THE EFFECTS OF TRAINING ON ANAEROBIC CAPACITY, ANAEROBIC POWER, AND RATE OF FATIGUE OF PREPUBERTAL, ELITE ICE HOCKEY PLAYERS

by

JAMES EDWARD POTTS

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James Edward Potts

Department of Physical Education

The University of British Columbia
1956 Main Mall
Vancouver, Canada
V6T 1Y3

Date September 30, 1985

ABSTRACT

The purpose of this study was to evaluate the effects of a 16 week training programme on selected on-ice and laboratory variables of 9-10 year-old boys involved in a competitive ice hockey programme.

Twenty-four players from two A-level representative teams were selected as subjects for this study. Players from one team served as the training group while players from the second team served as the age-matched control group.

On-ice measures were calculated from a Repeat Sprint Skate (RSS) whereby subjects performed 4 repetitions of 91.45 metres, commencing each repetition every 35 seconds. Laboratory measures included a Wingate Anaerobic Test (WAnT) which was extended to 40 seconds, an Anaerobic Speed Test (AST), and strength and power measurements (30, 100, 180 deg*sec^{-1}) of the quadricep and hamstring muscle groups.

Results from this study indicate that the training group showed significant ($p = .05$) improvement over the control group in the following variables: (1) the AST; (2) RQ (30 deg*sec^{-1}); (3) RH (30 deg*sec^{-1}); (4) RH (100 deg*sec^{-1}); (5) LH (30 deg*sec^{-1}).

Findings from this study indicate that intense anaerobic training will benefit prepubertal ice hockey players on selected anaerobic and strength measures.

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I

INTRODUCTION

There is a paucity of information available on the physiological characteristics of elite prepubertal athletes. Considering the obvious importance of early success and involvement in athletics for the eventual development and mastery of sport skills, the successful athlete who has not demonstrated an early ability in his sport is obviously rare. This is certainly true in the sport of ice hockey.

Previous research by Green and Houston (1975), Green et al. (1978; 1972), and Seliger et al. (1972) has attempted to define the acute stress placed on the various physiological systems in response to playing ice hockey, and to correlate these changes with the different energy capabilities of the players. It has been found that due to the intermittent nature of the game, wide variations exist in skating speed, durations in play, and recovery periods (Green and Houston, 1975). Time-motion analyses have suggested that both aerobic and anaerobic metabolism may be significantly involved in energy delivery depending on the characteristics of the particular shift (Green and Houston, 1975).

The actual amount of playing time during a game varies between 20-24 minutes, depending on the player's position, his age, and the level of competition being played (Green et al., 1978; Seliger et al., 1972). This is divided into approximately 15 to 18 shifts on the ice, each averaging 75-80 seconds, and separated by 3.5-4 minute recovery periods (Green et al., 1978; Seliger et al., 1972). In an individual shift there may be 2 or 3 play stoppages, providing only 35 to 40 seconds of continuous activity interrupted by 25 to 30 second stoppages (Green et al., 1978; Seliger et al., 1972). The average distance covered during a shift varies between 269-312 metres (Seliger et al., 1972).

Research by Seliger et al. (1972) demonstrated the relative contributions of both aerobic and anaerobic metabolism to the energetics of ice hockey. These results show that approximately 69% of the energy cost during an ice hockey match will be covered by anaerobic metabolism.

Previous studies by Cunningham and Faulkner (1969), Eriksson (1971), Eriksson et al. (1974), Faria (1970), Fox et al. (1973), Pollock et al. (1969), Roskamm (1967), Sharkey and Holleman (1967), Sharkey (1970), and Thorstensson et al. (1975) have shown that intensive training can elicit significant improvements in the function of metabolic processes involved in energy release. Although these programmes appear justified, very few attempts have been made to observe the effects of high intensity interval training on prepubertal children.

The ability of children to perform anaerobic-type activities is distinctly lower than that of adolescents and adults (Davies et al., 1972; diPrampero and Cerretelly, 1969). Performance expressed in absolute units of power (watts or joules) is positively related to age (Eriksson, 1971). When standardized for body weight (watts*kg^{-1} or joules*kg^{-1}), however, the power produced by an 8 year-old boy is still only 70% of that generated by an 11 year-old boy (Eriksson, 1971).

Many studies which have investigated the training effects on the anaerobic performance of children have utilized the Wingate Anaerobic Test (WAnT). The reliability, validity, and the sensitivity of the WAnT has been supported by investigations conducted mainly by researchers at the Wingate Institute in Israel (Ayalon et al, 1975; Bar-Or, 1978; Grodjinovsky et al, 1980; Inbar and Bar-Or, 1975).

Mosher et al. (1985) investigated the effects of a 12 week interval fitness training programme on prepubertal, elite-level male soccer players. Following the 12 weeks of training the training group was found to significantly increase their performance on a one mile run and on a modified Anaerobic Speed Test (AST), compared to age-matched controls. A significant improvement was also evident on a drop-off index between their initial and final (fastest-slowest) repeat runs, an indication of a lower rate of fatigue.

Tharp et al. (1985) conducted a study with young male track athletes ($\bar{x}$ age = 13.3 $\pm$ 1.2 years) and found WAnT scores for anaerobic capacity and power were only moderately correlated with 50 and 600 yard run times. Grodjinovsky et al. (1980) designed a study to determine whether or not the WAnT was sensitive to changes in anaerobic performance of 11 to 13 year-old boys following a 6 week training regimen. Anaerobic capacity and power showed an increase of approximately 3.5-5% following the training period. The findings of such studies indicate that improvement in the bioenergetic systems can occur in the prepubertal male athlete.

In the past, information on anaerobic capacity, anaerobic power, and rates of fatigue have been based on measurements from tests on maximal aerobic performance. The variation in protocols and the lack of stress on the anaerobic system underlie the wide range of reported values. The theoretical premise of these tests should be based on selecting a supra-maximal level of work designed to produce exhaustion. In such situations, the major contribution to energy supply is provided by anaerobic glycolysis. Since lactic acid is the end product of such metabolism, changes in blood lactate concentration should be found.

Hence, the purpose of this study was to investigate the effects of a 16 week training programme on the anaerobic capacity, anaerobic power, and rates of fatigue of elite prepubertal ice hockey players.

II

METHODS AND PROCEDURES

SUBJECTS

Twenty-four male subjects, all of whom were between 112 and 129 months of age ($\bar{x}$ age = 126.60 $\pm$ 4.27 months) at the beginning of this study, were selected from volunteers of two representative hockey teams in the greater Vancouver area. Players from one team served as the training group (N = 11), while players from the second team served as the age-matched control group (N = 13).

TESTING PROCEDURES

The subjects were tested on two separate days with at least one day separating the laboratory testing from the on-ice testing. The series of tests were then repeated approximately 16 weeks later.

The subjects were asked to refrain from any heavy training 24 hours prior to and on the day of testing. Testing was administered at approximately the same time of day and under similar environmental conditions during both the preliminary and final testing sessions.

Parental consent was obtained for each of the subjects in this study (see appendix E) and no subject was allowed to participate in the study without first being made aware of the purpose of the study, the testing procedures and protocols, and any known problems or side-effects which might result from the experimental procedures.

During both the preliminary and final laboratory testing sessions height, weight, body composition (hydrostatic weighing), peak muscular strength, and anaerobic capacity, anaerobic power, rate of fatigue, and post-exercise blood lactate (extended Wingate Anaerobic Test) was determined on each subject. Two days later, on-ice measures of anaerobic capacity, anaerobic power, rate of fatigue, and post-exercise blood lactate were determined from a modified Repeat Sprint Skate (Reed et al., 1979). Skeletal x-rays of the left hand and wrist were taken on each of the subjects at approximately the mid-point of the study.

TESTING PROTOCOLS

The physical characteristics which were determined included height, weight, and the percentage of body fat. The percentage of body fat was determined by a hydrostatic weighing technique outlined by Katch et al. (1967).

Laboratory measures of anaerobic capacity, anaerobic power, and rate of fatigue were calculated from the Wingate Anaerobic Test (WAnT) which was extended to 40 seconds. A Monarch ergometer was used, in which one pedal revolution causes a 6 metre advance of the flywheel. The resistance setting was adjusted to 0.55 grams*kg^{-1} of body weight for this study. On the command "start" the subject began to pedal as fast as he could. To overcome inertia, the initial resistance was very low, but it was quickly increased, and within 2-3 seconds reached the prescribed level. At that stage, the electrically triggered counter was activated and measurements taken. The number of revolutions was recorded at 5 second intervals for the total of 40 seconds. Total mechanical work in 40 seconds and the peak 5 second power output were taken as indices of anaerobic capacity and anaerobic power, respectively. The differences between the peak 5 second output and lowest 5 second output, divided by the time elapsed between the two points, was calculated. This value was used as an index of fatigue.

Post-exercise blood lactate was determined from a capillary blood sample drawn from an unwarmed fingertip. The sample was taken 5 minutes after the completion of exercise, stored, and then analyzed by a Komtron 640 automated lactate analyzer.

An Anaerobic Speed Test (AST) was modified to a speed of 11.67 k.p.m. and 18% grade to produce AST scores in the desired range (approximately 25-65 seconds). All subjects were given time to familiarize themselves with the treadmill. Practice running was initiated at low speed and 0% grade and progressed in three stages to the actual test speed and grade.

On-ice measures of anaerobic capacity, anaerobic power, rates of fatigue, and speed % drop-off were calculated from a modified Repeat Sprint Skate (RSS). The RSS was administered as follows. Six pylons were placed on the ice surface as indicated in figure

1. Timers were stationed at points A, B, and C, with position A serving as the starting point, position B serving as the end of the speed component of the test, and position C serving as the end of the repetition component of the test.

On the command "start", the subject sprinted in a straight line from point A to point B where he came to a complete stop with both skates beyond the line between the two pylons. He immediately reversed directions and sprinted through point C, and then coasted back to the starting point A, where he prepared himself for the next trial. The subjects began successive trials every 35 seconds of running time for 4 trials.

Timers A, B, and C were instructed to start their stop-watches at the beginning of overt movement by the subject. Timer A was responsible for monitoring the running time and for ensuring that the subject began each trial at the prescribed time. Timer B recorded the time for the subject to skate from point A to point B. Timer C recorded the total time for the subject to move from point A to point B and back through to point C.

Post-exercise blood lactate was determined from a capillary blood sample drawn from an unwarmed fingertip. The sample was taken 5 minutes after the completion of exercise, stored, and then analyzed by a Komtron 640 automated lactate analyzer.

Measurements of peak muscular strength were evaluated using a Cybex II Isokinetic Dynamometer. The muscle groups selected were the anterior thigh muscles (quadriceps), which were abbreviated RQ and LQ for right and left quadriceps, and the posterior thigh muscles (hamstrings), which were abbreviated RH and LH for right and left hamstrings. The muscle groups were recruited during extension and flexion of the knee. Three velocities of movement were selected (30, 100, 180 deg*sec^{-1}). The velocities of movement were progressively increased from 30 to 180 deg*sec^{-1} with each muscle group before the next muscle group was tested.

Biological age was determined on each of the subjects from skeletal x-rays of the left hand and wrist according to methods established by Greulich and Pyle (1959).

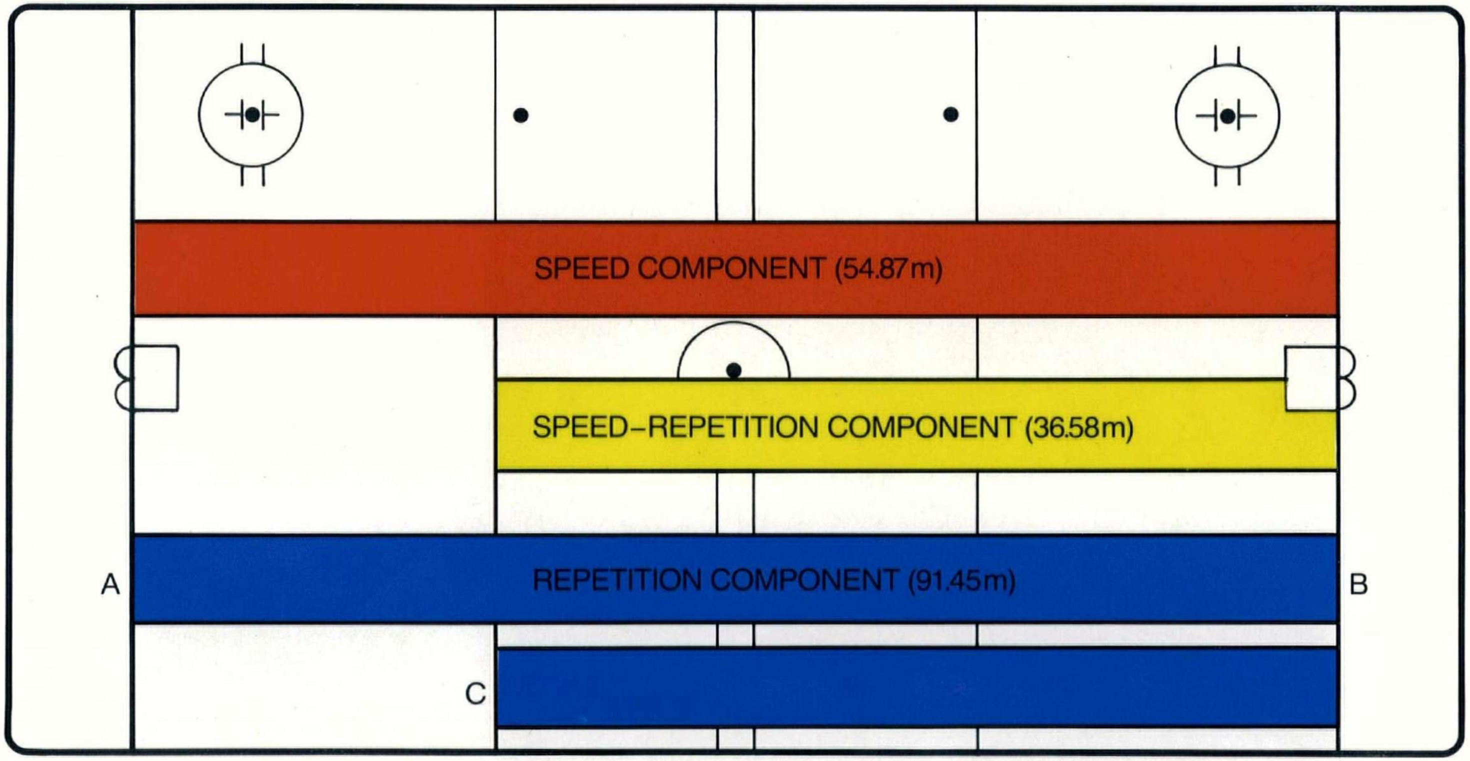
TRAINING INTERVENTION

Subjects in the training group had to undergo 16 weeks of intense anaerobic training both on the ice and in the laboratory. The subjects practised a minimum of twice per week during the period of this study. Each practice was approximately 75 minutes in length with 5 to 10 minutes devoted to high intensity skating drills designed to fatigue the anaerobic energy system. The subjects in the training group were scheduled to play at least 2 hockey games per week. One day per week was utilized for high intensity interval training in the laboratory. Cycling for 45 seconds at a pedalling frequency of 80 r.p.m. was utilized with a 1:2 work/rest ratio to simulate game-like conditions for this age group. Three sets of 3 shifts was progressively increased to three sets of 5 shifts over the period of this study. Push-ups, chin-ups, sit-ups, and squat-thrusts were encouraged as a means of improving muscular strength and endurance.

STATISTICAL ANALYSIS

The data was analyzed using a multivariate analysis of variance. This was accomplished by using the BMD P4V computing programme, a general univariate and multivariate ANOVA (URWAS, 1983) at the Computing Centre of the University of British Columbia. The P4V is a general purpose analysis of variance and covariance which does both univariate and multivariate analyses. Statistical significance was accepted at an alpha level of 0.05.

FIGURE 1
SCHEMATIC REPRESENTATION REPEAT SPRINT SKATE



III

RESULTS

The physical characteristics of the subjects involved in this study are presented in Table I. No significant differences between the groups for chronological age, height, weight, or % body fat were evident. During the 16 week period of this study significant increases in height and weight were noted for subjects in both the control and training groups ($p \leq .01$).

The results of the maturity assessment indicated that no differences existed between the groups with respect to their level of skeletal maturity. Both groups had a biological age which was approximately 7 months in advance of their chronological age.

Table II presents the laboratory metabolic variables which were calculated from either the WAnT or the AST. There were no statistically significant differences between the groups for anaerobic power, anaerobic capacity, or blood lactate. Initially, the training group showed a lower rate of fatigue ($m*sec^{-1}$) on the WAnT and a longer running time to exhaustion on the AST than the control group ($p \leq .05$; $p \leq .01$, respectively). During the period of this study significant increases in anaerobic power and rate of fatigue on the WAnT were noted for both groups ($p \leq .05$).

Similar increases were noted for both groups on running time to exhaustion on the AST ($p \leq .01$). During this same period of time the training group demonstrated a greater rate of improvement on the AST than the control group ($p \leq .01$).

Table III presents the on-ice metabolic variables which were calculated from the RSS. There were no statistically significant differences between the groups for anaerobic power, anaerobic capacity, speed % drop-off index, or blood lactate. Initially, the training group showed a lower rate of fatigue ($m*sec^{-1}$) than the control group. Over the duration of this study anaerobic capacity and blood lactate values of both groups for the RSS were found to be higher ($p \leq .01$; $p \leq .05$, respectively).

Table IV presents the time analysis of the RSS. Each of the skating segments of the RSS has been represented in this table. The training group showed a trend of being faster throughout each component of the RSS, both on the initial and final testing sessions.

The anterior thigh muscles (quadriceps) strength and power measurements are presented in Table V. Initially, statistical analysis revealed that the training group had greater strength and power than the control group. Both the right and left limbs when evaluated at 30, 100, and 180 $deg*sec^{-1}$ were significantly stronger in the training group ($p \leq .01$). During the period of this study significant increases in all strength and power measurements were noted for both groups ($p \leq .01$). During this same period of time the training group demonstrated a greater rate of strength gain for only one muscle group, the RQ (30 $deg*sec^{-1}$) ($p \leq .05$).

The posterior thigh muscles (hamstrings) strength and power measurements are presented in Table VI. Initially, the training group had significantly greater strength and power than the control group. Both right and left limbs when evaluated at 30, 100, and 180 $deg*sec^{-1}$ were significantly stronger in the training group ($p \leq .01$). During the period of this study significant increases in all strength and power measurements were noted for both groups ($p \leq .01$). During this same period of time the training group demonstrated a greater rate of strength gain of the RH (30 $deg*sec^{-1}$), RH (100 $deg*sec^{-1}$), and the LH (30 $deg*sec^{-1}$) ($p \leq .01$; $p \leq .05$; $p \leq .01$).

TABLE I

MULTIVARIATE ANALYSIS OF VARIANCE FOR PHYSICAL CHARACTERISTICS

		CONTROL GROUP		TRAINING GROUP		F RATIO $_{GROUP}$	F RATIO $_{PERIOD}$	F RATIO $_{(G \times P)}$
Chronological Age (months)	PRE	124.62	5.01	123.56	3.36	0.06	0.00	0.00
	POST	128.62	5.01	127.56	3.36			
Biological Age (months)	MID	133.54	10.67	133.18	10.31			
Height (cms)	PRE	142.59	5.94	141.80	6.71	0.30	81.76**	0.14
	POST	143.88	6.14	142.94	7.15			
Weight (kgs)	PRE	36.06	6.28	34.31	4.71	0.31	27.55*	1.82
	POST	36.85	6.37	36.00	4.82			
% Body Fat (%)	PRE	21.69	5.68	17.94	6.81	4.32*	2.90	0.11
	POST	19.62	4.90	13.58	5.51			

** $p = 0.01$

* $p = 0.05$

TABLE II
MULTIVARIATE ANALYSIS OF VARIANCE
FOR LABORATORY METABOLIC VARIABLES

		CONTROL GROUP		TRAINING GROUP		F RATIO $_{GROUP}$	F RATIO $_{PERIOD}$	F RATIO $_{(G \times P)}$
Anaerobic Power $_{WAnT}$ (watts)	PRE	242.62	36.25	238.82	39.93	0.13	6.08*	1.01
	POST	274.85	52.67	252.27	48.26			
Anaerobic Capacity $_{WAnT}$ (joules)	PRE	2895.15	516.11	3123.55	444.05	0.57	0.01	1.26
	POST	2981.23	757.86	3011.73	588.71			
Rate of Fatigue $_{WAnT}$ ($m*sec^{-1}$)	PRE	6.55	1.67	5.60	1.80	6.90*	5.20*	0.56
	POST	8.22	2.24	6.27	1.67			
Blood Lactate $_{WAnT}$ ($mmol*l^{-1}$)	PRE	6.60	1.30	7.43	1.52	1.70	1.61	0.64
	POST	7.26	1.39	7.57	2.00			
Anaerobic Speed Test (seconds)	PRE	41.46	15.20	62.67	17.94	10.45**	10.88**	9.04**
	POST	42.38	16.67	84.00	34.07			

** $p \leq 0.01$
* $p \leq 0.05$

TABLE III

MULTIVARIATE ANALYSIS OF VARIANCE

FOR ON-ICE METABOLIC VARIABLES

		CONTROL GROUP		TRAINING GROUP		F RATIO $_{GROUP}$	F RATIO $_{PERIOD}$	F RATIO $_{(G \times P)}$
Anaerobic Power $_{RSS}$ (watts)	PRE	2305.31	364.05	2270.64	288.88	0.07	2.90	0.11
	POST	2368.69	359.69	2309.91	268.36			
Anaerobic Capacity $_{RSS}$ (joules)	PRE	31534.62	5117.08	31327.36	4222.35	0.12	17.57**	2.20
	POST	33114.31	5529.60	34294.82	4408.78			
Rate of Fatigue $_{RSS}$ ($m*sec^{-1}$)	PRE	0.92	0.27	0.71	0.25	6.13*	2.05	0.97
	POST	0.90	0.32	0.57	0.21			
Speed % Drop-off Index (%)	PRE	19.54	6.88	14.33	5.47	0.06	2.91	0.13
	POST	17.85	7.78	11.22	4.82			
Blood Lactate $_{RSS}$ ($mmol*l^{-1}$)	PRE	6.74	0.76	8.16	1.52	3.84	5.53*	1.47
	POST	7.83	1.99	8.57	1.94			

$^{**}p \leq 0.01$

$^{*}p \leq 0.05$

TABLE IV

TIME ANALYSIS OF THE REPEAT SPRINT SKATE

		CONTROL GROUP	TRAINING GROUP
Speed Component (54.87 metres) (seconds)	PRE	9.66	9.56
	POST	9.46	9.41
Speed-Repetition Component (36.57 metres) (seconds)	PRE	8.46	8.37
	POST	7.91	7.50
Repetition Component (91.44 metres) (seconds)	PRE	18.12	17.93
	POST	17.37	16.91
Total Time (4 x 91.44 metres) (seconds)	PRE	77.99	76.60
	POST	76.13	72.43

TABLE V

MULTIVARIATE ANALYSIS OF VARIANCE

FOR ANTERIOR THIGH MUSCLES (QUADRICEPS) STRENGTH AND POWER MEASUREMENTS

		CONTROL GROUP		TRAINING GROUP		F RATIO $_{GROUP}$	F RATIO $_{PERIOD}$	F RATIO $_{(G \times P)}$
RQ (30 deg*sec^{-1})	PRE	213.77	60.31	353.44	48.08	19.84**	9.81**	0.03
(N)	POST	262.69	70.83	403.78	112.19			
RQ (100 deg*sec^{-1})	PRE	147.46	46.41	290.11	43.83	22.42**	9.19**	2.96
(N)	POST	217.92	56.64	314.33	96.69			
RQ (180 deg*sec^{-1})	PRE	120.23	47.63	267.89	51.06	25.81**	8.83**	5.98*
(N)	POST	195.08	45.90	283.11	99.14			
LQ (30 deg*sec^{-1})	PRE	220.46	54.29	342.56	59.64	16.42**	16.67**	0.03
(N)	POST	282.23	61.85	405.56	92.30			
LQ (100 deg*sec^{-1})	PRE	152.38	37.21	274.67	36.95	39.32**	33.22**	0.05
(N)	POST	226.23	50.47	353.33	62.24			
LQ (180 deg*sec^{-1})	PRE	130.69	42.10	269.22	54.92	30.32**	13.66**	2.64
(N)	POST	199.62	53.84	297.00	71.24			

** $p \leq 0.01$
* $p \leq 0.05$

TABLE VI

MULTIVARIATE ANALYSIS OF VARIANCE

FOR POSTERIOR THIGH MUSCLES (HAMSTRINGS) STRENGTH AND POWER MEASUREMENTS

		CONTROL GROUP		TRAINING GROUP		F RATIO $_{GROUP}$	F RATIO $_{PERIOD}$	F RATIO $_{(G \times P)}$
RH (30 deg*sec^{-1})	PRE	144.69	24.91	190.78	40.33	13.82**	20.62**	11.05**
(N)	POST	153.54	45.72	251.22	56.86			
RH (100 deg*sec^{-1})	PRE	110.92	26.95	168.00	42.83	15.01**	34.98**	5.73*
(N)	POST	135.15	41.97	228.44	56.00			
RH (180 deg*sec^{-1})	PRE	95.08	22.07	168.89	57.15	17.54**	6.84**	0.73
(N)	POST	119.92	28.62	180.11	39.24			
LH (30 deg*sec^{-1})	PRE	143.15	31.77	186.22	42.13	13.74**	25.81**	8.65*
(N)	POST	162.62	47.26	259.11	92.30			
LH (100 deg*sec^{-1})	PRE	118.08	33.11	157.56	22.17	13.13**	20.45**	1.88
(N)	POST	145.38	41.81	209.67	46.09			
LH (180 deg*sec^{-1})	PRE	95.23	33.68	163.00	39.37	17.40**	7.84**	0.95
(N)	POST	131.69	38.22	181.00	39.17			

** $p \leq 0.01$

* $p \leq 0.05$

IV

DISCUSSION

The physical characteristics of the subjects in this study suggest that this group of prepubescent hockey players represents a relatively homogeneous sample. The control group was slightly older (124.62 vs 123.56 months), taller (142.59 vs 141.80 cms.), heavier (36.06 vs 34.31 kgs.), and had a higher percentage of body fat (21.69 vs 17.94 %) than the training group. However, only the body fat was significantly different statistically.

The results of the maturity assessment indicate that the subjects in this study are maturing at a normal rate. Since each of the group's biological age is within 12 months of their chronological age they would be considered to be average with respect to their level of skeletal maturity. This is in agreement with the work of Bouchard et al. (1969) and Malina (1982) who found young ice hockey players to approximate the average or be slightly delayed in their level of skeletal maturity.

The physical characteristics of these groups are similar to those of Cunningham et al. (1976) who investigated the cardiopulmonary capacities of 10 year-old hockey players. Buti et al. (1984), Cunningham and Paterson (1985), and Sadi et al. (1984) have also found similar results in prepubescent athletes involved in tennis, running, and wrestling programmes, respectively. Krahenbuhl and Pangrazi (1983) investigated the characteristics associated with running performance in young boys. Their subjects were shorter and lighter than the subjects in this study.

The statistically significant increases in height and weight for both groups during the period of this study is in agreement with the findings of Buti et al. (1984). Initially, the training group had a lower percentage of body fat than the control group. During the period of this study a decrease in the percentage of body fat was noted for both groups. These changes probably result from the effects of growth and maturation during the 16 weeks of this study. The effect of ice hockey and the related training during this time period may also have contributed to the physical and anthropometric changes in these boys.

The anaerobic power scores on the WAnT for the training and control groups were 252.27 watts (7.06 watts$*kg^{-1}$) and 274.85 watts (7.50 watts$*kg^{-1}$), respectively. These values are higher than those reported by Inbar and Bar-Or (1975) for 7-9 year-old boys of 159.8 watts (5.88 watts$*kg^{-1}$). Similar results were found by Rhodes et al. (1985) for 7-8 year-old hockey players of 241.77 watts (7.89 watts$*kg^{-1}$). Grodjinovsky et al. (1980) reported values of 1902.0 kgm$*min^{-1}$ (310.78 watts) and 53.4 kgm$*kg^{-1}*min^{-1}$ (8.74 watts$*kg^{-1}$) for a group of schoolchildren, while Tharp et al. (1985) reported values of 228.77 kgm (448.57 watts) and 4.62 kgm$*kg^{-1}$ (9.18 watts$*kg^{-1}$) for 10-15 year-old track athletes. These values are higher than those reported in the present study.

The anaerobic power scores for the WAnT indicate that there were significant increases by both groups in anaerobic power during the 16 weeks of this study. The rate of improvement by the two groups ranged from 5.6%-13% which is higher than the 3.1%-5.3% reported by Grodjinovsky et al. (1980). Although no biochemical or histological measurements were taken during this study it is possible that these results indicate an enhancement of the alactic energy system within the musculature of these boys. This finding would be in agreement with Eriksson (1972) who reported an increase in the resting values of ATP, CP, and glycogen stores in the musculature of 11-13 year-old children following an aerobic/anaerobic training programme. Karlsson (1971) and Karlsson et al. (1972) found the stores of ATP and CP to increase by as much as 25% following an anaerobic training regimen. Thorstensson et al. (1975) found the activity level of CPK to increase by as much as 36% following a sprint training programme of 8 weeks.

The anaerobic capacity scores during the WAnT for the training and control groups were 3011.73 joules (83.73 joules*kg^{-1}) and 2981.23 joules (80.78 joules*kg^{-1}), respectively. These values are similar to those reported by Rhodes et al. (1985) of 3307.57 joules (108.09 joules*kg^{-1}). Higher values were reported by Grodjinovsky et al. (1980) of 1607.4 kgm*min^{-1} (4377.45 joules) and 45.2 kgm*kg^{-1}*min^{-1} (123.10 joules*kg^{-1}), Inbar and Bar-Or (1975) of 4463.0 joules (164.0 joules*kg^{-1}), Mayers and Gutin (1979) of 4766 joules (149.4 joules*kg^{-1}) for cross-country runners and 3883 joules (119.9 joules*kg^{-1}) for control subjects, and Tharp et al. (1985) of 1161.54 kgm (6326.47 joules) and

23.56 kgm*kg^{-1} (129.51 joules*kg^{-1}).

Statistically significant changes were not found for either group's anaerobic capacity. This is unlike the changes reported by Grodjinovsky et al. (1980) who demonstrated increases of 3.5%-5% to be highly significant. Grodjinovsky et al. (1980) indicated that the WAnT was sensitive in reflecting training changes in the anaerobic capacity of children, and thus, reflected a high rate of energy production by both the alactic (anaerobic power) and lactic (anaerobic capacity) components of anaerobic metabolism.

It is likely that the effect of the season of ice hockey, and the related training, was to enhance the alactic energy system of the subjects. The interval cycling programme which was imposed on the training group as part of the training intervention was neither specific enough, or was of insufficient frequency, intensity, or duration to realize a training effect.

The wide discrepancies which are reported for anaerobic power and capacity scores on the WAnT probably reflects the range of resistance settings which are found in the literature for studies involving children (.035-.075 grams*kg^{-1} body weight). The length of the test (25-40 seconds) may also contribute to the range of values reported for anaerobic power and capacity during the WAnT.

During the 16 week period of this study significant increases in the rate of fatigue were shown by both groups. The rate of fatigue is very dependent upon the anaerobic power of the individual. If one individual performs maximally in the first 5 seconds of the

WAnT, he will have a higher power score and also a much higher rate of fatigue than one who works at a lower level of intensity in the first 5 seconds. The increase in the rate of fatigue shown by both groups may then be explained by the increase in anaerobic power shown by both groups during the period of this study.

The WAnT reported blood lactate values of 7.57 $mmol*l^{-1}$ and 7.26 $mmol*l^{-1}$ for the training and control groups, respectively. Most of the reviewed literature does not report on blood lactates following the WAnT. However, Rhodes et al. (1985) reported values of 10.25 $mmol*l^{-1}$ in 7-8 year-old hockey players following a similar WAnT. The low correlations between anaerobic power or capacity on the WAnT when compared to blood lactates would suggest that blood lactates are not a good predictor of anaerobic power or capacity (performance), but are probably a good indicator of the intensity with which an exercise or activity has been performed.

The running time to exhaustion on the AST was significantly higher for the training group than for the control group. The 42.38 seconds for the control group is similar to the 43.9 seconds reported for a control group by Mosher et al. (1985) in a study involving 10-11 year-old soccer players. The training group's time of 84.00 seconds is higher than the 62.3 seconds reported by Mosher et al. (1985) for a group of trained soccer players.

The rate of improvement by the training group (34%) was significantly greater than the rate of improvement by the control group (2%), but similar to the findings of Mosher et al. (1985) who reported a 21% improvement on the AST by soccer players following a 12 week training period.

It is possible that the subjects of the training group were better runners than those in the control group. They may have done more running during the course of the training period, or perhaps they felt more comfortable running on a treadmill. The subjects in the training group were stronger and more powerful than those in the control group. The training intervention may also have contributed to the improvement in running time to exhaustion on the AST. The subjects in the training group may have developed a greater "exercise tolerance" as a result of the intervention. They were able to extend themselves both physiologically and psychologically on the AST, a test which had no fixed time component, while this was not possible on the WAnT which had fixed time components of 5 and 40 seconds.

The anaerobic power scores on the RSS for the training and control groups were 2309.91 watts (64.16 watts*kg^{-1}) and 2368.69 watts (64.28 watts*kg^{-1}), respectively. Rhodes et al. (1985) reported values of 1938.08 (55.47 watts*kg^{-1}) for 7-8 year-old ice hockey players which are lower than those reported in the present study.

The literature reviews a number of studies which report the time needed to skate the first length of the RSS. This time is very important in the calculation of the anaerobic power of the RSS (see appendix C). Reed et al. (1979) reported this time as 7.7 seconds for university and Junior "A" players, which is slower than the times reported by Smith et al. (1982) of 7.4 seconds for selected professional and Junior "A" players and 7.2 seconds for the Canadian Olympic Hockey Team (1980). In an unpublished study Rhodes et al. reported this time as 7.81 seconds for a group of 15-16 year-old hockey players.

The subjects in the present study covered the 54.87 metre distance in either 9.41 seconds (training group) or 9.46 seconds (control group). This is slightly faster than the time of 9.73 seconds it took for a group of 7-8 year-old hockey players to complete a similar distance (Rhodes et al., 1985).

The anaerobic power scores indicate that there were no significant improvements by either the training group or the control group during the 16 weeks of this study. This is in conflict with the results of the WAnT in which there was significant improvements in anaerobic power of both groups during the study.

If we assume that the season of ice hockey, and the related training, was responsible for improving the alactic energy system, then the anaerobic power during the RSS should have also showed an improvement. It is possible that while the alactic energy system may have improved, the mechanical efficiency of skating may not have improved in these boys to allow for an increase in skating speed. This would account for the reported lack of improvement in anaerobic power on the RSS.

It is possible that the season of ice hockey, and the related training, may have also improved the lactic acid energy system, which resulted in an increase in anaerobic capacity during the RSS. The calculation of anaerobic capacity during the RSS is very dependent on the maintenance of a high speed over the repeated trials of the test. If the lactic acid energy system is enhanced more energy can be produced for a longer period of time. This would enable an individual to maintain his speed for prolonged periods without fatiguing. This would result in a lower overall time for the repeated trials and an increase in the anaerobic capacity of the RSS.

The time component of the RSS (72-76 seconds) is almost twice that of the WAnT (40 seconds). This may be too short a period of time to make a calculation of anaerobic capacity for the WAnT.

The on-ice training intervention which was imposed on the training group was neither specific enough, or was of insufficient frequency, intensity, or duration to realize a training effect.

The rate of fatigue on the RSS was significantly lower for the training group than for the control group. This may have been due to the subjects in the training group being either stronger and more powerful, or perhaps more efficient skaters. The rate of fatigue for the training and control groups were 0.57 $m*sec^{-1}$ and 0.90 $m*sec^{-1}$, respectively. Rhodes et al. (1985) reported a value of 1.31 $m*sec^{-1}$ for 7-8 year-old ice hockey players.

The lower rate of fatigue demonstrated on the RSS in comparison to the WAnT is possibly due to the existence of a gliding phase in skating which is absent when cycling against a resistance. Since ice has a very low friction co-efficient momentum can be maintained during skating without a large increase in the rate of fatigue.

The RSS reported blood lactate values of 8.57 $mmol*l^{-1}$ and 7.83 $mmol*l^{-1}$ for the training and control groups, respectively. This is lower than the 10.11 $mmol*l^{-1}$ reported by Rhodes et al. (1985) for 7-8 year-old ice hockey players following a similar RSS.

Green (1978) reported higher lactate values in university players following an intermittent skating test than was found in the subjects of the present study. Green et al. (1978) and Green (1979) reported values ranging from 2.92 to 6.16 $mmol^{-1}$ of lactate during intermissions of hockey games.

The statistically significant increases in blood lactates shown by both groups during the period of this study may parallel the increases in anaerobic capacity which were evident on the RSS. However, the low correlations between anaerobic power and capacity when compared to blood lactates would suggest that blood lactates are not a good predictor of anaerobic power or capacity. Since lactic acid is the end-product of anaerobic glycolysis, and its maximal concentration in muscle reflects, in part, the maximal rate of glycolysis, lactates may indicate the intensity with which an exercise or activity has been performed.

The increases in all strength and power measurements which were noted for both the training and control groups were probably due to the normal process of growth and maturation, although the effects of the season of ice hockey, and the related training, may also have contributed. The greater rate of improvement shown by the training group in only 4 out of 12 strength and power measurements indicates a random finding. The training intervention was unsuccessful in eliciting the training response for strength and power that was hypothesized for these boys.

The peak muscular strength and power measurements of the muscles which cross the knee joint were assessed largely because of their involvement in the skating motion (Halliwell, 1977). The values noted at slower speeds (30 $deg*sec^{-1}$) indicate good strength development, but lower values at higher speeds (180 $deg*sec^{-1}$) suggests that little emphasis has been placed on the development of power and speed in these athletes. This aspect of the training of hockey players is important not only to skating but to shooting as well. Power and speed-work are often neglected in the on-ice and dryland training of ice hockey players.

V

SUMMARY AND CONCLUSIONS

There is a paucity of information available on the physiological characteristics of elite prepubertal athletes. Considering the obvious importance of early success and involvement in athletics for the eventual development and mastery of sport skills, the successful athlete who has not demonstrated an early ability in his sport is obviously rare.

The purpose of this study was to evaluate the effects of a 16 week training programme on selected on-ice and laboratory variables of 9-10 year-old boys involved in a competitive ice hockey programme.

Twenty-four subjects from two A-level representative teams were selected as subjects for this study. Players from one team served as the training group while players from the second team served as the age-matched control group. On-ice measures of anaerobic capacity, anaerobic power, rate of fatigue, speed % drop-off index, and blood lactate were calculated from a RSS. Laboratory measures of anaerobic capacity, anaerobic power, rate of fatigue, and blood lactate were calculated from a WAnT which was extended to 40 seconds. The running time to exhaustion on an AST (11.67 kph @ 18% grade) was assessed as a measure of anaerobic endurance. Strength and power measurements of the quadricep and hamstring muscle groups were assessed at 30, 100, and 180 deg*sec^{-1}.

At the beginning of this study several differences existed between the control and training groups. The training group had a lower % of body fat, a lower rate of fatigue on the WAnT and RSS, and a longer running time to exhaustion on the AST. The training group was significantly stronger and more powerful than the control group in all of the measured variables: RQ (30, 100, 180 deg*sec^{-1}), LQ (30, 100, 180 deg*sec^{-1}), RH (30, 100, 180 deg*sec^{-1}), and the LH (30, 100, 180 deg*sec^{-1}).

Over the 16 week period of this study both groups showed significant increases in a number of variables. Height and weight were the two physical characteristics which increased significantly over the period of this study. The WAnT elicited increases in anaerobic power and the rate of fatigue. The AST showed a longer running time to exhaustion. Increases in anaerobic capacity and blood lactate were found following the RSS. During the period of this study increases in all strength and power measurements were noted for both groups.

During the period of this study the training group demonstrated a greater rate of improvement on several variables. The training group showed a longer running time to exhaustion on the AST and a greater rate of improvement on 4 strength and power measurements: RQ (180 deg*sec^{-1}), RH (30, 100 deg*sec^{-1}), and the LH (30 deg*sec^{-1}). These changes may be attributed to the training intervention which was imposed on the training group.

Conclusions

The following conclusions can be reached:

(1) During the 16 week period of this study growth and maturational processes resulted in increases in height and weight for subjects in both the training and control groups.

(2) During the 16 week period of this study both groups showed increases in anaerobic power and the rate of fatigue on the WAnT, and running time to exhaustion on the AST.

(3) During the 16 week period of this study both groups showed increases in anaerobic capacity and blood lactate values on the RSS.

(4) Although the training group showed a trend toward being faster throughout each component of the RSS this difference was not reflected in the training group having higher anaerobic capacity and power scores or a lower rate of fatigue.

(5) During the 16 week period of this study both groups showed increases in all strength and power measurements.

(6) The training intervention was ineffective in bringing about changes in anaerobic capacity, anaerobic power, and rates of fatigue during either the RSS or the WAnT. The training group did, however, show significant improvements over the control group on the AST, and on several strength and power measurements (RQ @ 30 $deg*sec^{-1}$, RH @ 30 $deg*sec^{-1}$, RH @ 100 $deg*sec^{-1}$, and the LH @ 30 $deg*sec^{-1}$).

Recommendations for Further Research

(1) The use of subjects who were not involved in competitive ice hockey would assist in determining whether the increases shown by both groups in many of the variables over the period of this study were due to growth and maturation or to the season of ice hockey, and the related training.

(2) The WAnT should be standardized to a specific length of time and a specific resistance setting for tests involving children.

(3) Invasive research techniques should be utilized to report on the qualitative changes (biochemical and histological) which occur in children as a result of exercise and conditioning programmes.

(4) Training sessions of greater frequency and duration would be beneficial in determining the effects of training on the anaerobic performance of prepubertal children.

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APPENDIX A

REVIEW OF LITERATURE

INTRODUCTION

"Physical conditioning is the process by which exercise, repeated during weeks and months, induces morphologic and functional changes in body tissues and systems. Mostly affected are the skeletal muscles, myocardium, blood vessels, adipose tissue, bones, ligaments, tendons, and the central nervous and endocrine systems" (Bar-Or, 1983).

Research on the conditioning and training of children has inherent methodologic obstacles. As with other age groups, studies should include an intervention programme and a longitudinal follow-up. In adults, changes in function between pre- and post-intervention can be attributed with fair certainty to the conditioning programme. This is not the case with children or adolescents. Here, changes due to growth, development, and maturation often outweigh and mask those induced by the intervention (Bar-Or, 1983). Many of the physiological changes that result from conditioning and training regimens also take place in the natural process of growth and maturation.

It will be the purpose of this review to present current research pertaining to the trainability of prepubertal male athletes and its subsequent relationship with anaerobic capacity and power in the sport of ice hockey.

PHYSIOLOGICAL RESPONSES OF CHILDREN TO EXERCISE

(1) Aerobic Power

Research by several investigators including Andersen and Magel (1970), Andersen et al. (1974), Astrand (1952), Bar-Or and Zwiren (1973), Bar-Or et al. (1971), Chatterjee et al. (1979), Cunningham and Paterson (1985), Ekblom (1969), Gaisl and Buchberger (1977), Hermansen and Oseid (1971), Ikai et al. (1970), Kobayashii et al. (1978), MacDougall et al. (1979), Macek et al. (1979), Mocellin (1975), Nagle et al. (1977), Robinson (1938), Seliger (1970), Shephard et al. (1969), and Thoren (1967) have shown that with the growth of the child there is a parallel increase in his or her maximal aerobic power (expressed as maximal O_2 uptake). Until age 12 values increase at the same rate in both sexes, even though boys have higher values as early as age 5 (Yoshizawa et al., 1977). Maximal aerobic power of boys continues to increase to about 18 years of age, but it hardly develops beyond age 14 in girls.

Maximal aerobic power is strongly related to lean body mass (Burmeister et al., 1972; Eriksson and Thoren, 1978; Parizkova, 1968). When the maximal O_2 uptake of adolescents of different ages, but of the same body weight or height is compared, it is positively related to age (Sprynarova et al., 1978). This suggests that maximal aerobic power depends somewhat on the maturity of the individual.

Children have shorter O_2 uptake transients than do adults (Freedson et al., 1983; Macek and Vavra, 1980; Macek and Vavra, 1980; Robinson, 1938). The O_2 deficit of 10- to 11 year-old boys was found to be smaller than among young adults. Even more pronounced was the high rate at which boys increased their O_2 uptake when compared with adults. These boys reached 55% of their final O_2 uptake within 30 seconds and a steady state within 2 minutes. The adults reached only 33% of their final O_2 uptake within the first 30 seconds and required some 3-4 minutes to reach a steady state (Macek and Vavra, 1980).

Bar-Or (1983) suggested that due to their shorter O_2 transients children may not need to depend as heavily on anaerobic pathways for their energy requirements. He also suggested that these shorter transients may be compensatory for their low glycolytic capacity. Cumming (1978) suggested that the shorter transients in children could be a reflection of a smaller body surface area and the resulting shorter circulation time.

Among adults who undergo an aerobic conditioning programme there is an age-related trend; the younger the individual, the more trainable he or she is (Saltin, 1969). This does not appear to be the case with children. In some studies adolescents and children responded in a predictable manner to either general conditioning or specific training regimens (Bannister, 1965;

Dotan et al, 1982; Ekblom, 1969; Grodjinovsky and Bar-Or, 1983; Shephard et al., 1977; Sprynarova et al., 1978; Weber et al., 1976). There is, however, growing evidence to suggest that aerobic trainability in prepubescents, particularly in those less than 10 years of age, is lower than expected, even though their athletic performance may improve (Andersen and Froberg, 1980; Bar-Or, 1983; Bar-Or and Zwiren, 1973; Daniels and Oldridge, 1971; Daniels et al., 1978; Gilliam and Freedson, 1980; Kobayashi et al., 1978; Schmucker and Hollmann, 1974; Shephard et al., 1977; Stewart and Gutin, 1976; Yoshida et al., 1980).

Several studies involving prepubescent children have shown that following aerobic training programmes the children markedly improved their running performance without an increase in maximal aerobic power (Bar-Or and Zwiren, 1973; Mocellin and Wasmund, 1973; Stewart and Gutin, 1976; Yoshida et al., 1980). Daniels et al. (1978) suggested that an improvement in running performance without a concomitant increase in maximal O_2 uptake may be explained by an increase in the efficiency or economy of movement. Several authors suggest that the use of maximal O_2 uptake is not a sensitive indicator to show changes in maximal aerobic power of prepubescent children (Cumming et al., 1967; Mayers and Gutin, 1979; Rost et al., 1978; Schmucker et al., 1977). In some studies, which involve the use of a control group(s), another possible explanation for the apparent lack of training effects in prepubescents could be the high habitual activity level of the "controls" (Bar-Or, 1983; Cumming et al., 1969; Hamilton and Andrew, 1976).

Kobayashi et al. (1978) suggested that the effectiveness of aerobic conditioning programmes was greatest at, or around, peak height velocity (PHV). Andersen and Froberg (1980) could not identify such a critical stage in aerobic trainability. The conflicting results from these studies leave us unable to identify a concise developmental stage where aerobic trainability reaches that of young adults.

(2) Anaerobic Capacity and Power

The ability to perform short supramaximal tasks is dependent on, among other factors, anaerobic power (the alactacid component of the oxygen deficit) and anaerobic capacity (the lactacid component of the oxygen deficit) (Margaria, 1967; Houston and Thomson, 1977).

The ability of children to perform anaerobic-type activities is distinctly lower than that of adolescents and adults (Davies et al., 1972; diPrampero and Cerretelly, 1969). Performance expressed in absolute units of power (watts or joules) is positively related to age (Eriksson, 1971). When standardized for body weight ($watts*kg^{-1}$ or $joules*kg^{-1}$), however, the power produced by an 8 year-old boy is still only 70% of that generated by an 11 year-old boy (Eriksson, 1971).

Very few studies have employed prepubertal subjects in an interval training programme which was designed to elicit changes in anaerobic performance. Mosher et al. (1985) studied the effects of a 12 week interval training programme on prepubertal soccer players. These 10 and 11 year-old boys showed a significant improvement on an Anaerobic Speed Test (AST) (11.67 kph @ 18% grade), 1 mile run, and % drop-off index on a repeat sprint of 40 yards. The authors suggested that their results indicate that soccer players, and perhaps all boys of this age, can increase both anaerobic and aerobic fitness through participation in high intensity interval training programmes. The changes elicited in this study are particularly interesting when compared to a number of studies (Bar-Or and Zwiren, 1973; Gaisl and Buchburger, 1980; Wasmund and Mocellin, 1972) that have suggested 11 years of age to be the lower limit at which there is any likelihood of achieving any training effects.

Many studies which have investigated the training effects on the anaerobic performance of children have utilized the Wingate Anaerobic Test (WAnT). The reliability, validity, and the sensitivity of the WAnT has been supported by investigations conducted mainly by researchers at the Wingate Institute in Israel (Ayalon et al., 1985; Bar-Or, 1978; Grodjinovsky et al., 1980; Inbar and Bar-Or, 1975).

Bar-Or and Inbar (1978) concluded that the WAnT was a valid predictor of sprinting ability in non-athletic children. The relationship between the WAnT and run times (40, 300, 600 metres) in 35 non-athletic boys ($\bar{x}$ age = 12 $\pm$ 1.7 years) was examined. Moderate relationships were found between 30 second power outputs (anaerobic capacity) and run times. More exacting relationships were found between 5 second power outputs (anaerobic power) and run times.

Tharp et al. (1985) conducted a study with young male track athletes ($\bar{x}$ age = 13.3 $\pm$ 1.2 years) and found WAnT scores for anaerobic capacity and power were only moderately correlated with 50 and 600 yard run times. Partial correlations between these variables were found to be lower when age adjusted and higher when adjusted for body weight. They concluded that the WAnT is only a moderate predictor of sprint or run times, but became a stronger predictor when WAnT scores were adjusted for body weight.

Cumming (1972) used a prototype of the WAnT to examine anaerobic power in 12-to 17 year-old children at a summer athletic camp. He observed the relationship between a bicycle ergometer test of power and run times (100, 440, 880 yards, and 2 miles). His results indicated that the strength of the relationship between anaerobic power and run times decreased as the distance of the run increased.

Grodjinovsky et al. (1980) designed a study to determine whether or not the WAnT was sensitive to changes in anaerobic performance of 11-to 13 year-old boys following a 6 week training regimen. Anaerobic capacity and power showed an increase of approximately 3.5% to 5% following the training period. This study also provided some interesting findings on the relationship between body weight and age to WAnT scores. The WAnT becomes a strong predictor of sprint and run times when it is adjusted for body weight. Partial correlations adjusting for age or weight indicate that weight remains highly correlated with anaerobic capacity and power when the effect of age is removed, but age loses much of its correlation with anaerobic capacity and power when adjusted for weight.

(3) Biochemical Considerations, Children, and Exercise

Davies (1971) and Davies et al. (1972) suggested that differences in maximal aerobic power can be accounted for by the mass of active muscle tissue. This is not so with anaerobic capacity and power. The markedly lower anaerobic capabilities of the young child reflects, to a great extent, a qualitative deficiency in his muscle, or recruitment of motor units which innervate the muscle (Bar-Or, 1983).

Karlsson (1971) and Karlsson et al. (1972) found that the stores of ATP and CP increased by as much as 25% following an anaerobic training programme involving adults. Thorstensson et al. (1975) found that the activity level of Creatine Phosphokinase (CPK) increased by 36% following a sprint training programme of 8 weeks. Karlsson et al. (1972) using an adult population showed an increase in some glycolytic enzymes following an anaerobic training programme. Eriksson (1972) investigated the effects of a combined aerobic and anaerobic training regimen on 11-13 year-old children and found there was an increase in resting values of muscle ATP, CP, and glycogen, and that glycogen depletion was enhanced with exercise.

The primary age-related difference is in glycolytic capacity. Resting concentration of glycogen, and especially the rate of its anaerobic utilization, are lower in the child, who is therefore at a functional disadvantage when performing strenuous activities that last 10 to 60 seconds (Bar-Or, 1983; Eriksson et al., 1980; Eriksson et al., 1974; Karlsson, 1971).

One way of assessing glycogen utilization is by measuring lactate concentration in the blood or, preferably, in the muscle. Studies by Astrand (1952), Blimkie et al. (1978), Eriksson (1980), Eriksson et al. (1974), Eriksson et al. (1971), Karlsson (1971), Matejkova et al. (1980), and Moody et al. (1972) have shown that maximal lactate levels in the blood and in muscle are lower in children than in older subjects. Studies on rats have shown that lactate production is related to the level of circulating testosterone (Krotkiewski et al., 1980). Karlsson (1971) suggested that the ability of boys to produce lactate during maximal exercise depends on their sexual maturity.

The rate of glycolysis is also limited by the activity of such enzymes as phosphorylase, pyruvate dehydrogenase, and phosphofructokinase (PFK). Eriksson et al. (1974) and Eriksson (1972) found PFK to be less active in the muscle cells of 11-to 13 year-old boys than in young adults.

An additional indicator of anaerobic capacity is the degree of acidosis at which the muscle cell can function. Some trained adult athletes can push themselves to exercising at arterial blood pH as low as 6.80 (Kindermann et al., 1975), which is equivalent to a pH of 6.60 or less in active muscle cells (Bar-Or, 1983). Untrained individuals can seldom sustain exercise when their arterial blood pH reaches 7.20 (Bar-Or, 1983). Gaisl and Buchberger (1977), Kindermann et al. (1975), and Matejkova et al. (1980) have shown that children do not reach as high levels of acidosis as do adolescents or young adults.

(4) Skeletal Muscle Adaptation to Exercise

Being the effector organ of body movement, the skeletal muscle is expected to undergo a major adaptation to conditioning. Since the advent of a needle biopsy technique in the early 1960's, much research has been done on adults, demonstrating that histological and biochemical changes do occur. Due to ethical considerations data on adolescents is limited. Bar-Or (1983) indicated that children show a similar pattern of adaptation to that of adults.

Skeletal muscle hypertrophy, and possibly hyperplasia, occur in the chronically active muscles of adults. Fournier et al. (1982) and Jacobs et al. (1982) found that among adolescents undergoing an endurance training programme, hypertrophy, but not hyperplasia, occured. Fournier et al. (1982) found that a sprint training programme resulted in neither hypertrophy or hyperplasia. There is no evidence to support the hypothesis that a change in fiber type distribution will result from training (Eriksson et al., 1974; Fournier et al., 1982; Jacobs et al., 1982). An increase in muscle capillarization and the development of collateral circulation to skeletal muscle has not yet been investigated in children (Bar-Or, 1983).

The trainability of muscle strength in children has yielded inconclusive results. Rohmert (1968) found the muscle strength of 8 year-old girls and boys to be somewhat more trainable than among adults who were given the same relative training stimulus. Nielson et al. (1980) indicated that over a 5 week training period 7 - 13.4 year-old girls had a greater relative increase in isometric strength than did 13.5 to 19 year-old girls. In contrast to this data Vrijens (1978) observed that postpubescent boys had a greater response to a strength training programme than did prepubescent boys. In a study by Hettinger (1961) adolescents of both sexes had a lesser improvement in isometric strength than did young adults.

(5) Conditioning, Body Composition, and Children

When conditioning regimens are such that the cummulative energy expenditure is high or the effort is intense, changes in body composition may occur. The anabolic effect of exercise induces an increase in the lean body mass of the individual, while the increased energy expenditure serves to reduce the mass of the adipose tissue. The overall result is a relative increase in lean body mass and a decrease in adiposity. Goode et al. (1976), Moody et al. (1972), Parizkova (1977), and Parizkova (1968) indicated that following physical fitness programmes subjects increased their lean body mass and decreased their adiposity. Authors such as Berg and Bjure (1974), Clarke and Vaccaro (1979), Glick and Kaufmann (1976), and Sprynarova et al. (1978) have failed to find similar changes.

The main reason for such conflicting results is that changes in body mass and composition depend also on factors other than energy expenditure. Calorie intake and the composition of the consumed food is the primary nutritional consideration. An additonal factor to consider is the confounding effect of growth and maturation. Thus, while a certain conditioning programme effectively modifies body composition, the effects may be masked and even counteracted by growth and maturation related changes, as well as by changing dietary habits. Glick and Kaufmann (1976) and Moody et al. (1972) reported that obese children seem to respond to exercise regimens with greater changes in body composition that do non-obese children.

ICE HOCKEY

Research by Green et al. (1978), Green and Houston (1975), and Green et al. (1972) has attempted to define the acute stress placed on the various systems of ice hockey players, and to correlate this stress with the different energy capabilities of the players. Due to the intermittent nature of the game wide variations exist in skating speed, durations of play, and recovery periods. Much of the actual skating is explosive in nature, short bursts of skating being followed by a period of coasting.

The actual amount of playing time during a game varies from 18-24 minutes, depending on the position which is played (Green and Houston, 1975; Seliger et al., 1972). This is divided into approximately 17 separate shifts on the ice, each shift averaging 75-85 seconds, which are separated by 3-4 minutes of recovery time (Green and Houston, 1975). During an individual shift there may be 2 or 3 stoppages which provide only 35-40 seconds of continuous action interrupted by 25-30 second stoppages in play (Green and Houston, 1975).

Seliger et al. (1972) estimated the total energy expenditure that a player would expend in a game to be approximately 820 calories (450-1170 calories). Time-motion analyses have shown that the total length of ice which a player would cover during a game to be approximately 5160 metres (4860-5620 metres) (Seliger et al., 1972). This corresponds to the length of ice which an elite performer would cover during a game to be between 6400-7200 metres. Investigations by Seliger (1967) showed that younger hockey players cover approximately 2360 metres during a game.

Telemetered measures of heart rate, oxygen consumption (during actual play and recovery periods), and between-period determination of blood lactate have tended to support the importance of both the aerobic and anaerobic systems to energy delivery in hockey players (Green, 1978; Green et al., 1978; Green and Houston, 1975; Seliger et al., 1972; Seliger, 1968). Seliger (1972) reported that during a game approximately 69% of the energy expenditure is covered by anaerobic metabolism.

Green and Houston (1975) observed the effects of a season of ice hockey on 16-20 year-old hockey players. They concluded that over the 5 month training period essentially no change in aerobic power occured. The author's reasoned that the lack of improvement in aerobic power could result from an inability of the aerobic system to respond to the training programme, lack of stress necessary to realize a change in the aerobic system, or the inability of treadmill running to detect improvements realized as a result of ice skating.

Daub et al. (1983) reported that high intensity ice hockey training failed to elicit any alteration in maximal oxygen uptake, maximum heart rate, and maximum ventilation, either during cycling or ice skating. This finding is consistent with that of Hedberg and Wilson (1975), Green et al. (1979), Seliger et al. (1972), Seliger (1967), and Yokobori (1964). The hockey training appeared to modify selected physiological responses to prolonged ice skating but not to prolonged cycling.

Green (1978) observed the glycogen depletion patterns during continuous and intermittent ice skating. The results from this study demonstrated the importance of the vastus lateralis muscle in supramaximal bouts of ice skating, and that the activity of ice skating produces a pattern of glycogen depletion which is similar to that found following cycling. It was noted that the selective depletion of different muscle fibers was dependent upon the intensity of work which was done.

Daub et al. (1983) investigated the effects of a supplementary training programme of low intensity cycling on ice hockey performance. The cycling programme modified the cardiovascular response to submaximal cycling only, and did not influence the response to submaximal or maximal ice skating. The authors suggested that the relative work load was lower during prolonged cycling than during prolonged skating and thus did not elicit changes in the skating parameters.

Smith et al. (1982) monitored the on-ice and laboratory performance of the Canadian Olympic Hockey Team (1980). Among the selected physiological measurements which were evaluated were maximum aerobic power, muscular strength and power, body composition, and an on-ice test of skating power. The maximum aerobic power for this group was found to be lower than that reported for other elite teams (Green et al., 1978; Rusko et al., 1978), but similar to others (Green et al., 1979; Seliger et al., 1972). Knee and hip flexion/extension and shoulder abduction/adduction were assessed because they are largely involved in the hockey skills of skating and shooting (Smith et al., 1982). The high values reported for knee extension at slow speeds of movement (30 deg*sec^{-1}) in relationship to other athletes (Thorstensson et al., 1977) suggest good strength development, but lower values at higher speeds of movement (180 deg*sec^{-1}) in relationship to other athletes (Thorstensson et al., 1977) suggest little emphasis has been placed on the development of power at high speeds in these athletes.

Smith et al. (1982) used the on-ice test of Reed et al. (1979) to assess the skating power of the Olympic Hockey Team and their ability to repeat high speed intervals with short rest periods. The Olympic Team showed faster speed over 54.87 metres, but a greater time drop-off with six repeats of 91.45 metres when compared to professional and junior players (Reed et al., 1979). Smith et al. (1982) postulated that the faster speeds over 54.87 metres contributed to the greater time drop-offs over repeated trials.

In the early years of research into the involvement of youth in the sport of ice hockey many investigators were interested in the aquisition of skills by the young players (Doroschuk and Marcotte, 1965). In more recent years there has been a concerted effort to describe the physiological characteristics of young, elite ice hockey players. This was done to assess their capabilities, to reflect on past training programmes and, more recently, to prescribe new training programmes. Smith et al. (1982) suggest that the data which is gathered should provide a baseline from which comparisons with other athletes can be made, strengths and weaknesses assessed, and specific training prescriptions formulated.

McNab (1979) published the results from a 5 year longitudinal study of 15 boys involved in an intense ice hockey programme. The study was initiated when the boys were 8 years of age and continued up to and including 12 years of age. Each year evaluations of skating and puck control skills were made. In addition, annual measurements of height, weight, grip strength, physical work capacity (PWC_{170}), and the CAPHER fitness-performance items were taken. Results of the skating and puck control tests indicated learning curves which, while typical in nature, demonstrated extremely high levels of achievement for boys of this age (unpublished data by Hansen; McNab, 1979).

Blimkie and Cunningham (1978) and Cunningham (1979) investigated the maximal aerobic power of young hockey players and observed that young highly motivated boys found it difficult to develop high levels of blood lactate and to exercise at maximal levels so that a plateau in VO_2 is reached prematurely. In a study by Cunningham (1979) blood levels following tests of aerobic power were found to be 8.6 $mmol*l^{-1}$ at age 11, while this value gradually increased to 10.5 $mmol*l^{-1}$ at age 16.

DEVELOPMENT AND VALIDATION OF AN ANAEROBIC SKATING TEST FOR ELITE ICE HOCKEY PLAYERS

In an unpublished study the validity and reliability of two on-ice tests were evaluated by comparing on-ice blood lactates and performance measures with the same variables generated in the laboratory on an extended (40 second) WAnT. The two on-ice tests which were used in this study included the Sargeant Anaerobic Skate (SAS) and the Repeat Sprint Skate (RSS) which was developed by Reed et al. (1979). The three performance measures which were analyzed were anaerobic capacity, anaerobic power, and the rate of fatigue.

The mean scores for anaerobic capacity and power which were achieved on the SAS were significantly greater than those on the extended WAnT. Astrand and Rodahl (1977), Brouha (1945), and Fox (1975) have shown that individuals who are trained for heavy exercise of a particular type (skating) are able to do more relative work in that activity than when performing other forms of exercise (cycling). The mean scores for the rate of fatigue showed that subjects fatigued to a greater, relative degree on the WAnT than on the SAS.

Following the SAS a peak value of 10.69 $mmol*l^{-1}$ lactate was measured. This value is similar to that of the hockey players reported by Green (1978) following 5 repeats of 60 seconds skating at 120% of their maximum aerobic power. Green (1979) and Green et al. (1978) reported values ranging from 2.92 to 6.16 $mmol*l^{-1}$ lactate during intermissions of actual hockey games. Green (1978) felt that the blood samples in these experiments gave some indication of the contribution of glycolysis to the total energy supply, and that values were significantly elevated from resting levels.

SAS performance measures when correlated against the WAnT indicated it was a valid measure of anaerobic capacity, but not of anaerobic power or fatigue. The SAS was found to be reproducible and reliable.

The mean scores for anaerobic capacity and power which were achieved on the RSS were significantly greater than those on the extended WAnT. Anaerobic power scores were derived from the time to skate the first length of each trial. The mean times recorded in this study are similar to that reported by Reed et al. (1979) and Smith et al. (1982). The mean scores for the rate of fatigue showed that subjects fatigued to a greater, relative degree on the WAnT than on the RSS. The mean drop-off time on the RSS compared favourably with those of the elite players studied by Reed et al. (1979) and Smith et al. (1982). Following the RSS a peak value of 11.53 $mmol*l^{-1}$ lactate was measured.

RSS performance measures when correlated against the WAnT indicated it was a valid measure of anaerobic capacity, but not of anaerobic power or fatigue. The RSS was found to be reliable but not reproducible.

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APPENDIX B

DEFINITION AND CALCULATION OF ANAEROBIC CAPACITY

ANAEROBIC CAPACITY - the maximal amount of work that can be produced utilizing anaerobic metabolism (both the alactic and lactic acid components of anaerobic metabolism are used in the determination of this value).

REPEAT SPRINT SKATE

$$\text{Anaerobic Capacity} = \frac{\text{subject's wt. (kgs)} * \text{D. skated (365.80 m)}}{\text{time (seconds)}} = \text{kgm*sec}^{-1} * 60 = \text{kgm*min}^{-1}$$

$$\text{kgm*min}^{-1} - 6.12 = \text{watts}$$

$$\text{watts} * .06 = \text{joules}$$

WINGATE ANAEROBIC TEST

$$\text{Anaerobic Capacity} = \frac{\text{total revs. (40 sec)} * \text{circum (m)} * \text{res (kgm)}}{\text{time (40 seconds)}} = \text{kgm*sec}^{-1} * 60 = \text{kgm*min}^{-1}$$

$$\text{kgm*min}^{-1} - 6.12 = \text{watts}$$

$$\text{watts} * .06 = \text{joules}$$

APPENDIX C

DEFINITION AND CALCULATION OF ANAEROBIC POWER

ANAEROBIC POWER - the maximal amount of work that can be produced in a fixed period of time (the alactic component of anaerobic metabolism is primarily used in the determination of this value).

REPEAT SPRINT SKATE

$$\text{Anaerobic Power} = \frac{\text{subject's wt. (kgs)} * \text{D. skated (54.87 m)}}{\text{time (seconds)}} = \text{kgm}*\text{sec}^{-1} * 60 = \text{kgm}*\text{min}^{-1}$$

$$\text{kgm}*\text{min}^{-1} - 6.12 = \text{watts}$$

WINGATE ANAEROBIC TEST

$$\text{Anaerobic Power} = \frac{\text{total revs. (5 sec)} * \text{circum (m)} * \text{res (kgm)}}{\text{time (5 seconds)}} = \text{kgm}*\text{sec}^{-1} * 60 = \text{kgm}*\text{min}^{-1}$$

$$\text{kgm}*\text{min}^{-1} - 6.12 = \text{watts}$$

APPENDIX D

DEFINITION AND CALCULATION OF RATE OF FATIGUE

RATE OF FATIGUE - a reduction in the efficiency of movement (distance covered) that is generated over a period of time and a series of repeated trials.

REPEAT SPRINT SKATE

$$\text{Rate of Fatigue} = \frac{\text{trial D. (54.87 m)}}{\text{fastest trial time (sec)}} - \frac{\text{trial D. (54.87 m)}}{\text{slowest trial time (sec)}} = \text{m*sec}^{-1}$$

WINGATE ANAEROBIC TEST

$$\text{Rate of Fatigue} = \frac{\text{(highest 5 sec. revs) - (lowest 5 sec. revs) * circum (m)}}{\text{time (5 seconds)}} = \text{m*sec}^{-1}$$

APPENDIX E

PROTOCOL AND CONSENT FORM

TITLE OF RESEARCH: The Effects of Training on Anaerobic Capacity, Anaerobic Power, and Rate of Fatigue in Prepubertal Elite Ice Hockey Players.

Researchers: Dr. E.C. Rhodes, J. Potts, Dr. B. Ho, Dr. R. Lloyd-Smith, Dr. R. Mosher, and Dr. J. Taunton.

The purpose of this study is to investigate the effects of training on 9 and 10 year-old representative hockey players. This research will require your son to participate in a series of testing procedures in November, and a repeat of these tests 16 weeks later in March. These testing procedures will be divided into an on-ice component and a laboratory component.

The on-ice tests will include a Repeat Sprint Skate in which each subject will be required to skate a distance of 91.45 metres (300') on 4 separate occasions (trials). The total time involvement of this test is two minutes and twenty seconds. Following this test your son will be asked to sit down and rest for 5 minutes at which time a small quantity of blood (25 micro-litres) will be removed for analysis by a fingertip prick method. A physician (either Dr. Taunton or Dr. Lloyd-Smith) will supervise the removal of blood from subjects.

The laboratory tests will consist of taking an initial set of skeletal x-rays of the left wrist and hand of your son. The amount of radiation your son will be exposed to will be minimal (100 mRads). The skeletal x-rays will give the researchers the level of skeletal development (maturation) of your child. This information may then be used to explain any results that may be attributed to "early" vs. "late" maturation. The supervision and analysis of the x-rays will be done by a radiologist (Dr. Brian Ho, U.B.C. Department of Radiology).

A bicycle ergometer test will also be administered. Your son will be asked to pedal a bicycle as fast as he can against a resistance that has been predetermined by his body weight. The duration of this test is 40 seconds. Following the test your son will be asked to sit and rest for 5 minutes after which his finger will be pricked and a small quantity of blood removed (25 micro-litres).

Measures of peak muscular strength will then be determined on muscle groups of the thigh and leg. The muscular strength will be assessed at three velocities of movement (30, 100, 180 deg*sec-1) so as to assess both the integrity and dynamic capabilities of the involved joints.

The final laboratory measure is a hydrostatic weighing technique which will be used to evaluate your son's body composition. Hydrostatic weighing is used to determine an individual's body density from which a percentage of body fat can then be calculated. This procedure is not difficult although it requires the subject to be submerged under water for 4 or 5 seconds.

It is expected that your son will complete these tests without complications. Because of the very uncommon, unpredictable response of some individuals to exercise, unforseen difficulties may arise which would necessitate treatment. Complications have been few during exercise tests and these usually clear quickly with little or no treatment. Your son is asked to report any unusual symptoms during the testing procedures. Your son will be able to stop exercising at any time because of feelings of fatigue or discomfort. Every effort will be made to conduct the tests in such a way as to minimize discomfort and risk.

Prior to the actual testing sessions your son will be allowed a 5-10 minute warm-up period. At any time through the course of the study you or your son may feel free to ask questions about the nature or design of the study.

In signing this consent form you state that you have read and understand the description of tests, and the possible complications involved. Your son enters the testing procedures willingly, but may withdraw or refuse to participate at any time. Finally, all of the information and data that is collected about your son will be kept in the strictest confidence, in a locked filing cabinet.

CONSENT: I have read the above comments and understand the explanations which are given. I approve of my son participating in these testing procedures.

SUBJECT'S NAME: ____________ PARENTAL CONSENT GIVEN BY: ____________

DATE: ____________ WITNESS: ____________