2\max}$ and lactate when tested on the treadmill, while skating a continuous 140m oval course; and skating a 20m shuttle course with or without equipment. Compared with the runners, the hockey players required 15% less energy to skate at a given velocity. However, the hockey players required 7% more energy to run on the treadmill.

Table VI. Maximum oxygen uptake of elite teams

Group	n	Weight (kg)	$\dot{V}O_{2max}$ (ml/kg/min)	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	75.6	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	8	77.4	61.3	Green et al. (1978a)
University	19	77.6	58.9	Green et al. (1979b)
Junior	9	78.7	59.1	Green et al. (1979b)
Swedish national 1971	24	78.1	56.3	Wilson & Hedberg (1976)
Junior	44	78.2	55.4	Houston & Green (1976)
University	11	79.5	56.4	Montgomery (1982)
Swedish national 1966	24	80.0	53.6	Wilson & Hedberg (1976)
University	9	80.9	56.3	Hutchinson et al. (1979)
Professional	12	83.4	55.3	Green et al. (1979b)
Montreal Canadiens 1981-82	27	85.9	55.6	Montgomery & Dallaire (1986)
Professional		86.4	53.6	Wilmore (1979)
NHL forwards 1985-86	27	87.1	57.4	Rhodes et al. (1986)
NHL defense 1985-86	40	90.3	54.8	Rhodes et al. (1986)
NHL goalies 1985-86	8	79.2	49.1	Rhodes et al. (1986)
Cycle ergometer				
Quebec Nordiques 1972-73	12	75.9	54.1	Bouchard et al. (1974)
University	15	76.9	54.5	Thoden & Jette (1975)
Junior	24	77.0	58.4	Bouchard et al. (1974)
University	9	77.1	53.2	Hermiston (1975)
University	18	78.1	55.2	Romet et al. (1978)
Canadian National	34	78.5	53.4	Coyne (1975)
Czechoslovakian National	13	79.1	54.6	Seliger et al. (1972)
University	5	79.5	54.3	Daub et al. (1983)
University	21	79.8	58.4	Krotee et al (1979)
Canadian National	23	81.1	54.0	Smith et al. (1982)
Finnish National	27	81.1	52.0	Vainikka et al. (1982)
Junior	9	82.4	52.6	Green et al. (1979b)
Professional	38	82.3	43.5	Romet et al. (1978)
Montreal Canadeins 1982-83	29	86.8	51.9	Montgomery & Dallaire (1986)
NHL Forwards 1985-86	27	87.1	53.3	Rhodes et al. (1986)
NHL Defense 1985-86	40	90.3	51.6	Rhodes et al. (1986)
NHL goaltenders 1985-86	8	79.2	44.1	Rhodes et al. (1986)
Skating				
University	10	72.8	62.1	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)

Leger et al. (1979) recommends a functional skating test or a performance test to establish a hockey player's aerobic skating ability. When the maximal skating speed data were analysed, there was a small coefficient of variation indicating a homogeneous group. In contrast, a large coefficient of variation resulted from skating $\dot{V}O_{2\max}$ data, revealing a wider distribution. The mechanical efficiency of skating contributes to these findings.

During the $\dot{V}O_{2\max}$ testing, both runners and hockey players had a 10 beats/min lower maximal heart rate on ice as compared with the treadmill run test of similar duration. The arena temperature (10°C) was cooler than the laboratory temperature (22°C). Since the test duration was relatively short (5 to 10 minutes), the subjects probably did not elevate the core temperature to an extent where it would compensate for the lower ambient temperature.

Brayne (1985) compared similar variables from the repeat sprint skate test and laboratory tests. His subjects were 31 varsity and junior varsity hockey players who were tested in the middle of the hockey season. Correlation coefficients between an 8-minute skating endurance test and $\dot{V}O_{2\max}$ (cycle ergometer) were non-significant for both varsity and junior varsity players. The only significant correlation was between on-ice speed index and the cycle ergometer anaerobic power output.

When evaluated using on-ice skating tests, elite hockey players appear as a homogeneous group in comparison with an evaluation using laboratory tests (Brayne 1985). Since skating ability is one criterion used to select a team, it may account for the low values for the coefficient of variation for the 3 skating test variables – speed (2.6%), anaerobic endurance (4.3%), and aerobic endurance (3.9%). The laboratory tests to measure similar qualities produced coefficients of variation that were 4 to 6 times greater than for the on-ice tests. Results from aerobic and anaerobic laboratory tests should be used with caution if the objective is to evaluate on-ice fitness of elite ice hockey players. On-ice performance tests are recommended as an essential part of the hockey player's physiological profile.

Watson and Sargeant (1986) also compared la-

boratory and on-ice tests of anaerobic power. University and junior players ($n = 24$) performed a 40-second Wingate test, and 2 on-ice tests (repeat sprint skate test and the Sargeant anaerobic skate test). Even though intertest correlations of anaerobic endurance were significant, the highest predictive capability estimate (r^2) was only 53%. It was concluded that the 40-second Wingate test does not demonstrate a high relationship with on-ice measures of anaerobic endurance and power.

10. On-Ice Evaluation

Ice skating performance tests measure both physiological endowment and skill (Shephard 1981). One popular test of aerobic endurance is the 8-minute skate (Montpetit et al. 1971). An oval course (140m) is set with the players instructed to skate as far as possible in 8 minutes. Norms have been published for minor league hockey players (Lariviere 1974; Lariviere & Godbout 1976). Average velocity for pee-wee, bantam, midget and junior level players is reported to be 295 ± 24 , 316 ± 31 , 341 ± 27 , and 375 ± 11 m/min, respectively (Dulac et al. 1978).

Reed et al. (1979a) have validated an on-ice test of hockey fitness. The repeat sprint skate test consists of 6 bursts of maximum velocity skating for 91.4m (300ft). Repeats are initiated every 30 seconds. The time to skate one length of the ice [180ft (54m)] is designated as the speed index. The total time for the 6 repetitions is the anaerobic endurance component. A drop-off index is calculated as the time difference between the slowest and fastest repetitions. Heart rates are measured immediately upon completion of the test, and at 3 and 5 minutes postexercise. Recovery is calculated as the difference between the exercise and postexercise heart rates. Some results for the test are shown in table VII. The test is widely used in Canada to evaluate on-ice fitness. A modified version (4 repetitions) of the repeat sprint skate test has been used with young hockey players (Adrian & Rhodes 1986; Rhodes et al. 1985).

Chouinard and Reardon (1984) have developed a skating agility test based on skating techniques

used during game situations by elite hockey players. To determine the influence of the aerobic and anaerobic energy system upon test results, blood lactate, exercise $\dot{V}O_2$ and recovery $\dot{V}O_2$ were measured. A low correlation was found between time and change in lactate levels ($r = -0.33$) as well as for time and the sum of exercise and recovery $\dot{V}O_2$ ($r = 0.26$). This skating agility test is reliable ($r = 0.99$) and has a low correlation to the aerobic and anaerobic energy system.

When a battery of hockey tests are administered to young hockey players, the more complex the skill aspect, the greater the difference between competitive and recreational players (MacNab 1979). Forward skating speed is a less discriminative test in comparison with puck control or agility tests.

11. Muscle Strength and Endurance

In a contact game like hockey, it is necessary for players to have both lower body and upper body strength and power. Many muscular endurance tests have been given to younger players, including measures of sit-ups, push-ups, pull-ups and dynamometry (Lariviere & Godbout 1976; MacNab 1979). Handgrip strength is frequently measured. Elite hockey players have high values compared with other athletic teams (Chovanova 1976). Table VIII summarises mean values from some elite teams. There appears to be a trend for professional

players to have higher handgrip strength than university or junior players.

Reed et al. (1979b) observed a trend towards greater right than left grip strength that was unrelated to shooting 'handedness'. Although 80% of the players (94 junior and 54 professional) were right-handed, not a single left mean strength score was greater than its right counterpart in the remaining 20% of the sample. All of the teams in table VIII show dominance of the right grip over the left grip.

Quinney et al. (1984) developed a test to measure abdominal muscular endurance of hockey players. Curl-ups are completed at a rate of 25 repetitions per minute for a maximum of 100 repetitions. Data from 117 professional hockey players revealed 49.7 ± 23.7 repetitions with scores ranging from 15 to 100. Only 11% of the players were able to achieve 100 repetitions (table IX).

Muscle strength appears to be one of the factors that discriminates between professional and amateur players in Canada. A comparison of professional ($n = 54$) and junior ($n = 94$) players on 11 strength measures revealed that the professional players were significantly stronger on 6 of the tests (Reed et al. 1979b). These tests involved shoulder and forearm strength. No significant differences were observed on handgrip, chest or leg strength measures.

Defensemen are significantly stronger than forwards for the bench press test (Montgomery & Dal-

Table VII. Repeat sprint skate test results (mean $\pm$ SD) for elite hockey teams

Group	Speed index (sec)	Anaerobic endurance (sec)	Drop-off (sec)	Reference
Canadian Olympic team				Smith et al. (1982)
forwards	7.0 $\pm$ 0.5		3.2 $\pm$ 0.8	
defense	7.3 $\pm$ 0.5		2.8 $\pm$ 0.7	
Professional & junior	7.4		2.9	Reed [cited by Smith et al. (1982)]
University & junior	7.6 $\pm$ 0.3	94.6	1.1	Watson & Sargeant (1986)
University - varsity	7.7 $\pm$ 0.2	93.3 $\pm$ 4.0	2.9 $\pm$ 1.0	Brayne (1985)
University - jr varsity	8.0 $\pm$ 0.2	95.8 $\pm$ 4.5	3.4 $\pm$ 1.3	
University & university	8.0 $\pm$ 0.3	95.5 $\pm$ 4.0	2.2 $\pm$ 0.9	Montgomery (1982)
University - varsity	7.3 $\pm$ 0.2	89.3 $\pm$ 2.7	2.6	Gamble (1986)
University - jr varsity	7.7 $\pm$ 0.3	93.5 $\pm$ 1.9	3.6	

Table VIII. Hand grip values (kg) in elite teams

Level	n	Right	Left	Reference
Czechoslovakian elite	11	60.8	54.9	Chovanova (1976)
Canadian Olympic team – 1980	23	66.4 ± 6.3	63.7 ± 5.8	Smith et al. (1982)
NHL defense 1985-86	27	68.4 ± 7.5	67.3 ± 7.3	Rhodes et al. (1986)
NHL forwards 1985-86	40	66.5 ± 8.0	65.5 ± 7.1	Rhodes et al. (1986)
NHL goaltenders 1985-86	8	56.6 ± 4.1	53.6 ± 3.8	Rhodes et al. (1986)
Edmonton 1980-81	20	62.5 ± 6.3	60.7 ± 6.7	Smith et al. (1981a)
University	17	55.0 ± 9.6	52.7 ± 11.5	Song & Reid (1979)
Professional	52	59.6 ± 7.1	56.6 ± 8.1	Gauthier et al. (1979)
Junior	87	57.7 ± 7.6	56.2 ± 8.1	Gauthier et al. (1979)
Midget (mean 16 years)	18	52.9	49.5	Lariviere et al. (1976)
Czechoslovakian elite 1970	55	60.8	54.9	Chovanova (1976)
University	18		64.5 ± 6.4	Romet et al. (1978)
Team Canada 1974	36		71.0 ± 8.2	Romet et al. (1978)
Montreal Canadiens 1981-82	27		66.6 ± 5.8	Montgomery & Dallaire (1986)
Montreal Canadiens 1982-83	30		67.6 ± 7.8	Montgomery & Dallaire (1986)

Table IX. Abdominal endurance (mean ± SD) of elite hockey teams

Level	n	Repetitions	Reference
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 ± 12.6	Rhodes et al. (1986)
NHL goalies	8	37.5 ± 13.3	Rhodes et al. (1986)
Montreal Canadiens 1981-82	27	54.2 ± 26.9 ^a	Montgomery & Dallaire (1986)
Montreal Canadiens 1982-83	30	70.8 ± 22.5 ^a	Montgomery & Dallaire (1986)

a Feet stabilised.

laire 1986). When the data were expressed relative to bodyweight, the scores were similar. Team average bench press score for the 1982-83 Montreal Canadiens team was 98.1 ± 18.3kg. The players pressed 13% more than their bodyweight.

Torque outputs during knee and hip flexion-extension movements are frequently assessed because these actions are involved in skating. Compared with other athletes (sprinters, jumpers, downhill skiers, race walkers, and orienteers), hockey players have good knee extension at slow speed (30°/sec) but lower values at higher speed (180°/sec). Smith et al. (1982) recommended greater emphasis be placed on developing power at high speed. The hip flexor muscles of hockey players are well developed compared with the other parts of

the body (Duda 1985). Hip flexor strength was related to skating ability among the New York Islander players. Among university players, leg strength was unrelated to skating speed (Song & Reid 1979).

Data analysis of flexion/extension ratio of the hip and knee joints at 30 and 180°/sec for the 1980 Canadian Olympic team and the 1980 Edmonton Oilers are shown in table X. A comparison with playing position revealed that the amateur team had higher extensor relative to flexor torques than the professional group (Smith et al. 1981a). This finding may have been related to the training programmes since more amateur players were participating in both resistance and speed training.

Elite Finnish hockey players obtained high scores

Table X. Maximal peak torque values (Nm/kg) for hip and knee joints of two elite teams (Smith et al. 1981)

Movement	Canadian Olympic team 1980	Edmonton Oilers 1980
Hip flexion 30°/sec	2.10 ± 0.08	2.09 ± 0.08
Hip extension 30°/sec	3.40 ± 0.13	3.23 ± 0.12
Ratio	0.63 ± 0.02	0.66 ± 0.02
Hip flexion 180°/sec	1.33 ± 0.06	1.40 ± 0.07
Hip extension 180°/sec	2.44 ± 0.08	2.44 ± 0.09
Ratio	0.56 ± 0.03	0.57 ± 0.02
Knee flexion 30°/sec	2.12 ± 0.06	2.05 ± 0.06
Knee extension 30°/sec	3.62 ± 0.09	3.12 ± 0.10
Ratio	0.59 ± 0.02	0.66 ± 0.02
Knee flexion 180°/sec	1.40 ± 0.04	1.42 ± 0.03
Knee extension 180°/sec	1.85 ± 0.05	1.64 ± 0.04
Ratio	0.76 ± 0.03	0.87 ± 0.02

for total and relative leg force in comparison with elite athletes from other sports. Among 11 teams, only the canoeists and power events had higher values (Komi et al. 1977).

Three studies have reported pre- and postseason strength scores of elite teams. If strength is neglected during the competitive season, then decrements in strength may occur. At the start and at the end of the 1978-79 hockey season, muscular strength tests were administered to players (n = 16) of an NHL hockey team. Daily hockey practices at the professional level were not adequate in maintaining muscular strength in all regions of the body (Cotton et al. 1979). Grip strength and leg thrust scores were similar at the pre- and postseason tests. Chest strength was significantly lower at the end of the hockey season. Hansen et al. (1979) administered 6 strength tests to 22 major junior A players at 4 time periods (June, September, December and March). Strength gains over the period June-September were attributed to an off-season strength programme. Gains made in the off-season were maintained during the initial part of the season with significant decreases occurring over the December-March period. The strength decrement was attributed to the lack of a specifically designed strength maintenance programme.

One report (Goldenberg & Ellett 1986) has examined the effect of an in-season strength maintenance programme. After the competitive season, 1 junior team was placed on a strength development programme. Prior to training camp, the team was tested for leg extension endurance, leg press (repetition maximum), pullover for upper body endurance, bench press (repetition maximum), maximum chin-ups and grip strength. During the competitive season, the team was put on a maintenance programme (2 workouts per week) using variable resistance equipment, implementing a one set to failure routine of the major muscle groups. After 38 games of the 60-game schedule, the team (n = 17) was retested. There was no significant change in muscular strength during the hockey season.

12. Flexibility

There are little data on the flexibility of hockey players. Trunk flexion, trunk extension and shoulder extension results for professional hockey players show similar scores for forwards and defense-men (Montgomery & Dallaire 1986; Rhodes et al. 1986). Goalies had significantly better flexibility for trunk flexion and shoulder extension.

Song (1979) measured the flexibility of 17 university players and compared the results with other university athletic teams (basketball, baseball, football, shotput and discus throwers, swimming, and wrestling). Measurements were made of 19 joint actions. Hockey players exceeded the other athletes (except swimmers) on wrist, hip, knee and ankle flexibility. The flexibility of the hockey players was exceeded by the other teams on neck rotation, all shoulder, elbow radial-ulnar actions, trunk extension-flexion, and lateral flexion.

13. Training Studies

Training studies have attempted to improve specific components of hockey fitness. Hollering and Simpson (1977) investigated the effect of 3 training programmes on skating speed of university players. The 3 programmes were 6 weeks in duration (3 sessions/week) and involved: (a) leg

squats using weights; (b) resistance skating by pushing a partner; and (c) speed skating with instruction. Skating speed was not significantly improved by participation in the 3 training programmes. Kober (1971) also found no change in skating speed of university hockey players when ankle weights were used to provide an overload stimulus.

Hutchinson et al. (1979) examined the effect of a 6-week preseason training programme on the aerobic capacity of university hockey players ($n = 11$). The programme involved continuous running, stair running, flexibility, and strength exercises. By the third week, the exercise sessions were 90 minutes in duration (6 days per week). $\dot{V}O_{2\max}$ increased by 11% from 56.5 to 62.6 ml/kg/min. During the competitive season, there was a lack of emphasis given to aerobic training. On the post-season test, $\dot{V}O_{2\max}$ had decreased to 54.9 ml/kg/min. The authors concluded that if aerobic fitness is to be maintained during the competitive season, an aerobic training programme must be continued throughout the season.

Studies of recreational players on the effects of hockey training differ from investigations using elite players. Initial level of fitness probably accounts for the contrary findings. Montgomery (1981) has shown that a 5-month ice hockey programme consisting of 3 hours of ice time per week (60% of the activity in the form of interval training and drills for fitness as well as skill; 40% of the time used for scrimmage) significantly improved both aerobic fitness (8-minute skating test) and anaerobic fitness [12 repeats $\times$ 60 feet (18m)] for a group of 43 university professors. In the aerobic test, the players skated 2890m on the pretest and 2984m on the post-test. In the anaerobic test, skating time was reduced from 52.0 to 50.3 seconds. Since these subjects had lower aerobic and anaerobic fitness levels than elite hockey players, the initial level of fitness was a factor in determining the magnitude of the improvement resulting from the hockey training programme.

Painter and Green (1978) have examined changes in cardiac output prior to the hockey season and following 4 months of the season. Cardiac

output was determined from a CO_2 rebreathing procedure at 2 submaximal workloads (600 and 900 kpm/min). For both workloads, hockey training resulted in significant ($p < 0.05$) reductions in heart rate and arteriovenous O_2 difference, whereas stroke volume increased. There was no change in cardiac output. This study concluded that hockey training induced changes in cardiovascular function that were similar to those found using continuous training.

Green and Houston (1975) examined adaptive changes in the energy system resulting from a season of hockey. Two junior teams ($n = 26$) were tested at the start and end of the competitive season. Pre- to postseason changes in $\dot{V}O_{2\max}$ were significant only when expressed in L/min (4.30 vs 4.43) with similar values when corrected for body-weight (56.4 vs 57.1 ml/kg/min). Minkoff (1982) also found no change in $\dot{V}O_{2\max}$ (ml/kg/min) over a season of play by professional players. Green and Houston (1975) speculated that the lack of improvement was due to inability of the aerobic system to respond to hockey training, a lack of stress necessary to realise change, or inability of the exercise test (treadmill running) to detect improvements resulting from the hockey training. The frequency of games (3 per week) in Junior A hockey have discouraged intense practices. On non-playing days practices have emphasised individual and team skills rather than sustained efforts.

Observations of hockey practices (Romet et al. 1978) revealed that hockey players skate for only 20 minutes during a 60-minute practice. Telemetry monitoring of heart rate during practice found insufficient duration with the heart rate in excess of 150 beats/min to provide a significant aerobic training stimulus.

Pre- to postseason changes in anaerobic endurance result from hockey training. Treadmill run time to exhaustion increased by 16.3% (64.3 to 74.8 seconds) over a season of play (Green & Houston 1975). Observation of Canadian hockey practices would support these laboratory findings. Traditionally hockey coaches have concluded practices with drills designed to promote anaerobic development. It appears that the improvement in the

anaerobic potential over a hockey season is not associated with increases in the levels of glycolytic enzymes (Green et al. 1979).

It is well established that endurance training can elicit significant increases in the oxidative capacity of both slow and fast twitch fibre populations. The activities of the key enzymes involved in energy production has been studied in 21 elite hockey players (Green et al. 1979b). The marker for oxidative potential, succinic dehydrogenase was 35% higher than in an active control group of kinesiology students. The marker enzyme of free fatty acid oxidation, 3-hydroxyacyl CoA dehydrogenase (HADH) was 49% higher in the hockey players. When the enzymes of glycolysis were examined, there was no difference between groups for phosphorylase, phosphofructokinase, and lactate dehydrogenase activity. In a pre- to postseason comparison, the hockey groups displayed higher hydroxyacyl dehydrogenase and lower phosphorylase and phosphofructokinase values on the post test. No differences in succinic dehydrogenase and lactate dehydrogenase activities were evident over the 6- to 7-month season that involved almost daily practices or games. In comparison with other elite athletes, Finnish hockey players have a higher level of succinic dehydrogenase activity (Rusko et al. 1978). In a review article, Green (1979) states: 'In view of the potential for a greater than two-fold increase in the activities of both succinic dehydrogenase and hydroxyacyl dehydrogenase with prolonged training and the small changes observed in these enzymes over the time frame in question, it appears that an ice hockey season does little to improve the oxygen transport system or the utilisation of oxygen at the cellular level. This may well reflect a serious deficiency of our training or an inability to induce significant adaptations in situations where a large volume of games are played.'

When daily activity is reduced significantly following a season of hockey training, the oxidative potential of the muscle cell and the aerobic power decline very little (Green et al. 1980). Muscle biopsies from the vastus lateralis were used to assess enzymatic changes. There was a significant reduction in succinic dehydrogenase (15%), hydroxyacyl

dehydrogenase (33%) and phosphorylase (17%) after 6 weeks of detraining. The reduction in phosphofructokinase (20%) was significant by 18 weeks of detraining.

The nature of the laboratory test may be important when examining response to training. During the speed skater's competitive season, training effects have been demonstrated on a cycle ergometer (Geijssels 1979, 1980). Geijssels (1979) pointed out that marathon speed skaters have similar $\dot{V}O_{2\max}$ values as those skaters with slower performance times. However, the better skaters had improved endurance times at a continuous workload (5.0 W/kg) on a cycle ergometer.

Using both ice skating and cycling tests, Daub et al. (1983) found that hockey training did not elicit any alteration in $\dot{V}O_{2\max}$ or in the supporting processes, $HR_{\max}$ and $V_{E\max}$. Addition of a supplementary programme of low intensity cycling also was unsuccessful in altering $\dot{V}O_{2\max}$ of hockey players during an ice skating test. There was a non-significant increase (6%) in cycling $\dot{V}O_{2\max}$. The cycling programme may have potentiated an increase in capillary-to-fibre ratio in both slow and fast twitch fibres (Daub et al. 1982). Capillary number was elevated by 23% in the slow twitch fibres and 31% in the fast twitch a fibres. In contrast, the group that only participated in hockey training had no change in the average number of capillaries in contact with slow twitch fibres, while also suffering an 18% reduction of capillary contact with fast twitch a fibres. When the enzyme activities representative of the energy supplying pathways were examined, there was no change in hydroxyacyl dehydrogenase, phosphorylase, phosphofructokinase, and lactate dehydrogenase as a result of a season of hockey training. There was an increase in succinic dehydrogenase activity. It appears that hockey training causes minimal adaptations in the skeletal muscles. The addition of a supplementary cycling programme caused no further adaptation in the metabolic profile (Daub et al. 1982).

Recently (Kandou et al. 1987) reported that skateboard exercise is a more specific training exercise than cycling for speed skating. They dem-

onstrated that substantial differences, both biomechanical and physiologically, exist between maximal speed skating and cycling activities of relatively short duration. Differences existed between the movement patterns in hip and knee joints during cycling compared with skating. In contrast, board skating showed a high degree of similarity to skating as reflected by movements in the hip and knee joints. Skateboard exercise was recommended for inclusion in the off-season training of speed skaters.

Two reports (Jones et al. 1983; Jones & Green 1984) have examined muscular fatigue in hockey players over a 6-day cycle of practices and games. Fatigue was measured isometrically during knee extension using a maximal voluntary contraction (MVC). There was a 28.8% decrease in MVC on day 1 and MVC remained depressed on days 2 and 3. MVC values on days 4, 5, and 6 were lower than the baseline value on day 1 but were not significant. Involuntary activation of the muscle via low frequency electrical stimulation of the quadriceps revealed similar decrements. Following an initial hockey practice, muscle force output is impaired and remains impaired throughout the hockey player's typical cycle of practices and games.

Jones and Green (1984) hypothesised that the onset and persistence of muscle fatigue was associated with lactic acidosis. Two schedules of high intensity intermittent cycle exercise were designed to elicit either a high or low lactate concentration. Exercise was performed for 60 minutes using a 1 : 3 work to rest ratio (10 seconds work vs 30 seconds rest). Knee extension torques were recorded during exercise and recovery for both MVC and electrical stimulation. Both schedules of high intensity exercise reduced torque during a MVC at all exercise and recovery times. During involuntary stimulation, torque was significantly reduced at 15, 30 and 60 minutes of exercise and at 1 hour of recovery for only the high lactate condition. These results showed that metabolic acidosis affected muscular force output.

The effect of a season of hockey play on blood status was examined by Quinney et al. (1982). Just prior to the NHL play-offs, 24 members of the Ed-

monton Oilers hockey team were assessed physiologically, including a resting blood sample. Haemoglobin, haematocrit red blood cell data indicated 2 borderline anaemic players who both also had low serum iron levels and high total iron binding capacities indicating potential nutritional iron deficiency. The team mean haemoglobin and haematocrit values were within the normal range while the mean red blood cell values were in the low range of normal. Eight players had serum iron levels between 11 and 16 $\mu\text{mol/L}$ and 8 players had total iron binding capacity values over 62 $\mu\text{mol/L}$. The data reveal the importance of monitoring blood status throughout the hockey season to alleviate problems prior to a critical point in the hockey season.

14. Nutritional Aspects

A 7-day dietary survey of professional hockey players revealed a high protein intake with a low intake of vegetables and fruit. Despite a high percentage of calories from meats and alcohol as well as calorie intake towards the end of the day, the players averaged only 14.8% fat (Houston 1979).

Food intake records over a 3-day period centred about a home game showed that professional players ($n = 11$) from an NHL team consumed 3841 ± 1088 kcal/day. The relative contributions to the energy intake were: protein $17.3 \pm 3.2\%$; carbohydrate $41.4 \pm 3.6\%$; fat $38.4 \pm 4.8\%$; and alcohol $3.7 \pm 3.4\%$ (Thomson et al. 1981). All players exceeded 100g of protein per day. The carbohydrate intake was 396 ± 105 g/day. Despite the large food intake, 2 players ate diets rated as poor for vitamin and mineral intake.

Simard and Jobin (1977) compared the effect of a glucose supplement and a placebo drink during a hockey game. The experimental group consumed 380 kcal prior to the game and 82 kcal during the game. Muscle biopsies were taken before and after the game. The glycogen level of the control group was 1.89 ± 0.22 g/100g of muscle prior to the hockey game and 0.98 ± 0.15 g/100g after the game. In comparison, the experimental group had

values of 2.09 ± 0.42 and 1.09 ± 0.20 g/100g, respectively.

15. Environmental Factors

Since ice hockey is usually played in environments where there is a relatively wide gradient between body and ambient temperatures, there is little risk of encountering heat-related ailments. Because protection is needed in this high speed, contact game, the player suits up with shoulder pads, padded pants, leg guards, gloves and recently helmets with face shields and throat protectors. The result is a uniform that reduces heat transfer. In warm arenas, profuse sweating typically brings about a 2 to 3kg weight loss during a hockey game despite *ad libitum* rehydration (Green et al. 1978a; MacDougall 1979; Wilson & Hedberg 1976).

MacDougall (1979) recommends that excess heat retention may be reduced by the following procedures:

- 1. Removal of gloves and helmet between shifts.
- 2. *Ad libitum* fluid replacement during games and practices.
- 3. Wearing fish-net underwear instead of the traditional 'long-johns'.
- 4. Wearing open-neck porous jerseys and discouraging the use of 'turtleneck' undershirts.

16. Visual Speed and Span

The visual system is important in hockey. The ability to scan the peripheral field and make adjustments to the positioning of team-mates and opponents as well as a puck which may travel at 40 m/sec is vital to a player's 'quickness'. Minkoff (1982) found that visual functions, especially eye speed and span, were positively correlated to face-off ability, shot accuracy and goal-tending capability among members of the New York Islanders professional team. The eye span test required peripheral vision by spreading visual targets apart for identification. The goaltenders and 'all-star' players had relatively high scores on the visual tests.

Adam and Wilberg (1986) used a backward masking paradigm to examine individual differ-

Table XI. Causes of injury in ice hockey (Moore 1980)

Cause	Frequency (%)
Skater being checked	21.9
Player trying to gain possession of the puck	15.2
Carrying or passing the puck	17.8
Checking	14.8
Scrambles in front of the net	7.0
Blocking a shot	4.0
Skating without interference	3.0
Miscellaneous causes (including fighting)	16.3

ences in the rate of visual information processing among hockey players. Displays containing 4 letters were presented for stimulus durations ranging from 25 to 300 msec followed by a masking stimulus for 200 msec. Individual differences existed in the rate of visual information processing among hockey players. Professional players were classified as 'fast' or as 'slow' visual information processors. In a previous study, these authors reported that rate of visual information processing was a correlate of performance success in varsity hockey players. Rate of visual information processing was a non-significant correlate of performance success among the professional players. The authors implied that reading familiarity may be a confounding variable in their procedure since it is known to influence the identification of short duration alphanumeric stimulus material.

17. Injuries

Injuries are common in professional hockey. Injuries forced players to miss 11% of the games in one NHL season (Moore 1980). Bishop (1981) collected injury data from 1662 regular season professional games. The overall injury rate was estimated at 800 injuries per 1000 league games. Defensemen had the highest injury risk. Playing zone analysis revealed that 40% of the injuries occurred in the defensive zone, 25% in the neutral zone, and 35% in the offensive zone. Results of this 3-year study of NHL injuries (cited by Moore 1980) are summarised in table XI.

During a Round Table discussion (1983), Suth-

erland reported that more injuries occur during minor hockey games than practices due to the intensity of competition. There was a higher incidence of injuries at the end of the season which may be related to the competition for play-off positions. He also found a high incidence of injuries early in the season which he attributed to improper conditioning and inadequate equipment. Forwards sustained 62% of the injuries compared with 31% for defensemen and 7% for goalies. Sutherland's study found the area around the goal had the greatest incidence (42%) of injuries. Most of the injuries were non-penalty related. Penalties were assessed in 26.6% of the injuries.

18. Conclusions

Over the past decade, sport scientists have made some advances in our knowledge of the physiological response to playing ice hockey. Although detailed study of time-motion characteristics of play are published, it is time to once again re-examine the pattern of play since shift duration is now shorter and intensity of play is higher. The existing data clearly show that ice hockey demands well developed aerobic and anaerobic energy systems. Previous on-ice training programmes during the competitive season have not been able to increase the $\dot{V}O_{2\max}$ of elite hockey players. The aerobic power of a typical ice hockey player is about 55 to 60 ml/kg/min. On-ice and off-ice training programmes should focus on the development of aerobic endurance, anaerobic power and endurance, muscular strength and skating speed as well as specific hockey skills.

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