CHANGES IN THE NEUROMUSCULAR AND CARDIORESPIRATORY PERFORMANCE DURING THE COMPETITIVE SEASON IN EARLY AND LATE MATURED 14-15- YEAR OLD MALE ICE HOCKEY PLAYERS

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ABSTRACT

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Ice hockey as a game is metabolically very demanding, and well trained aerobic and anaerobic metabolism is needed. Adolescent players have their own schedule according to growth and maturation. There might be huge differences at growth and maturity during pubertal and adolescent years. The aim of this study was to examine changes in the performance profile during the competitive season and compare changes in performance profile between early and late matured subjects.

The measurements were done during the competitive season (Spring 2011 – Spring 2012). Subjects of this study were 14-15-year old male ice hockey players, who were competing at the highest national level. The measurements were done four times during the competitive season: PRE before preparatory period, MID1 between preparatory and competitive period, MID2 on Christmas break and POST after the competitive season. Neuromuscular (maximal and explosive strength of lower- and maximal strength and muscle endurance of upperbody and trunk), cardiorespiratory (maximal graded bicycle ergometer test) and on ice skills (skating- and stickhandling track) were tested.

The neuromuscular performance improved significantly ($p<0.05$) between PRE to POST in maximal bilateral isometric leg extension (from 3425±578N to 3847±696N) and maximal trunk extension and flexion (trunk extension from 85.8 ±12 kg to 98.7±14 kg and trunk flexion from 68.4±13 to 74.9 ± 15 kg). Between the group comparison the early matured group were stronger in all measurements. No differences were found in the speed and explosive strength tests. The cardiorespiratory performance measured by peak power (W) in the maximal graded bicycle ergometer changed significantly ($p<0.05$) between PRE to POST (from 282,9±26 W to 298±26 W). The early matured group had significantly ($p<0.05$) higher peak power compared to late matured group in all measurements. In relative change during competitive season, the late matured subjects improved performance more compared to the early matured group in strength, speed strength, speed and on ice skills.

The physical performance tests showed that subjects were able to improve and maintain their physical performance level over the competitive season. According to the present results, the early matured subjects were bigger and stronger compared to the late matured group. In speed, on ice skill and explosive strength tests, no differences were found. This information suggests that early matured players have an advantage at the game, because they are bigger and stronger, and are as fast and skilled as late matured players. Late matured players improved physical performance level and on ice performance more compared to early matured subjects. According to this information, it may be too early to jugde players at this age, because growth is still going on.

Keywords: Ice hockey, adolescent , performance profile, biological age

CONTENTS

1. INTRODUCTION

Ice hockey is a physically demanding sport. Aerobic metabolism creates foundation to player's actions and allows players to work longer by delaying fatigue. (Westerlund, 1985.; Twist, 1997) Short bursts and explosive activities are common in the game. These actions relies on high energy phosphates and neuromuscular performance ability. If action continues with high intensity, anaerobic glycolysis will be the major source of energy. (Twist & Rhodes, 1993.) According to Twist (1997) lower body strength influences to skating, agility, body checking and speed bursts.

Physiological growth and development includes development of the nervous system, hormonal maturity, cardiovascular development, muscle development and development of bones, tendons and ligaments. The nervous system development is fast. At 5-6 years of age, the nervous system is developed at 80% of its total size. (Mero, 1990., Mero, 2007., Hakkarainen, 2009) Hormonal levels remains low during childhood. During puberty growth hormone and testosterone secretion increases and causes growth. (Mero, 1990., Mero, 2007., Round et. al. 1999) Cardiovascular development increases after birth with normal growth. Increases in heart size is larger in the left ventricle, because it pumps blood. Age, weight and height correlates with heart size. (Malina et. al., 2004) Growth of human muscle cells is considered to be only growth of muscle cells (hypertrophy), not increased amount of muscle cells (hyperplasia). (Malina et. al., 2004)

There are somatic, sexual and skeletal methods to evaluate biological age. A common somatic method is Peak height velocity, which includes follow up of the stature longitudinally. Hand and wrist bones provides primary basis for assessing skeletal maturation. It is based on changes in skeleton development which can be viewed and evaluated with standardized radiograph. Sexual maturation assessment is based on secondary sex characteristics. Use of these characteristics is limited to pubertal or adolescent phase of growth and maturation. (Malina & Beunen, G. 2008)

Trainability before and during puberty is commonly based on the long term athletic development (LTAD) model and sensitive periods/windows of opportunity. LTAD models are developed from physiological perspective. The aim of these models is to develop athletic potential alongside with biological growth. The data where the model is based on includes erroneous methodology and questionable assumptions. It is important to see this model as a “work in progress”, and model should be questioned, revised and tested by scientifically. (Ford et. al., 2011.)

The increase in muscle strength during childhood is largely neural. Only minimal hypertrophy may occur. During puberty greater gains in strength are noticed. (Round et. al. 1999)

Data about trainability of anaerobic capacity in children and adolescent is limited. Some studies have shown that anaerobic power is increased following a period of high intensity training in youth. It appears that puberty is an important period in development of anaerobic power. This probably reflects changes in body size, muscle mass and glycolytic capacity. Neural factors are also involved. (Malina, R.M. & Eisenmann, J.C., 2003)

Data about when a childhood pattern of cardiovascular responses to exercise change to adult pattern is not presently available. According to Naughton et. al. (2000) growth related changes in performance after aerobic training between trained adults and well trained adolescents are related to changes in hormonal secretion during maturation.

2. ICEHOCKEY AS A GAME

2.1. Physiological demands

Ice hockey is metabolically a very special and demanding game. It is physically demanding and well trained aerobic and anaerobic metabolism is needed.

According to Westerlund (1984) aerobic metabolism creates foundation to player's actions. It helps player to recover and saves anaerobic energy production. According to Twist (1997) good aerobic condition allows player to work longer by delaying fatigue. Vo2max values from players at different levels are presented in table 1.

TABLE 1. Vo2 max values of ice hockey players from different levels. Modified from Twist & Rhodes (1993)

Reference	**Level**	**Age (Mean)**	**Weight**	**VO2 Max (ml/kg-min)**
Cunningham et. al. 1976	Youth hockey	11	63,9	56,6
Montpetit, et. al. 1979	University	21	70,5	58,1
Rusko, et. al. 1978	National	22	81,4	61,5
Rhodes, et. al. 1988	Professional	25	85,5	54

Ice hockey includes a lot of starts, stops and maximal bursts when player reacts to game situations. Movements like this places demand to anaerobic energy production. Also explosive starts, body checking and slap shots relies heavily on anaerobic energy production. Immediate sources of energy lasts for ca. 10 seconds. If work continues intensive after that anaerobic glycolysis will be a major source of energy. (Twist & Rhodes, 1993)

The role of anaerobic glycolysis is major during 30-45 seconds lasting bouts of intensive exercise. Partly from that reason shifts in ice hockey lasts that long. (Twist,

1997) According to Westerlund & Summanen (2000) anaerobic glycolysis is a major source of energy (60-70% from it's total energy production) during one shift.

According to Twist (1997) lower body strength influences to skating, agility, body checking and speed bursts. Upper body strength influences to body checks, shooting and stickhandling. Upper body strength and lower body power helps player to manage in 1 on 1 situations during game. A sufficient level of muscle hypertrophy and strength also decreases risk of injury during the game.

Player's skating is highly dependent from the strength level of the lower extremities. Maximal strength and power relates to players ability to explosive starts and change of directions. Checking power, shooting and skating rhythm comes from the upper body. Player's balance, shooting and checking power also comes from the core and hip area force. (Hakkarainen, 2008)

2.2. Technical skills

Technical skills in ice hockey are skating, passing, shooting and stickhandling/ puck control. Skating is the most important technical skill in ice hockey and it could be splitted in different skating techniques which are skating straight, crossovers, stops and starts and turns. Each of them is possible to perform either forward or backward.

Technically shooting includes four different techniques which are slap shot, wrist shot, sweep shot and backhand shot. Westerlund (2007) sees shooting skill training more and more situation which happens under opponents pressure, but also remembers that technique should be also learned well.

2.3. Tactical aspects

The aim of team tactics is to use own strengths and avoid the use of own weaknesses. Oppositely also try to find out other teams weaknesses and eliminate their strengths. Team tactics is often driven by the game system, which is planned with in co-operation with team tactics. In practice these goals are scoring in the offensive game and protecting the own net in a defensive game. In practice, tactic is dependent on individual's ability to make solutions. To execute team play effectively, individual has to understand teams aims in different game situations and co-operation principles. (Westerlund, 1997)

3. PHYSICAL GROWTH AND DEVELOPMENT OF MALES

3.1. Nervous system development

According to Hakkarainen et. al. (2009) the neuromuscular system consists of nerves (brain, spinal cord, nerve cells) and muscles. When fetus is six months old nerve cells are created and growth of the nervous system after that is due to the increase of nerve cell size, myelinisation and increase of connective tissue. Nerve cell can increase it's size even 200 000 times larger compared to the birth size. At 5 to 6 years age, the nervous system is 80-90 % of adult the size. After 12 years development of the nervous system is much slower compared to other organs. Early maturation of the nervous system creates opportunity for trainability of skill and coordination at young age. During first 10 years of life, skill training is emphasized. (Malina et. al., 2004,Mero, 1990., Mero, 2007., Hakkarainen, 2009)

3.2. Hormonal maturity

Overall children growth regulates hypothalamus, pituitary, liver and growth cartilages. Regulation is complex and main hormones are growth hormone, testosterone and estrogen.

Growth hormone has a major role in growth regulation. It also takes part to many metabolic issues. Right after birth GH concentration in children might be high, but later it is usually low. Circulating (figure 1.) insulin like growth factor- 1 (IGF-1) increases during years before and after PHV (Round et. al. 1999). High concentration might reveal after meals or during sleep. During puberty GH concentration increase. Thyroid hormone also has major role to growth during childhood. The Increase in height velocity occurs via increased androgen secretion. Androgens could speed up growth also without GH. Growth hormone speeds up especially the growth of limbs and androgen effects to the spinal cord. Androgens speeds up growth cartilage development. Overall GH physiological factors effects are anabolic effects, effect to electrolytes, effect to bone and cartilage growth and effects to carbohydrate and fat metabolism. (Malina et. al., 2004; Mero, 1990., 2007.)

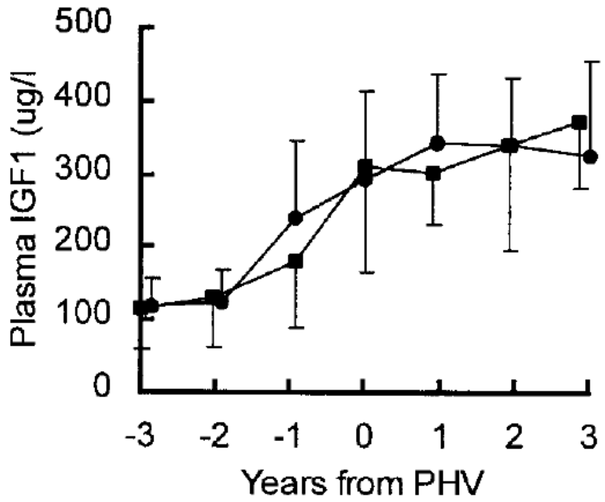


FIGURE 1. Circulating IGF-1 in relation to PHV (Mean + SD). Circles are boys and squares are girls. (Round et. al. 1999)

Testosterone is another growth and maturity stimulating hormone. At the moment of birth, production of testosterone is minor, but it increases during the first months of life. 3 months old boy child has already ca. a half of testosterone concentration of the adult male in his plasma. Concentration decreases after that a little and remains minor until puberty. During puberty the level of testosterone (figure 2.) increases step by step to the adult level. According to Round et. al (1999) circulating testosterone levels starting to rise year before PHV and then increases steadily and reaches the adults level ca. 3 years after PHV. Secretion of testosterone varies which became apparent from momentary variation. Ca. 95% of blood testosterone emanates from the testicles and the rest from the adrenal gland. The straight effect of testosterone occurs in epiditymises, muscles, production of red bloodcells and armpits and pubic hairs. Biological effects of testosterone occurs genital growth, bone and muscle growth, increase of pubic hairs, increase of red bloodcells through erythropoetin.

(Mero, 1990., 2007.)

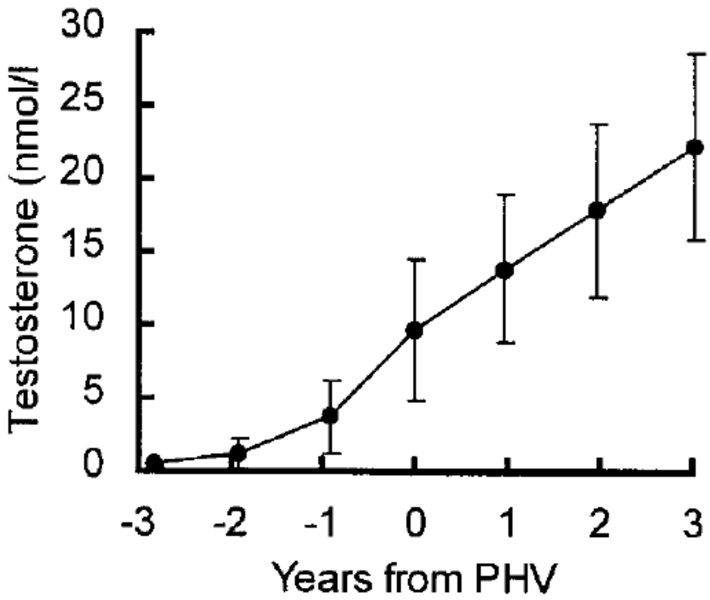


FIGURE 2 Circulating testosterone in relation to PHV (Mean + SD). (Round et. al. 1999)

3.3. Growth and development of the cardiorespiratory system

Heart size changes significantly after birth in the left side, particular the left ventricle grows faster than the right side. The left ventricular's progressive hypertrophy is related to the fact that the left side pumps blood against a higher pressure than the right side. Heart volume increases until young adulthood. Heart size increases after the birth with normal growth and the increased level of activity. Heart size doubles at 6 months age, quatrubles to 2 years of age and reaches approximately 600-800 cm3. Changes in hearts capacity correlates with age, body mass (especially fat free body mass) and height. Heart rate frequency decreases slowly from the birth to puberty. Boy's average heart rate frequency is 10% lower than in girls during puberty. Systolic blood pressure increase also slightly more in boys than girls. The amount of hemoglobin and red blood cells decreases during the first months of living, but according to Hakkarainen (2009) those start to increase pretty soon after that. A total amount of blood increases during child growth from 10 years old boys values of 2,0 L to the puberty value of 4 L and adult value of 5-6 L. (Malina et. al., 2004, Hakkarainen, 2009, Mero, 2007)

TABLE 2 Heart dimensions of boys 8 through 18 years of age. (Modified: Malina et. al, 2004)

Age	Body weigth (kg)	Heart length (cm)	Heart Width (cm)	Heart depth (cm)	Heart volume (cm2)	Heart volume/ BW (cm2/bw)
8	28,4	11,2	9,1	7,8	282	10,0
9	30,8	11,8	9,1	8,1	312	10,3
10	32,3	11,8	9,6	8,2	328	10,1
11	35,6	12,2	9,8	8,6	362	10,3
12	38,6	12,4	10,0	9,0	395	10,3
13	44,8	13,2	10,4	9,1	444	10,1
14	49,0	13,7	10,9	9,5	503	10,3
15	56,1	14,1	11,5	9,6	551	9,8
16	63,0	14,8	11,9	9,7	603	9,6
17	66,7	14,8	12,2	10,2	646	9,7
18	66,8	15,3	12,3	10,2	671	10,1

A wide range of individual variation occurs in heart rate of the newborn infants. Basal heart rate is about 140 b/min at the newborn and continues to decline during childhood. By late adolescence, boys have an average heart rate of about 60 b/min. (Malina et. al., 2004.)

Stroke volume of the heart refers to volume of blood ejected from the left ventricle during one contraction and cardiac output is the output of left ventricle in one minute (product of heart rate and stroke volume). Stroke volume increases during childhood and adolescence from about 3-4 ml to 40 ml and reaches the level of 60 ml male rest level after adolescent growth spurt. (Malina et. al., 2004.)

The basic structure of the cardiorespiratory system is ready at the moment of birth. The functional structure, capacity and ability to gas exchange changes during entire growth. The size of the lungs changes with upper body growth. The volume of the lungs increases size six times and the weight increases three times larger during the first year of life and mass size increases 20 times larger from birth to adult. Elasticity of the lungs supporting structure also increases during growth. This makes breathing out more effective .The quantity of pulmonary alveoli increases during the first 8 years of life from 20 million to 300 million. Gas exchange area also increases strongly. (Hakkarainen, 2009, Mero, 2007)

During childhood and adolescence, blood volume is highly related to body mass and heart size and correlates also with maximal oxygen uptake. Blood volume increase through adolescence and young males have about 5 l blood which contains 3 l plasma and rest is primarily blood cells. (Malina et. al., 2004.)

Hematocrit (percentage of blood volume occupied by blood cells) is an important characteristic of blood. Adult male hematocrit value varies between 40-45% on average and it increases progressively through childhood and adolescence in boys.
Red blood cells and haemoglobin have important roles in delivering oxygen to body tissues. Red blood cells are produced in the bone marrow in virtually all bones during infancy and early childhood. After about 5 years of age, marrow of the long bones contributes progressively less to red blood cell production. (Malina et. al., 2004.)

3.4. Development of muscles

Growth of human muscle cells is considered to be only growth of muscle cells (hypertrophy), not increased amount of muscle cells (hyperplasia). Hyperplasia has been found from animal studies, but not from children during growth. Muscle fiber increases in diameter with age and body size postnatally. The Adult diameter are attained in late adolescence. During growth the size of muscle varies with use of the muscles. A 5-10 time increase of growth in muscle CSA has been noticed from birth to late puberty. At the same time muscle mass increases heavily, especially during puberty in boys. (Mero, 2007, Malina, 2004)

3.5. Development of bones, tendons and ligaments

At the moment of birth child has already all primary consolidation nuclei. Consolidation happens in the defined order and that is the reason why children maturity is described through age of bones. This growth varies a lot between individuals. Bone mass depends what type of loading is directed to them, nutrition and hormonal factors. (Mero, 1990., 2007., Hakkarainen, 2009)

4. METHODS TO ESTIMATE BIOLOGIGAL AGE AND MATURITY

4.1. Somatic maturity

The use of stature as an indicator of maturity requires longitudinal data from adolescent years. Adolescent growth spurt timing and tempo could be able to estimate. The percentage of mature/adult size can also be used to indicate maturity, if the adult stature is available.

Peak height velocity means maximum rate of growth during adolescent spurt. Age when PHV occurs, is an indicator of somatic maturity. The data for longer time period is needed to estimate age at PHV and related parameters of adolescent growth. The spurt in stature begins in boys at about 10-11 years , peaks at about 14 years and stops at about 18 years. There is also an earlier mid growth spurt at about 6,5-8,5 years age, but this spurt is much smaller. All children don’t have this mid growth spurt. Growth curves fitting into individual growth records is used for velocities and acceleration and also for calculation of timing and magnitude of spurt. (Malina & Beunen, G. 2008)

The stature and weight are the most commonly used measurements used in growth studies. Both dimensions are usually measured as regular basis (hospitals, schools, sport clubs etc.). Both stature and weight, follows a four phase pattern of growth. These patterns include rapid gain in infancy and early childhood, rather steady gain during middle childhood, rapid gain during the adolescent growth spurt, and slow increase in gain to the adult attainment level. Growth curves, which represent average curves of height and weight are used to indicators of growth status (figure 3.). (Malina et. al. 2004)

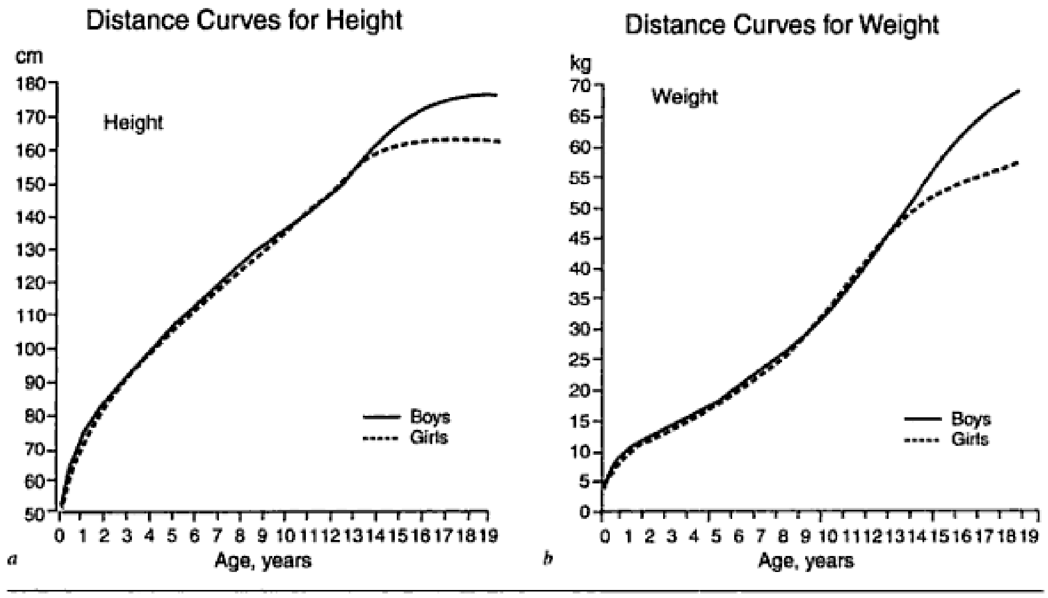


FIGURE 3. Distance curves for length and stature (a) and weight (b) for american children from birth to 19 years of age. (Malina et. al., 2004)

Distance or size attained curves are commonly used to estimate of single child or sample of children. When doing so, it is called to comparing them to the reference data, which is measured from the healthy, non diseased reference group. Standards do not exists so reference values are used. (Malina et. al., 2004)

The maturity offset method predicts time from PHV and it indicades maturity. This method requires age, height, sitting height, leg length, weight/ height ratio, and interaction terms. The outcome of this method is the predicted age at PHV.
The method which provides longitudinal data is the percentage of the maturity stature attained at a given age and indicates also somatic maturity. Children with closer to mature stature compared to other same chronological age child who is not that close, is more advanced in the maturity status. (Malina & Beunen, G. 2008)

Height and weight appears to be closely related to gains in strength. During prepubertal years correlation between weight and strength appears to be low to moderate and then increases and peak during pubertal growth period. Correlation between height and strength is low to moderate in prepubertal years, increase to moderate level during puberty and diminishes to lower level during post puberty. (Blimkie & Digby. 1998)

4.2. Skeletal maturity

Hand and wrist bones provides the primary basis for assessing skeletal maturation. It is based on changes in skeleton development which can be viewed and evaluated with standardized radiograph. Traditionally hand is placed on x-ray plate fingers apart and the left hand is usually used. Bone changes through initial ossification to adult morphology are quite uniform. Three methods are available to assess skeletal maturity. The Greulich- Pyle method is based on matching X-ray images to standard plates and comparing different bones. With this method skeletal age is based on the standard plate. The Tanner-Whitehouse method called also bone specific approach matches features of 20 individual bones. There are written criteria and specific scores for each stage that bones passes from the initial to mature state. There are also three versions of this method. The first one scores are summed to give the skeletal maturity score. Second method provides carpal skeletal age based on 7 carpals, radius, ulna, short bone skeletal age in addition to 20 bones skeletal age. The third method provides separate assessments of 13 long and 7 round bones. It is not providing score for 20 bone skeletal maturity score. The Fels method includes same 20 bones and pisiform and adductor sesamoid. The specific criteria is based on the shape change varieties and the ratios of linear width measurements. The method uses different bones for estimation of skeletal age, depending of age and sex of the child. This method provides standard error. Skeletal age assessment is the method to estimate maturity of the child relative to the reference data of healthy children. The methods described earlier differ from each other with criteria, scoring and reference sample. The changes of each bones are the same from initial phase to adult. The progress of changes varies between individuals. (Malina & Beunen, G. 2008)

4.3. Sexual maturity

The sexual maturation assessment is based on secondary sex characteristics. Use of these characteristics is limited to the pubertal or adolescent phase of growth and maturation. Secondary sex characteristics development is usually described at five stages or grades for each character. The most commonly used scale is Tanner (1962). This includes evaluation of pubic hair and genital maturation in males. Stage 1 indicates the prepubertal phase and in this phase genital area is approximately the same size as in early childhood. Stage 2 indicates the initial phase of development. This means genital enlargement and pubic hair appearance. Stages 3 and 4 are the continued progress of maturation characteristics and are more difficult to evaluate. Stage 5 is the adult/ mature state of each characteristics

Stage ratings are often made at clinical conditions. The method has limitations because it requires invasion of individuals privacy. Evaluations could be done with photographs by comparing to the standardized pictures. From pictures it might be quite difficult to recognize, for example the initial phase of pubic growth. The commonly used reference data have also somewhat later ages for stage 2 pubic hair development. Clinical observations give better estimates. (Malina & Beunen, G. 2008)

Characteristics are assessed using the criteria of Tanner. The stages of pubertal development are specific to different characteristics. Sexual characteristics should be evaluated individually for different characteristics (e.g. Pubic hair stage 3 and genital stage 4). (Malina & Beunen, G. 2008)

In males the evaluation of sexual maturity from the testes size is also possible at clinical conditions. This application requires direct manipulation of the testicles. The method is commonly used evaluate boy’s extremely late maturation or disorders of growth and sexual maturation. Self assessment is also possible. In this method subject compares his own characteristics to the standardized photographs. Good quality photographs should be used, and evaluation should explain carefully and made individually by respecting individuals privacy. (Malina & Beunen, G. 2008)

5. TRAINABILITY BEFORE AND DURING PUBERTY

5.1. Performance profile of the adolescent national team ice hockey players

Tikka (2000) studied finnish junior national teams physical profile during years 1997-2000. He concluded that especially two youngest age groups (1985 and 1984) should start to focus on planning and completing endurance and speed training, when compared to former age groups. He discussed that decrease in the results may have influenced improper physical training, but in this study there were not information about training background. The results of U-16 and U-17 years national team physical profile are in table 3 and table 4. Finnish ice hockey associations results from spring 2012 of U-17 year old national team are in table 5 (FIHA, 2012).

TABLE 3 Physical profile of U-16 national team. Years 1997 – 2000. (Modified from Tikka, 2000.)

U16- National team			Height cm	Weight kg	Fat %	PP-ergometer Watts	VO2max (ml/kg/min)	CMJ (cm)
1997	**1982**	**MEAN**	176,8	70,96	12	314,07	56,86	37,28
n=44		**SD**	6,13	7,02	2,87	27	4,29	3,68
1998	**1983**	**MEAN**	175	68,35	11,1	304,8	56,95	37,4
n=43		**SD**	5,34	6,51	2,85	30,71	4,7	4,22
1999	**1984**	**MEAN**	174,5	66	12,42	294,09	56,94	37,76
n=34		**SD**	5,16	6,69	2,17	30,2	3,47	3,6
2000	**1985**	**MEAN**	175,23	67,69	13,08	280,26	53,6	36,62
n=43		**SD**	5,96	8,34	2,34	30,17	5,07	4,31

TABLE 4 Physical profile of U-17 national team. Years 1997 – 2000. (Modified from Tikka, 2000.)

U17- National team			Height cm	Weight kg	Fat %	PP-ergometer Watts	VO2max (ml/kg/min)	CMJ (cm)
1997	**1981**	**MEAN**	177,5	73,82	11,63	323,04	56,32	39,37
n=28		**SD**	7,12	8,59	3,39	31,39	4,65	3,91
1998	**1982**	**MEAN**	179,36	75,51	11,9	331,9	56,28	40,48
n=29		**SD**	5,5	7,34	2,35	32,22	3,34	4,78
1999	**1983**	**MEAN**	177,89	73,76	11,35	317,29	55,11	41
n=28		**SD**	4,66	6,57	2,01	39,56	3,99	4,47
2000	**1984**	**MEAN**	178,34	70,88	11,68	298,14	54,02	38,77
n=29		**SD**	5,25	6,84	1,49	33,22	3,47	3,43

TABLE 5 Physical profile of U-17 national team. Year 2012. (Modified from FIHA, 2012.)

U17- National team 1996 (spring 2012)			Height cm	Weight kg	Fat %	PP-ergometer Watts	VO2max (ml/kg/min)	CMJ (cm)
2012	**1996 ALL**	**MEAN**	180,22	74,79	12,65	319	54,67	34,94

Kauhanen & Savolainen (1995) examined strength characteristics in junior ice hockey players. They reported that at the ages of 15-16 years, maximal force were 74% of that recorded from adult players. They also found strong age dependence from two youngest age groups (r = 0.77). Results are in figure 4.

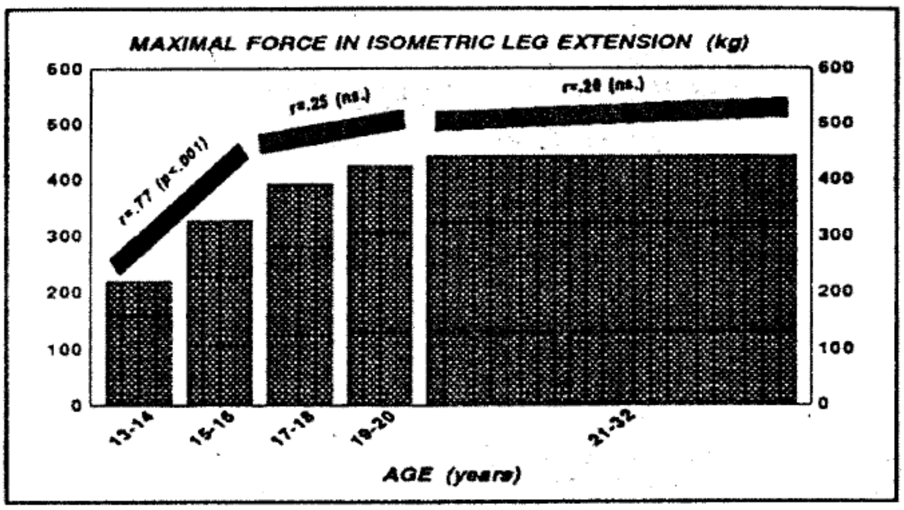


FIGURE 4 Maximal Isometric force of ice hockey players at different ages. (Kauhanen & Savolainen 1995.)

5.2. Sensitive periods/ Windows of opportunity

Long term athletic development (LTAD) plan should consider "windows of opportunity". Those are the periods when certain ability develops partly through natural growth, and improvement is easier and training more effective. (Hakkarainen, 2009) The LTAD (an example in the figure 5. below) models are developed from physiological perspective. The Aim of these models is to develop athletic potential alongside biological growth. The model focuses to develop performance longitudinally, and considers sensitive developmental periods known as the windows of opportunity. However, it looks that the model is only one dimensional, and there is a lack of empirical evidence upon which the model is based. The data where the model is based on includes erroneous methodology and questionable assumptions. It is important to see this model as a "work in progress", and the model should be questioned, revised and tested by scientifically. (Ford et. al., 2011.)

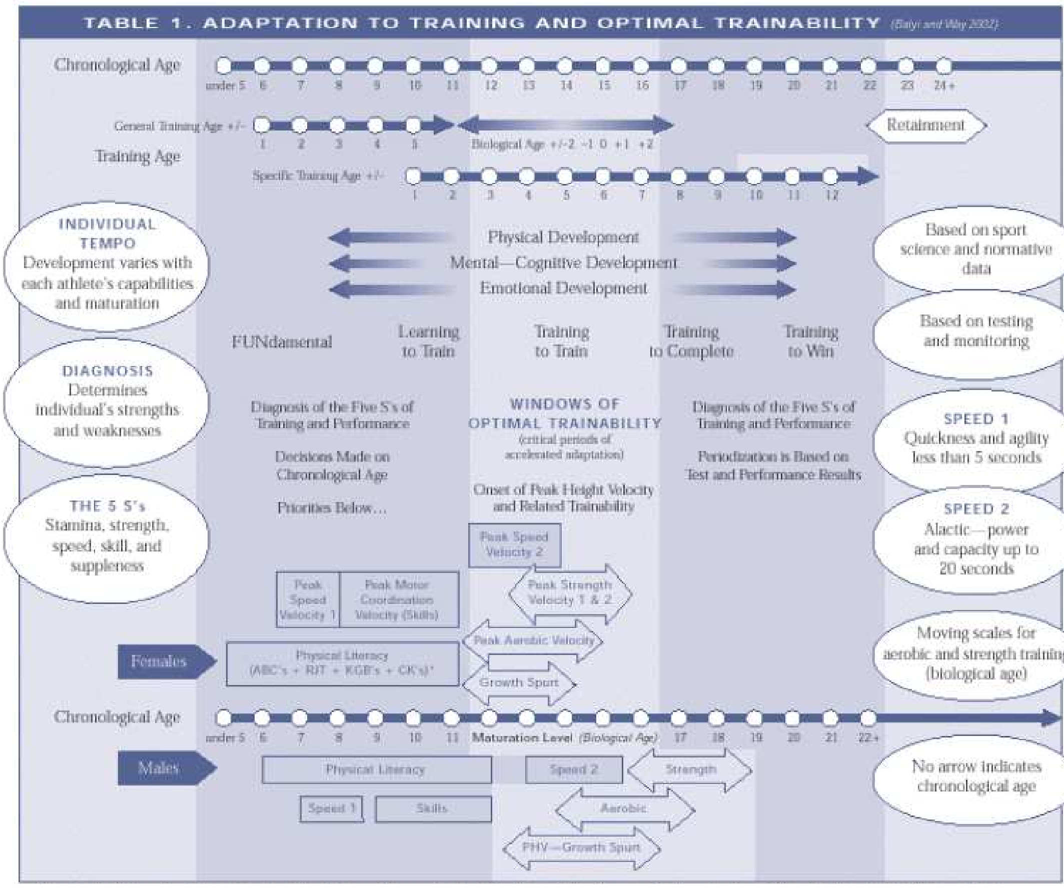


FIGURE 5. Adaptation to training and optimal trainability (Balyi, I. 2003.)

5.3. Muscle Strength, endurance and power trainability

5.3.1. Muscle strength

Strength characteristics follow a general type of growth. Muscle strength increases naturally without special strength training during the first 20 years of life. Increased hormonal activity during puberty causes a fast increase of maximal strength to ca. 20 years of age. Muscle mass also increases greatly during that period. (Häkkinen, K. 1990). Age associated changes in muscle size and strength during puberty have been attributed largely to hormonal influences. Especially changes in testosterone secretion. Testosterone increases about 4 fold during early phase of puberty and after that increase rapidly by another 20 fold during mid and late puberty in males (Blimkie & Digby. 1998).

From 3 years of age to 6 years of age, the mean level of static strength increases gradually. Static strength increases linearly from 6 to 12-13 years of age in boys. The increase happens in several muscle groups. Explosive strength increases also linearly during ages of 6 – 13 when measured as a standing long jump or vertical jump. Muscle endurance increases markedly after 12 years of age in boys, when measured by flexed arm hang.

Blimkie et. al. (1990) studied prepubertal boys resistance training with dynamic, isometric and isokinetic exercises. The 20 week training program included 3 times/ week resistance training. Subjects improved strength significantly in both, upper and lower body strength tests. Conclusion were that motor skill coordination, tendency toward increased motor unit activation and other undetermined neurological adaptations (muscle coordination at involved muscles) are likely major determinants to strength gains in that study.

Boys have a clear adolescent growth spurt 3 months to 1 year after Peak height velocity in static, explosive and muscle endurance of the upper body. During preadolescence and also adolescence, biological maturity effects positively to static strength. From 13- years forward, explosive strength and muscle endurance of the upper body and lower trunk are positively associated to biological maturity, even when controlling of variation in chronological age, stature and body mass are considered. During adolescence, interaction between the stature, body mass and biological maturity explains a significant part of variation in strength. In preadolescence body mass and stature are more important predictors. Strength gain after weight training programme is only partially genetically determined. (Beunen, G. & Thomis, M., 2000.; Malina et. al. 2004.)

Many recent research shows that children and adolescent can significantly improve their muscle strength and power by proper resistance training (Faigenbaum et. al. 2007, Tsolakis et. al. 2004.). Strength training can be very beneficial to children and youth if it is done properly. Strength gains followed by resistance training were typically 13-30% larger than could be expected with natural growth following resistance training programs of 8-20 weeks (Falk & Tenenbaum, 1996). Strength gains expected after short term resistance training program are roughly 30% in children and adolescents. Strength training led to better motor performance in several studies (Szymanski et. al., 2007; Flanagen et al., 2002; Faigenbaum & Mediate, 2006), but strength and power did not necessary lead to improved performance in motor tasks (Faigenbaum et. al. 2005; Faigenbaum et al., 1993; Flanagen et al., 2002). To gain the greatest improvement, strength training should be specific and muscle type action similar to performance. (Ignjatovic et. al., 2009.)

Resistance training has been effective to increase strength, but increases in muscle size have been pretty small. Some more sensitive measures (MRI, ultrasound) have suggested that hypertrophy may occur. All in all, strength gains in children are mainly caused by neurological adaptation. (Ignjatovic et. al., 2009.)

Round et. al. (1999) studied longitudinally 50 boys and 50 girls from ages 8-12 to ages 13-17. The results show that boys have an additional factor which can be fully attributed to testosterone compared to girls. Testosterone might have also an indirect effect to strength by promoting also growth of the muscle. (Figure 6 & 7)

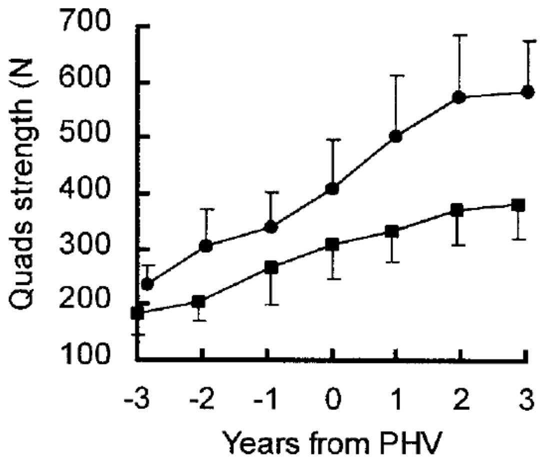


FIGURE 6. Quatriceps strength in relation to PHV (Mean + SD). Round circle are boys and squares are girls. (Round et. al. 1999)

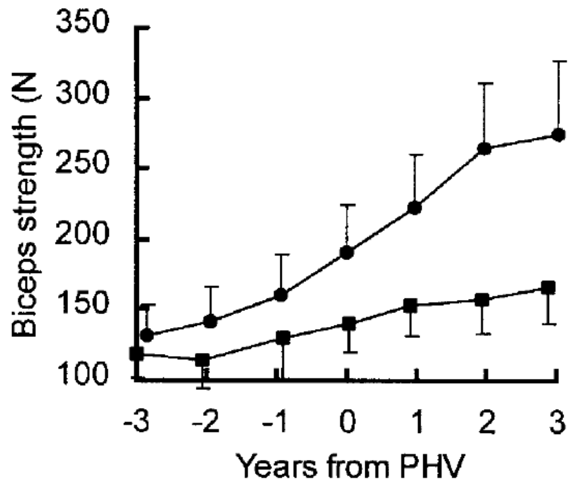


FIGURE 7. Biceps muscle strength in relation to PHV (Mean + SD). Round circles are boys and squares are girls. (Round et. al. 1999)

Conservative taught is that prepubertal children are not as responsive to strength training as pubertal or postpubertal, but are still able to increase their strength level through training. Boys between 6-11 years and 9-11 years age did a supervised strength training program and had greater gains in strength compared to the control group. Prepubertal children respond to training with gains in strength but show minimal muscular hypertrophy. (Malina, R.M. & Eisenmann, J.C. 2003) Relatively small increase in muscle size compared to gains in strength suggests that the response to resistance training in prepubertal children is largely neural. (Malina, R.M. & Eisenmann, J.C. 2003). Training is effective to develop strength of a prepubertal child. Muscle hypertrophy is very seldom directed to gains of muscle strength. (Rowland, T.W., 2005.)

Structured resistance training has been demonstrated to significantly improve running, jumping and throwing performance in children and adolescents. When motor skills are considered to be essential part of different sports, it could be thought that resistance training have positive transfer to sport specific performance. (Behringer et. al. 2011)

Meta-analysis which included 28 studies examining effects of resistance training under 18 years of age, shows (figure 8.) that resistance training is effective to different ages and body parts. Research suggests that children and youth are able to demonstrate considerable increases in muscle endurance and strength with proper training. (Payne et. al. 1997)

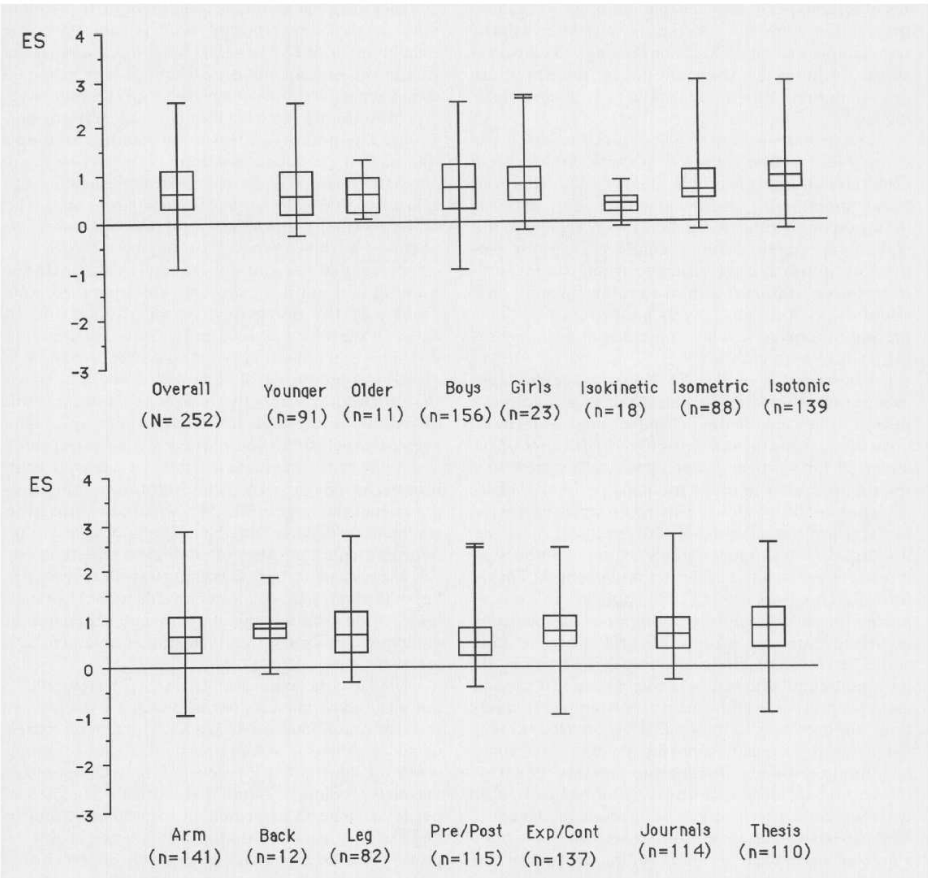


FIGURE 8. Box and whiskers of mean effect size by study characteristics. (Whiskers shows the minimum and maximum values and boxes shows 75%, 50% and 25% values) (Payne et. al. 1997)

5.3.2. Muscle endurance and power

Upper body muscle endurance tested by flexed arm hang improves linearly from 5 to 13-14 years at boys. After that comes spurt. (Malina et. al. 2004) Comparisons among children and adolescent have demonstrated higher muscle power and endurance in trained subjects compared to untrained. Trained 13-16 year old boys had 14% and 15% higher peak- and mean power than untrained boys in the wingate anaerobic test. Ingle et. al. (2006) reported 4-5,5% increase in anaerobic peak- and mean power, 40-m running sprint and vertical jump in pre- and early pubertal boys. The study included a 12 week training programme 3 times week combination of resistance and plyometric training. After 12 weeks of detraining, benefits were lost. The studies show that a training program may improve muscle power and endurance in children. (Blimkie & Bar-Or, 2008.) Explosive strength performance increase fairly linearly between 6 and 12 to 13 years of age. Vertical jump test results around PHV are in the figure 9. (Beunen & Thomis, 2000.)

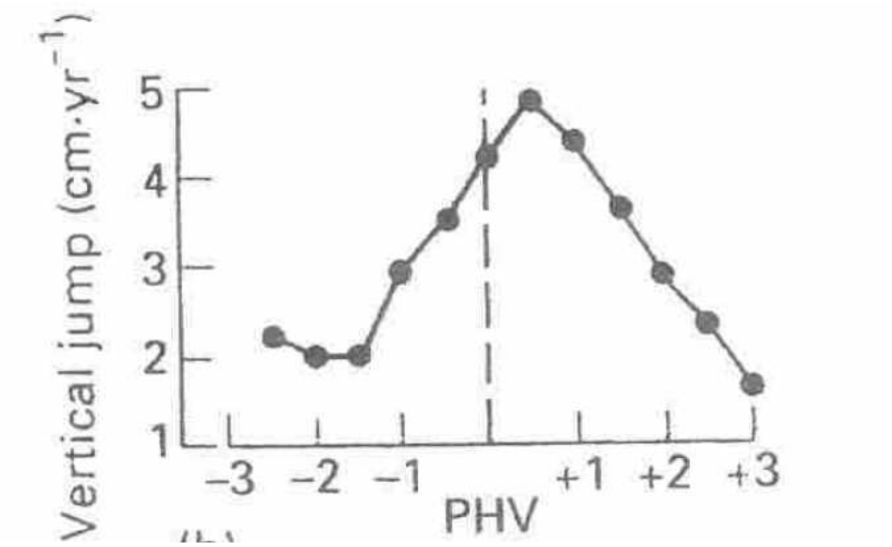


FIGURE 9. Results of vertical jump test align at the age of PHV. (Beunen & Thomis, 2000.)

Obert et. al. (2001) reported that a training group of 10-11 years old boys and girls increased maximal power during force velocity test 23 % in absolute terms and 18 % related to fat free mass. The control group did not show any changes. Baquet et. al (2001, 2004) reported improvements in standing broad jump among prepubertal children and adolescents during a 7-10 weeks training program. Program included maximal and supramaximal high intensity aerobic training. Keiner et. al. (2012) reported 13,6 % (U-17) and 10 % (U-16) improvement in countermovement jump (CMJ) at the adolescent soccer players, who performed periodized strength training beside regular soccer training about one year. Strength training group improved CMJ significantly more than the group who did not performed strength training.

Trainability in children seems to depend prior to starting fitness level of training program. 4-week. 3 times per week training program to 12 year old Canadian ice hockey and soccer players, who had just completed their season didn't bring any significant training induced differences in performance. . (Blimkie & Bar-Or, 2008.)

5.4. Endurance training

5.4.1. Aerobic performance

During puberty, a rise of VO2max accelerates in males as a result of anabolic influences of testosterone. (Rowland, T.W., 2005.) Growth related factors to aerobic performance are changes in body size, proportion and composition and motor skill development. Increased size of the heart muscle during growth is associated with increases in the stroke volume during growth when exercise is performed at the same absolute power output. Heart rate declines during growth and the product of heart rate and stroke volume increases. The data about when a childhood pattern of cardiovascular responses to exercise change to an adult pattern is not presently available. According to Naughton et. al. (2000) growth related changes in performance after aerobic training between trained adults and well trained adolescents are related to changes in hormonal secretion during maturation. Suggestion is that aerobic training in phase where there is lack of circulation metabolites, may reduce training adaptation response. Ventilation is higher in child than in adolescent or adult and the ventilatory equivalent decreases with age. Respiratory rate is higher in children at rest or during exercise. The ratio of tidal volume to vital capacity is lower in children. This suggests that children have lower ventilatory efficiency than adolescents or adults. (Malina et. al., 2004)

Power output in predominantly aerobic conditions increases with age during growth. Changes at any levels of power output are clearly illustrated from heart rate. In boys power output is triple time larger when comparing ages 7 and 17. When expressed power output units/ Body mass, it remains almost constant. (Malina et. al., 2004)

5.4.2. Anaerobic performance

The data about trainability of anaerobic capacity in children and adolescent is limited. Some studies have shown that anaerobic power is increased following a period of high intensity training in youth. It appears that puberty is an important period in development of anaerobic power. This probably reflects changes in body size, muscle mass and glycolytic capacity. Neural factors may also be involved. (Malina, R.M. & Eisenmann, J.C., 2003)

Anaerobic fitness can be explained by a capability to perform maximal anaerobic exercise. Capacity to generate highest mechanical power (peak power) over a few seconds (maximal anaerobic power), and sustain high power output over a short period of time (mean power), can be considered as prime indicators of anaerobic fitness. (Inbar & Chia, 2008) Philippaerts et. al. (2006) reported the largest gains in speed around the time of peak height velocity. Writer mentioned that sprint performance had declined 12 months before PHV and results might be influenced from previously impaired performance. Improvements in speed may also be related to increased length of the lower limbs. Venturelli et. al. (2008) found that speed gains were similar between coordination and straight sprint training in the pre adolescent training groups. This supports the role of coordination and neural control of movement in speed development prior to maturation.

Adolescents have lower power generation per body mass compared to adults. There are various mechanisms which may explain this lower anaerobic power in young populations. These include lower phosphofructokinase (rate-limiting enzyme of glycolytic pathway) levels, lower sympathoadrenal activity, maturational differences of muscle fibre distribution and immature anabolic hormone response (eg. testosterone). Increased anaerobic potential refers to enhanced rates of ATP release. This happens either via ATP-PCr catabolism or breakdown of carbohydrate in active tissue during intense exercise. Anaerobic potential increases progressively during adolescence. Supporting facts are increased enzymatic activity, anaerobic performance and serum lactate levels. Gains in muscle mass and body size appears enhancement in anaerobic trainability of adolescent boys A couple of studies about muscle storages of phosphagens have shown that the content of peripheral energy delivering substrates is the same in children and adults at rest. It is still assumed that the rate of anaerobic glycolysis is limited in children because of lower phosphofruktokinase (PFK) activity.

The assumption is only discussed on the basis of PFK activity at rest. (Naughton et. al., 2000.)

During exhaustive exercise and recovery, high-energy phosphate kinetics differ between children and adults. Ability to use anaerobic metabolism is lower in children, and drop in pH level is also minimal compared to adults. Children show relatively low muscle and blood lactate response to high intensity exercise. Prepubescent children and adolescent have lower glycolytic capacity than adults during sustained high-intensity exercise. (figure 10.) Occuring hormonal changes and neurological adaptations are the most important contributors to anaerobic function improvement during growth. (Van Praagh, E., 2000)

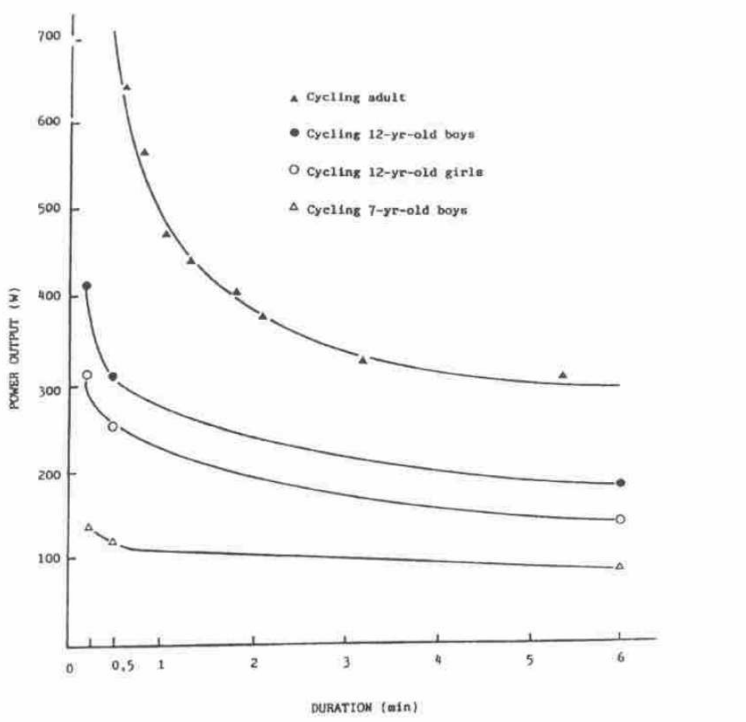


FIGURE 10. Power- duration curves for adults and children. (Van Praagh, 2000)

6. PURPOSE OF THE STUDY

The purpose of this study was to examine changes in the neuromuscular and cardiorespiratory performance during the competitive season, and compare differences between the 14-15-years old early and late matured males in sport specific and physical performance characteristics. This study also investigated relationships between physical performance and sport specific performance.

Research problems:

1. How does the neuromuscular performance change during the season?
2. How does the cardiorespiratory performance change during the season?
3. How do the changes differ between the early and late matured subjects?
4. Are there relationships between sport specific performances, physical measurements and estimated rate of puberty?

7. METHODS

7.1. Subjects

Subjects were 22 healthy (-96 and -97 born) 14-15-year old male ice hockey players. Subjects performed physical training, which was relatively similar in volume and intensity to every subject, during one competitive ice hockey season (spring 2011 to spring 2012). Measurements included Baseline tests before training start, 2x midtests during the season and post tests after the season. Before measurements subjects went through medical examination to estimate biological age on Tanner scale and make sure subjects were able to perform maximal exercise tests. Heart rest EKG and small blood count were also taken.

7.2. Measurements

Baseline- mid- and post measurements included the same tests (not all during both mid tests). Field tests included a 30 meter sprint running, 5-times jump test, pull ups and situps with 2,5 kg resistance. Laboratory measurements included the body composition evaluation by bioimpedance (Inbody 720), countermovement jump, maximal bilateral isometric leg extension, maximal graded bicycle ergometer test (Watts & heart rate), maximal isometric trunk extension & flexion and maximal upperbody strength by isometric bench press. On ice tests were stickhandling track and skating skill test. Laboratory tests were performed in the department in Biology of Physical activity, field tests in Hippos halli and on ice tests in practice rink in Jyväskylä.

7.3. Physical performance tests

7.3.1. Anthropometry

Body composition and weight measurements were performed with Inbody 720 device. Subjects were instructed to remove jewelleries or other medals from their bodies. Height was measured before the body composition analysis.

7.3.2.Neuromuscular performance

Maximal bilateral isometric leg extension force was measured in leg dynamometer build in the department in Biology of Physical Activity by using 107 degree knee angle (Häkkinen, 1985). Knee angle were tracked by using goniometer. If subject gained height between the measurements knee angle was checked, otherwise the same settings were used. The subjects were told to produce force as fast and as much as possible. If the result improved over 5 %, more trials were performed. Proper recovery between the trials was allowed.

Maximal isometric trunk extension & flexion forces were measured in the device (build in the department in Biology of Physical activity) at standing position where subjects body were leaning against the immovable board. Board were adjusted to chest level, under collar bone. Tight belt were adjusted on subjects waist.

Maximal isometric bench press force was measured with the isometric device. The bar was adjusted over chest, and height of bar was adjusted so that elbow angle was 90 degrees. The same settings were used in all measurements. If subject gained height between the measurements, settings were checked. Each subject performed at least three trials with proper recovery.

7.3.3. Cardiorespiratory performance

Maximal graded bicycle ergometer test was performed with Ergoline and Monark bicycle ergometers. Starting load was set to 50 watts (W) and load was increased 25 watts (W) in every 2 minute periods. Heart rate (Polar RS800, Polar Electro OY, Kempele, Finland) and Rate of perceived exertion was followed throughout the test. Test was continued to subjects exhaustion. Maximal oxygen uptake (VO2max) was estimated with equation.

7.3.4. Field tests and on ice performance

Countermovement jump were performed on a contact mat. This test was chosen to measure power of lower extremities (Komi & Bosco, 1978.) Subjects were instructed to stand hands on his hips in comfortable starting position. From this position, subject bended his knees, hips and ankles and then immediately jumped as high as possible. Subject was instructed to land legs straight to the ball of the foot. Each subject performed at least three jumps with proper recovery.

30 meter sprint running was performed on indoor running track. Time was measured with light cells. Each subject performed at least three sprints with proper recovery.

5-times jump test were performed on indoor long jump place. Start points were set in 10,11 and 12 meter points. Each subject performed at least three jumps with proper recovery.

Pull ups was performed by maximal repetition test. Subject was instructed to fully extend his arms between repetitions. Help with legs was not allowed. Every subject performed one trial and maximal amount of repetitions were counted.

Sit ups test was performed with 2,5 kg extra weight behind head. The test was 60 seconds maximum repetition test. Test was done in pairs, and legs were supported in 90 degree knee angle. In a proper repetition shoulders touched the ground and elbows touched knees. The amount of repetitions was count.

Stickhandling track measures players stickhandling skills in the skating track. Subject were instructed how track should be performed (figure 11). Time was measured from the track. Each subject performed test once. If player made a mistake, he had change to do test again.

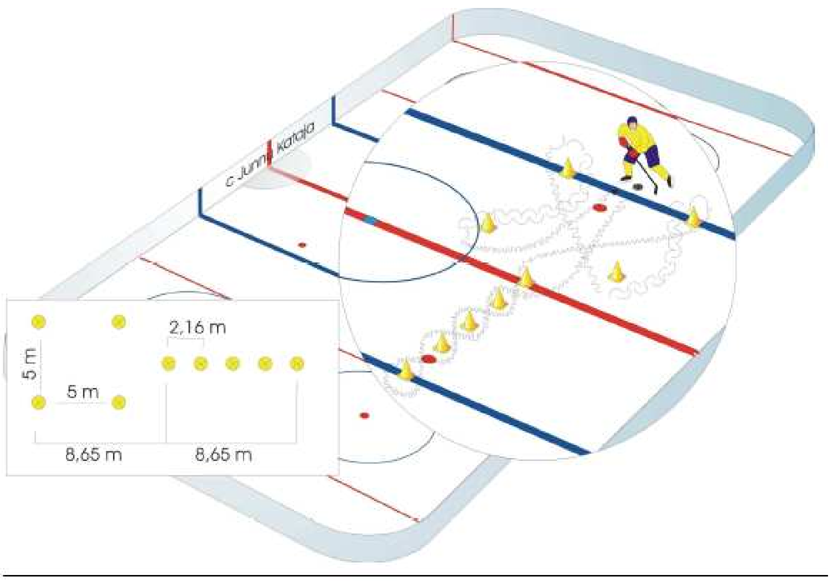


FIGURE 11. Stickhandling track (IIHCE, 2012)

Skating skill test measures players skating skills. Subject were instructed how track should perform (figure 12). Time was measured from the track. Each subject performed test once. If player made mistake, he had change to do test again.

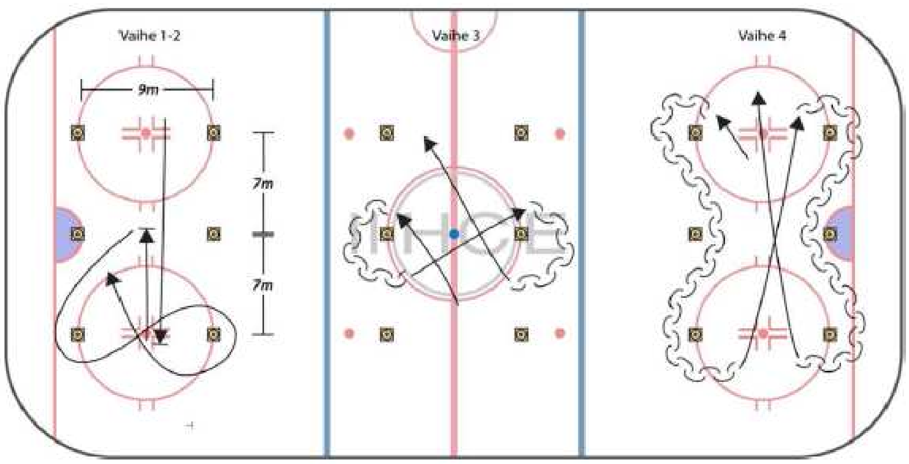


FIGURE 12. Skating skill track (IIHCE, 2012)

7.4. Training

During the competitive season subjects performed physical training which was relatively the same by its volume and intensity in team practices. Data about organized team practices and games were collected throughout the season. Ice practices and physical off ice practices were collected min/ week or sessions/week. Physical training was also classified in strength, speed and endurance training.

Strength training was classified in hypertrophic type strength training, speed strength training and muscle endurance training. Plyometric exercises were considered as speed strength practices. Endurance training was divided in anaerobic endurance and aerobic endurance training. In this study warm ups and cool downs performed at aerobic intensity were calculated to aerobic endurance training. Interval type ball games were calculated as anaerobic endurance training. Speed and off ice skill practices were calculated together.

7.5. Statistical Analysis

Average and standard deviation was calculated with Excel 2003 (Microsoft Oy, USA) software. Pearson's correlation was used for correlation analysis. All statistical differences were calculated by using SPSS software (SPSS inc.,USA).

Within group differences were analysed by using repeated measures ANOVA. Between group differences were analysed by using nonparametric 2 independent samples test. The level of significance was set to $p < 0.05$ level at both measurements.

8. RESULTS

8.1. Training

During the off ice preparatory season (weeks 21-29) subjects practiced on average of 392 ± 43 minutes/ week. At the first half of the competitive season (weeks 30-50), team training volume slightly increased. During the first half of the competitive season, the team practiced 460 ± 43 minutes / week. 255 ± 44 minutes/ week was off ice training and 204 ± 42 minutes/ week was on ice training. During the first half of the season, the team played 1.8 ± 0.8 games/ week. During the second half of the competitive season (weeks 52-10) training volume decreased compared to the earlier training periods. The team trained 375 ± 55 minutes/ week during this training season. Off ice training time was 190± 65 minutes/ week and on ice practice time was 185 ± 45 minutes. The team played 1.7± 1 games/week during this training period. Week by week statistics are presented in figure 13. Table 6 shows how off ice training time was divided into different areas of physical training.

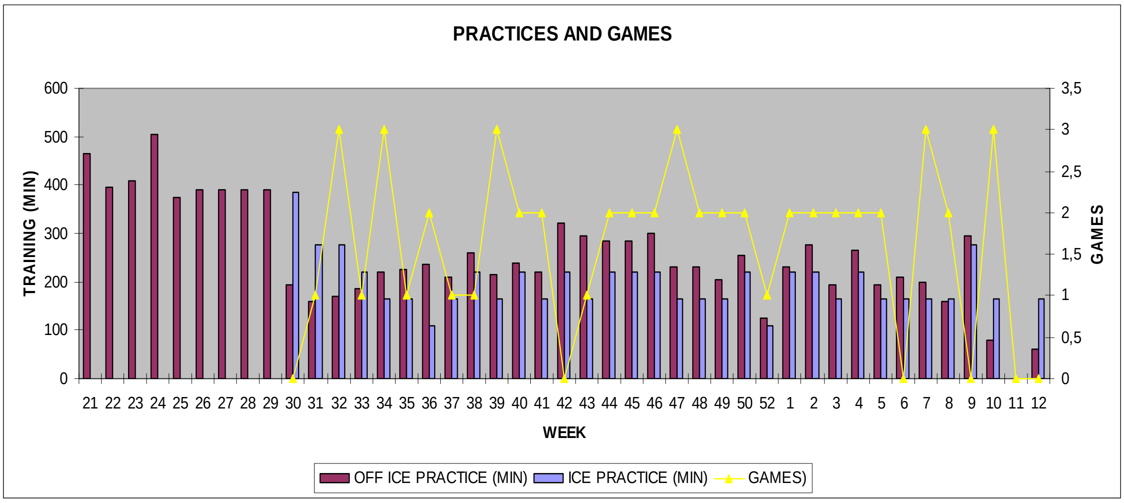


FIGURE 13. Amount of training time (minutes) and games (games/ week) throughout the season.

TABLE 6. Amount of off ice practices in different practice periods.

	PRE - MID1 (21-30) PREPARATORY PERIOD		MID1 - MID2 (31-50) COMPETITIVE PERIOD 1		MID2 - POST (52-10) COMPETITIVE PERIOD 2	
	TIMES/WK	DURATION (min/wk)	TIMES/WK	DURATION (min)	TIMES/WK	DURATION (min/wk)
STRENGTH TRAINING	3,7	153,0	3,4	103,3	3,3	80,7
HYPERTROPHIC			0,9	40,5	0,8	38,8
SPEED STRENGTH & PLYOMETRIC	0,7	21,5	0,8	21,8	0,8	17,6
MUSCLE ENDURANCE	3,0	131,5	1,8	41,0	1,8	24,3
ENDURANCE TRAINING	4,8	167,0	3,7	92,0	3,0	63,8
AEROBIC	3,7	128,5	3,7	92,0	3,0	63,8
ANAEROBIC GAMES	1,1	38,5				
SPEED & SKILL PRACTICE	2,8	66,0	2,9	60,5	2,8	45,6

8.2. Performance profile

8.2.1. Anthropometry

Subjects average height increased significantly ($p<0.05$) between all measurements from the PRE value of 172.9 ± 5.6 cm to POST 175.4 ± 4.8 cm. Average body weight increased also significantly ($p<0.05$) between all measurements from PRE 66.4 ± 8.2 kg to POST 70.9 ± 8,1 kg. No significant ($p<0.05$) changes were found in subjects body fat percentage (table 7.).

TABLE 7. Changes in anthropometry during the preparatory and competitive season.

		PRE	MID1	MID2	POST
WEIGHT (KG)	**MEAN**	66,4	67,7#*	68,7#*	70,9#*
	SD	8,2	8,2	7,9	8,1
HEIGHT (CM)	**MEAN**	172,9	174,5#*	174,9#*	175,5#*
	SD	5,6	5,2	4	5,8
FAT %	**MEAN**	12,5	12,6	12	12,6
	SD	3,8	4,5	3,4	4,3

*** = significant difference to the previous measurement (p<0.05)**
 # = significant difference to PRE measurement (p<0.05)

Between the group comparison in subjects height, weight and body fat percentile, showed a statistically significant (P<0.05) difference only in body weight. The difference was significant (p<0.05) in every timepoint between the early and late matured subjects (Table 8). Early matured subjects were heavier than late matured subjects. Early matured subjects were also slightly taller and had higher body fat percentage than late matured subjects.

TABLE 8 . Between group differences in anthropometry throughout the competitive season.

		PRE		MID1		MID2		POST	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
WEIGHT (kg)	**EARLY**	71,6*	5,7	72,6*	6,1	73,7*	5,5	76,35*	6,7
	LATE	61,8*	7,5	63,3*	7,6	64,5*	7,3	66,3*	6,8
HEIGHT (cm)	**EARLY**	174	4,7	175,3	4,4	175,7	4,5	176	4,6
	LATE	170,9	5,4	172,7	4,9	173,6	4,4	174	4,1
FAT %	**EARLY**	13,4	3,7	13,7	4,8	12,8	4,1	14,07	4,9
	LATE	11,9	3,9	12,2	4,2	11,3	2,5	11,7	3,3

*** = significant difference between groups (p<0.05)**

There was a significant (p < 0.05) correlation between weight and estimated rate of puberty (figure 14.). In comparison of fat% and performance measures a strong correlation (n=16) was found in post measurement with skatingskill test (figure 15.). A moderate correlation were found also in post measurement with 5-times jump (r = -0.544) , stickhandling track (r= 0.469) and 30 meter sprint run (r=0.322).

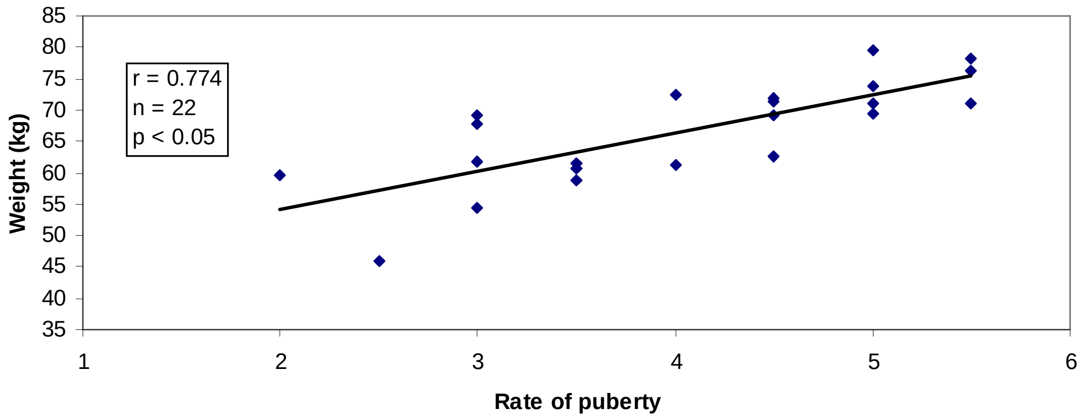


FIGURE 14. Correlation between weight and estimated rate of puberty.

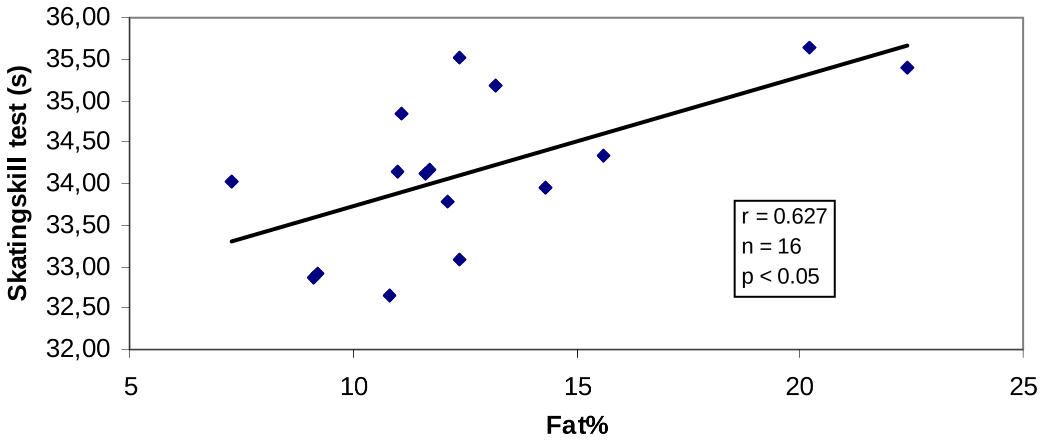


FIGURE 15 Correlation between fat% and Skating skill test - POST measurement

8.2.2. Maximal bilateral isometric leg extension

Maximal bilateral isometric leg extension force changed significantly (p<0.05) between PRE to POST (from 3425±578N to 3847±696N), PRE to MID1 and MID2 to POST (figure 16.). No significant change (p<0.05) was found during the first part of the competitive season. The relative change of the whole competitive season was significant (p<0.05). (figure 17.) Most of the change happened during the preparatory training period.

Relative strength (N/kg) changed significantly (p<0.05) from PRE 50.5±5N/kg to POST 53.5±7N/kg. The increase was significant (p<0.05) also between PRE to MID 1 (from 50.7±5N/kg to 54.5±7.6 N/kg) but decreased significantly (p<0.05) between MID1 (54.5±7.6 N/kg) and MID2 (52.3±8.1 N/kg) measurements.

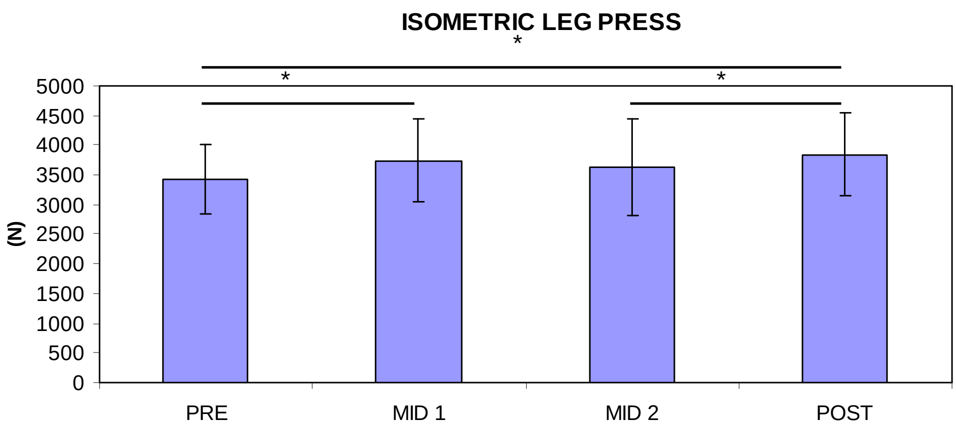


FIGURE 16. Maximal bilateral isometric leg extension force (N). (PRE – MID1 = Preparatory period, MID1 – MID2 = Competitive period 1, MID2 – POST = Competitive period 2) *= significant change at p<0.05

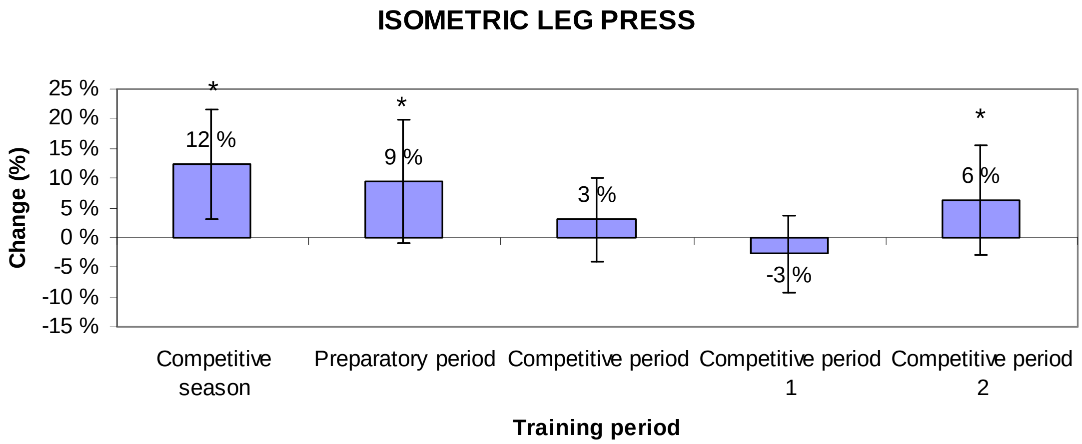


FIGURE 17. Relative change in maximal isometric force of the lower extremities during the different periods (* = significant change at p<0.05)

A significant (p < 0.01) correlation was found between maximal force and peak power of graded bicycle ergometer test in every measurement. There was also a moderate correlation between relative force (N/kg) and 5-times jump distance in PRE (figure 18.) and MID (r = 0.384).

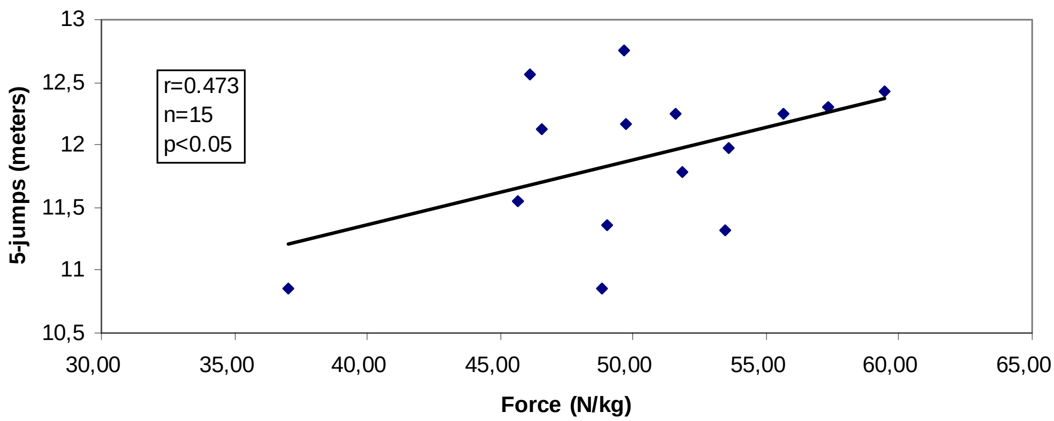


FIGURE. 18. Relationship between relative isometric force of the lower extremities and 5 times jump test distance – PRE measurement.

In maximal isometric strength of the lower extremities test the early matured group was stronger than the late matured group in every time point. The only statistically significant (p<0.05) difference was at the PRE (figure 19). In relative change no significant differences was found between the groups. The late matured group had larger increases in relative change (figure 20.). Maximal isometric force and estimated rate of puberty correlated moderately in PRE (figure 21.).

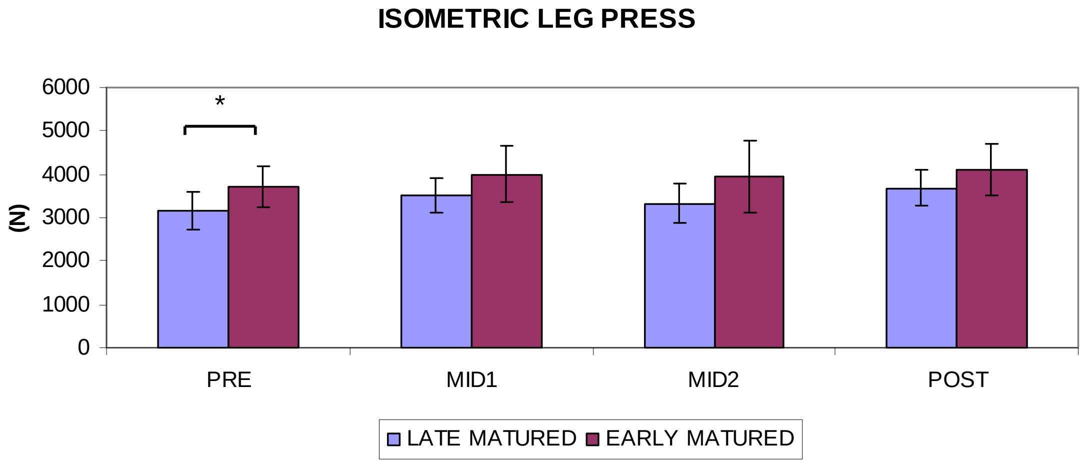
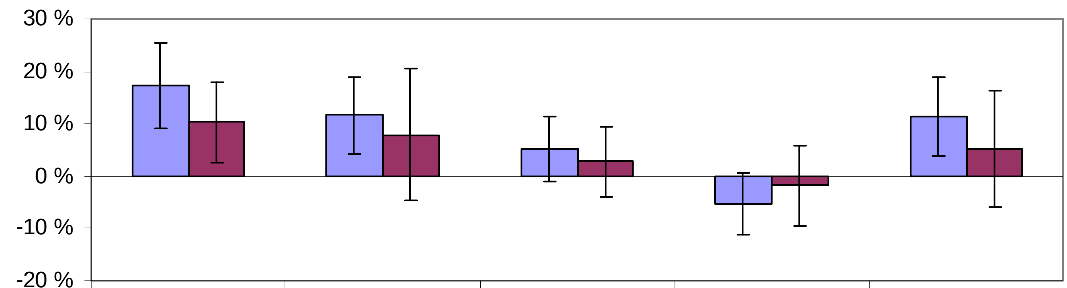


FIGURE 19. Between group differences in maximal isometric strength of the lower extremities. (PRE – MID1 = Preparatory period, MID1 – MID2 = Competitive period 1, MID2 – POST = Competitive period 2) *= significant difference between groups ($p < 0.05$)



	Competitive season	Preparatory period	Competitive period	Competitive period 1	Competitive period 2
LATE	17 %	12 %	5 %	-5 %	11 %
EARLY	10 %	8 %	3 %	-2 %	5 %

FIGURE 20. Relative change between groups in maximal isometric strength of the lower extremities.

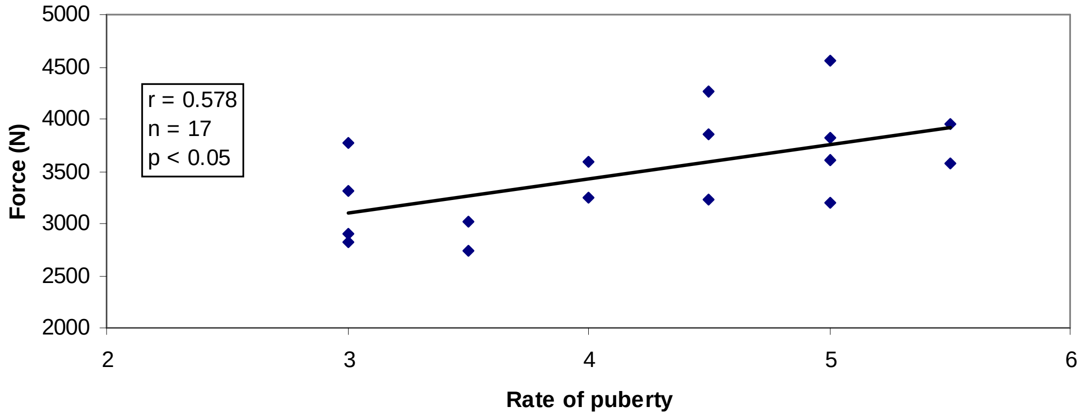


FIGURE 21 . Relationship between estimated maturation level and maximum isometric force of the lower extremities. (PRE)

8.2.3. Maximal isometric trunk extension and flexion

Trunk extension force increased significantly ($p<0.05$) during the off ice training season (PRE to MID1) from 85.8 ±12 kg to 95.7±12 kg, but decreased slightly during the first part of the competitive season (MID1 to MID2). Force increased again significantly ($p<0.05$) at the second part (MID2 to POST) of competitive season. The change between PRE to POST was also significant (from 85.8 ±12 kg to 98.7±14 kg). Relative change in trunk extension force was significant during the competitive season (figure 22.).

Relative trunk extension force increased significantly ($p<0.05$) between PRE to POST (from 1.29±0.16 kg/bw to 1.39±0.15 kg/bw). Relative trunk extension strength increased significantly during the off ice training season but decreased during the first part of the competitive season. A slight increase occurred during the last part of the competitive season (MID2 to POST).

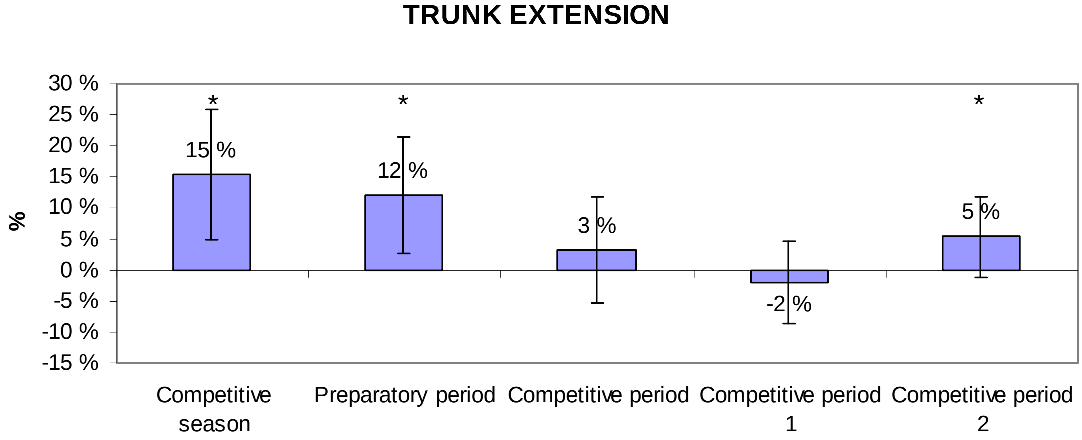


FIGURE 22 Relative change in maximal isometric trunk extension during the different periods (* = significant change at $p<0.05$)

Maximal trunk flexion force increased significantly ($p<0.05$) during the off ice preparatory period (PRE to MID 1) from 68.4±13 to 78.9±11. During the first part of the competitive season (MID1 to MID 2) force decreased significantly ($p<0.05$) from 78.9±11.6 to 72.2±13.0 kg. From PRE to POST the increase was significant ($p<0.05$) (from 68.4±13 to 74.9 ± 15 kg). Relative change in trunk flexion force was significant during the competitive season (figure 23.). Relative trunk flexion force increased significantly ($p<0.05$) between PRE to MID1 but decreased significantly ($p<0.05$) between MID1 to MID2.

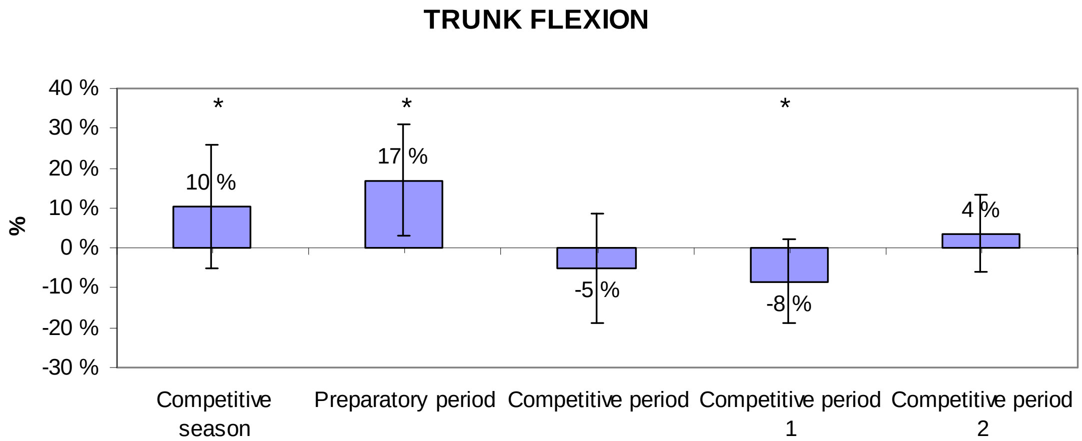


FIGURE 23. Relative change in maximal isometric trunk flexion during the different periods (* = significant change at $p<0.05$)

In trunk extension and flexion test the early matured subjects were significantly ($p<0.05$) stronger in all measurements. Both groups improved their strength during the season. Only a slight decrease occurred between MID1 and MID2 (figure 24 & 25). No significant differences was found at the relative changes between the groups. In trunk extension, both groups increased force 15 % between PRE to POST. In trunk flexion the late matured group increased force 12 % and the early matured group 8 % from PRE to POST.

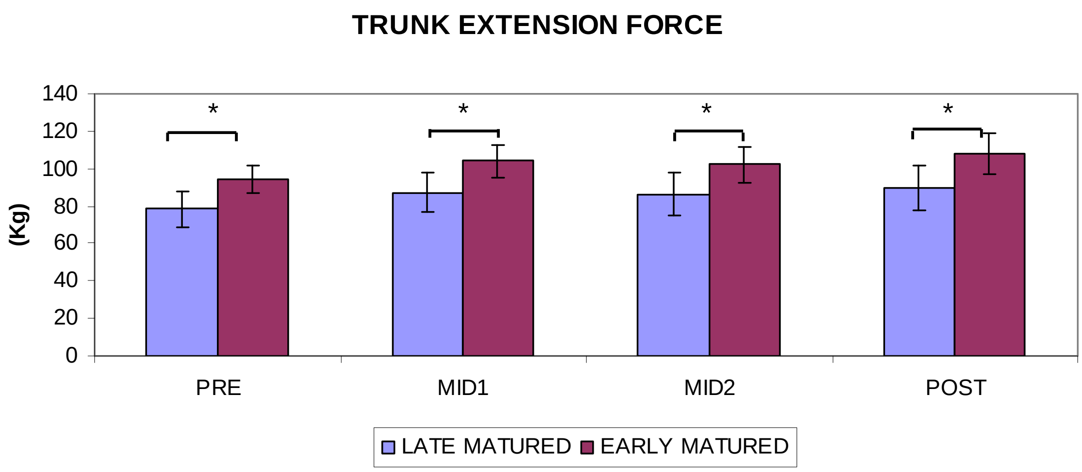


FIGURE 24. Between group difference in maximal isometric trunk extension (kg).
(* = statistically significant difference between groups $p<0.05$)

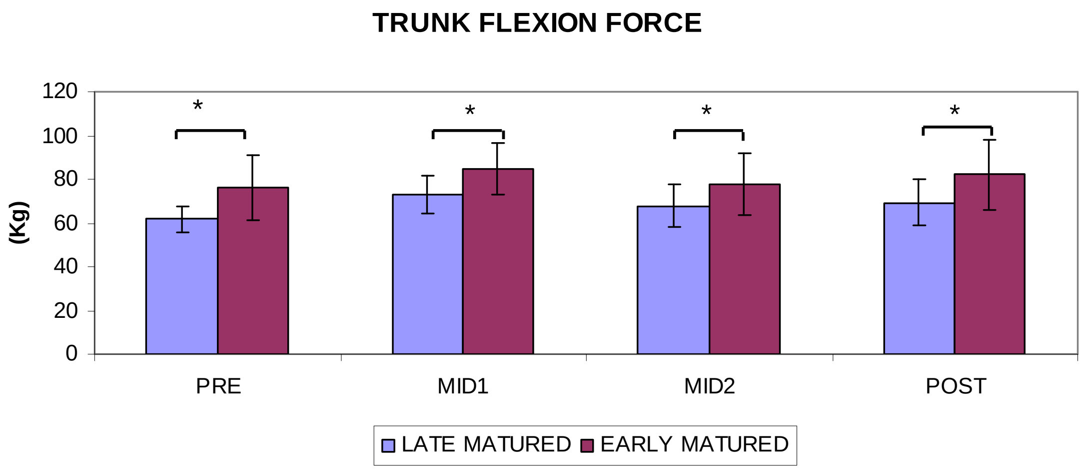


FIGURE 25. Between group difference in maximal isometric trunk flexion (kg).
(* = statistically significant difference between groups $p<0.05$)

8.2.4. Maximal isometric upper body strength

Isometric bench press force increased significantly ($p<0.05$) during the competitive season from MID1 to POST (from 81.3±10.3 to 86.7±14.9). During first part of the competitive season, force increased significantly (p<0.05) (figure 26.). The relative change during competitive season was 4%. In the relative force measurements force decreased significantly (p<0.05) from PRE to MID 1(from 1.26 ± 0.1 kg/bw to 1.20 ± 0.1 kg/bw) but increased between MID1 to MID2 (from 1.2 ± 0.1 kg/bw to 1.26 ± 0.1 kg/bw). The force decreased significantly (p<0.05) again between MID2 to POST from 1.26 ± 0.1 kg/bw to 1.21 ± 0.1 kg/bw. In the maximal isometric bench press the early matured subjects were stronger in all measurements than late matured subjects. The difference were statistically significant (p<0.05) in PRE, MID1 and MID2 (figure 27).

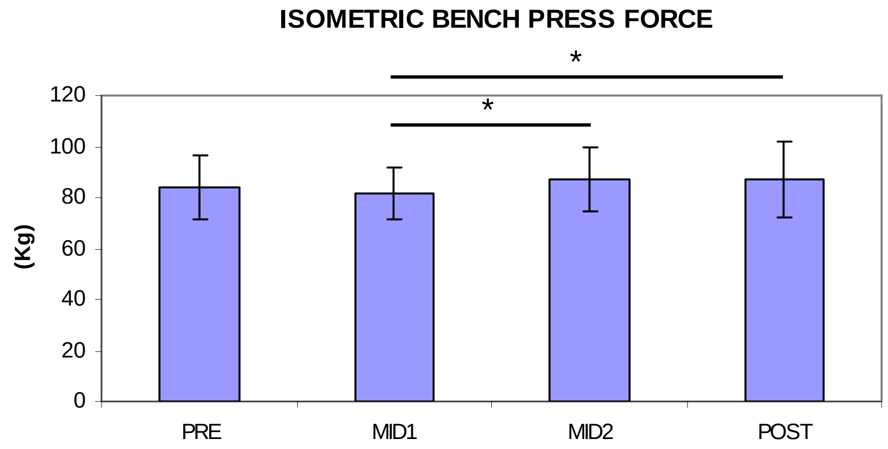


FIGURE 26. Maximal isometric upper body strength. *= significant change at p<0.05

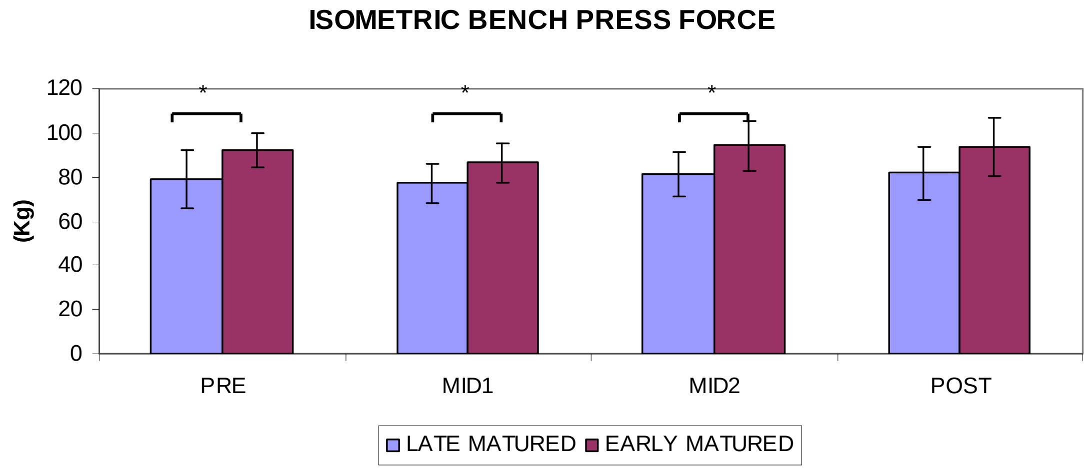


FIGURE 27. Between group difference in maximal isometric bench press (kg).

* = statistically significant (p<0.05) difference between groups

8.2.5. Speed and explosive strength

In explosive strength, measured by counter movement jump (CMJ), significant (p<0.05) changes occurred during the competitive period (figure 28.). During the first part of the competitive period (MID 1 to MID 2) jump height increased significantly (p<0.05). The changes during the whole competitive period (MID1 to POST) was also significant (p<0.05). In relative change, a significant (p<0.05) increase occured in CMJ during competitive period 1 and the whole competitive period (figure 29.). A slight decrease occurred during the preparatory training period (PRE to MID1). The highest correlation between on ice performance measures and CMJ was observed at MID with stickhandling track (r = -0.353).

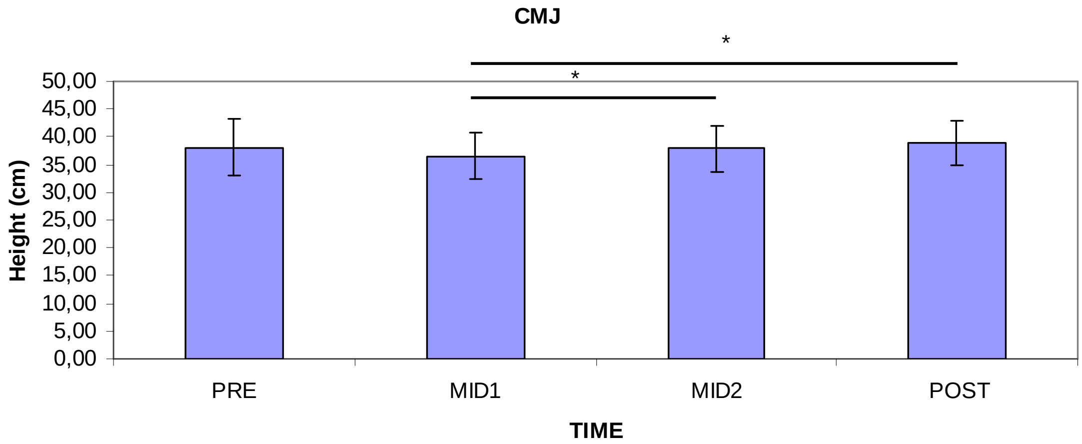


FIGURE 28. Changes in lower body explosive strength during the competitive season.
*= significant change at p<0.05

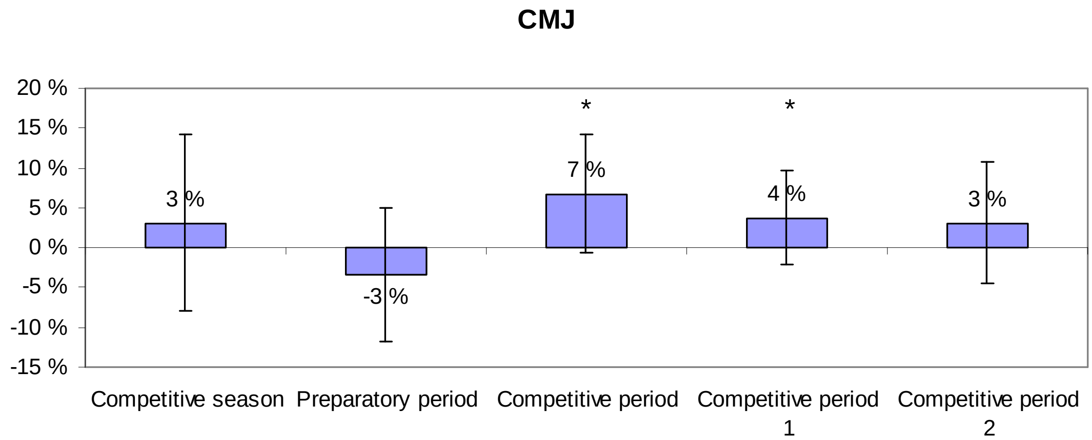


FIGURE 29. Relative change in CMJ. (* = significant difference between groups at p < 0.05)

In 30 meter sprint run time increased significantly (p<0.05) during the preparatory training period (PRE 4.45±0.16 s to MID1 4.51±0.13 s), but decreased significantly during the competitive season (MID1 4.51±0.13 s to POST 4.38±0.15 s). There was also a significant ($p<0.05$) change in time between PRE to POST. 5- times jump distance decreased slightly between PRE to MID1. During the whole season (PRE to POST) and during the competitive training period (MID1 to POST) there was a significant ($p<0.05$) increase. Between PRE to POST the distance increased from 11.9±0.6 to 12.4±0.5 meters. The change from MID1 to POST was from 11.8±0.5 to 12.4±0.5 meters. A significant increase was found in relative change of 5-times jump during the competitive season and the whole competitive period (figure 30.).

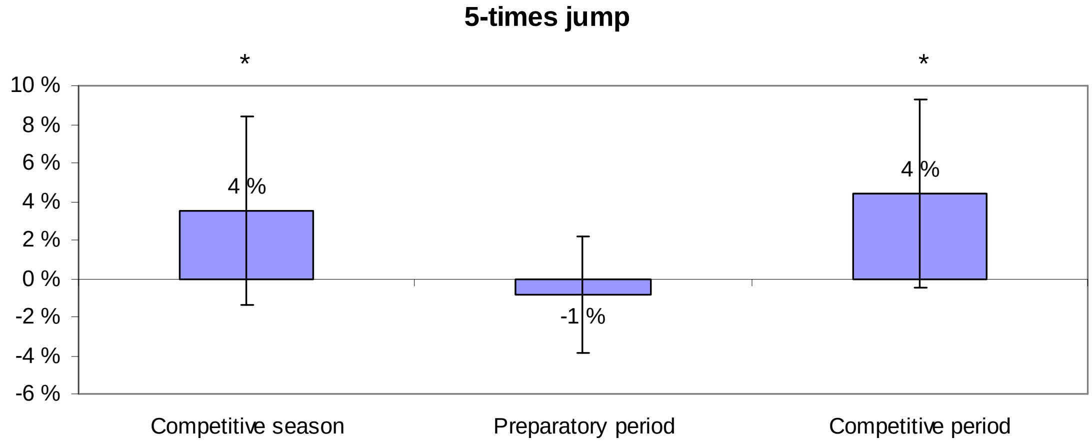


FIGURE 30. Relative change in 5-times jump test. (* = significant difference at $p < 0.05$)

5- times jump test correlated significantly with 30 meter sprint run (PRE and MID ($p<0.05$), POST ($p< 0.01$)) (figure 31.) and stickhandling track (POST $p<0.05$) (figure 32). A moderate correlation between the relative change with stickhandling track was found during the competitive period (figure 33). 5- times jump test correlated also significantly (PRE and MID $p<0.05$ and POST $p<0.01$) with countermovement jump.

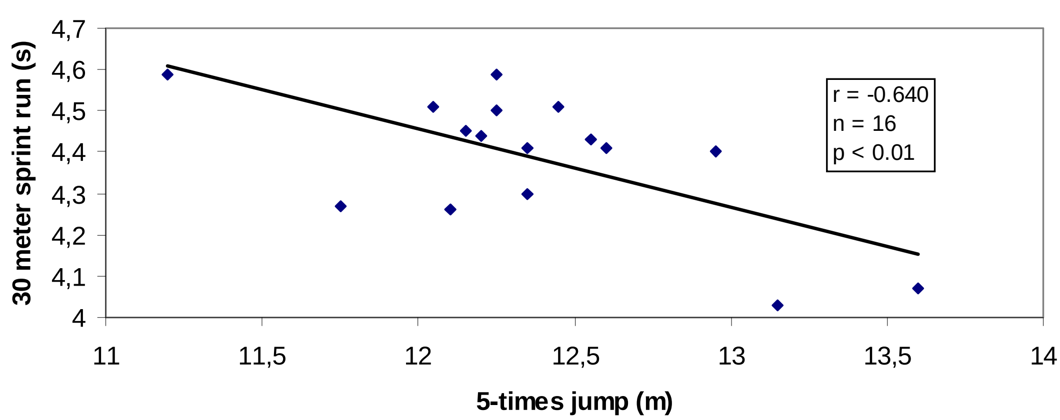


FIGURE 31 . Relationship between 5-times jump distance and 30 meter sprint run (s) – POST measurement

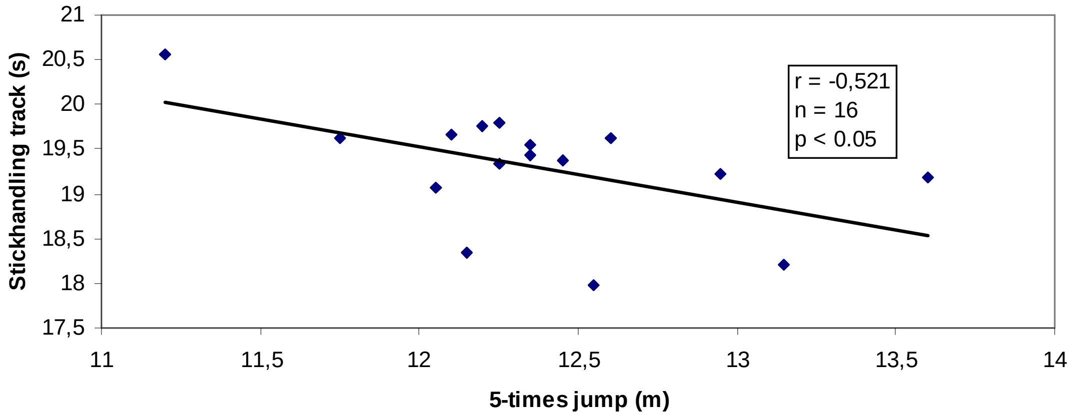


FIGURE 32. Relationship between 5-times jump and stickhandling track – POST measurement.

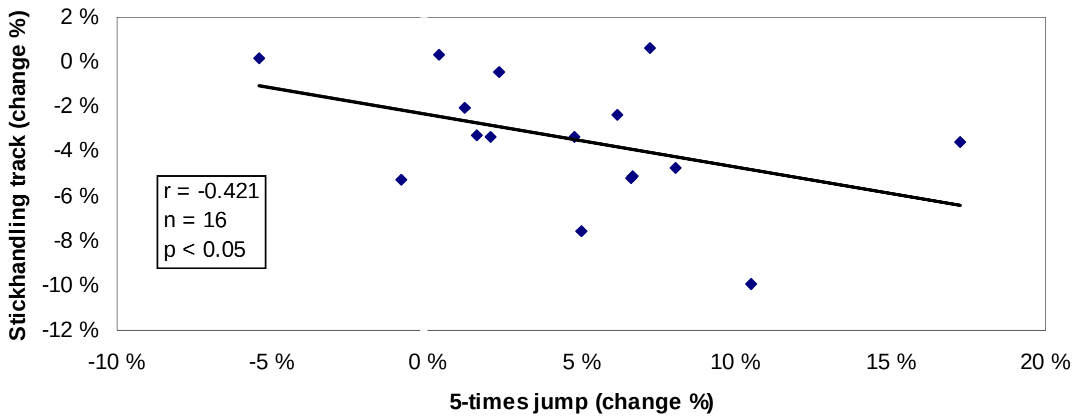
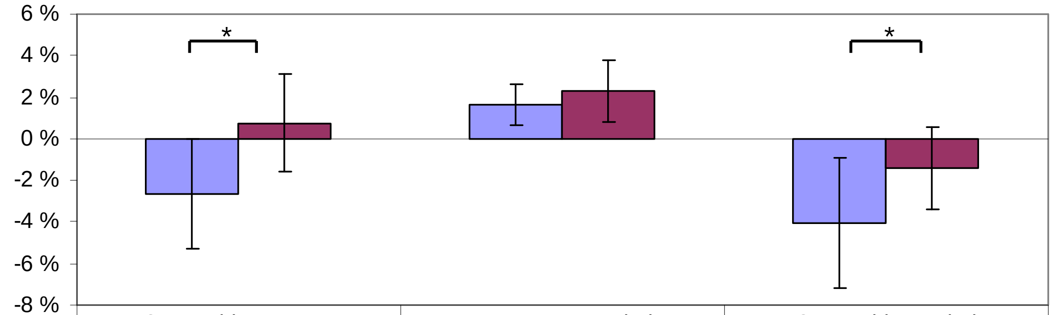


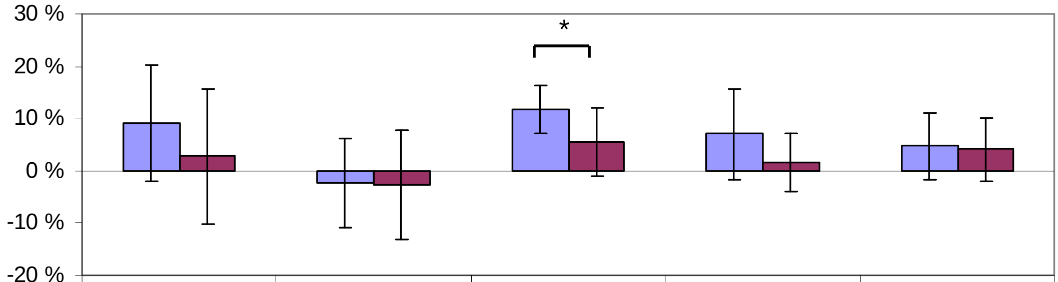
FIGURE 33. Relationship between 5-times jump and stickhandlingtrack change % between mid –POST measurements.

In 5-times jump, counter movement jump (CMJ) and 30 meter sprint run, significant ($p<0.05$) differences between the relative change of the groups were found from 30 meter sprint and CMJ during the competitive period, and from the competitive season in 30 meter sprint and 5-times jump (figures 34, 35 & 36) . In 5-times jump test the early matured group were slightly better in PRE and MID, but the late matured group showed better results in POST. In the CMJ test the late matured group had slightly better results in all measurements. In 30 meter sprint run the early matured group was better in PRE and MID, but late matured had better result in POST (table 9).



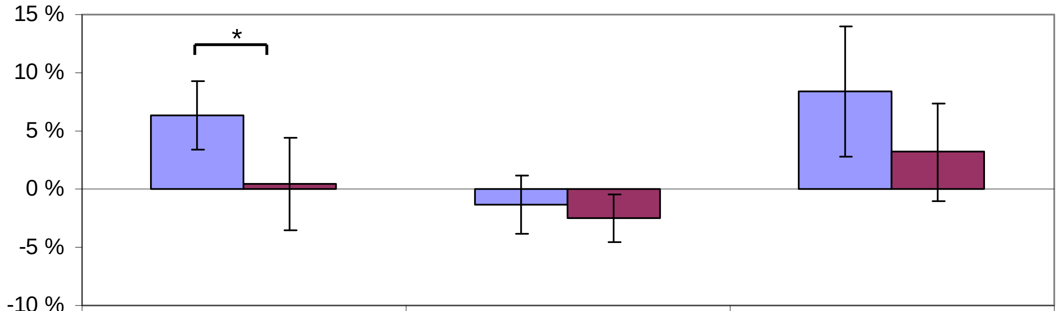
	Competitive season	Preparatory period	Competitive period
LATE	-3 %	2 %	-4 %
EARLY	1 %	2 %	-1 %

FIGURE 34. Relative change between groups in 30 meter sprint. (* = significant difference between groups at $p < 0.05$)



	Competitive season	Preparatory period	Competitive period	Competitive period 1	Competitive period 2
LATE	9 %	-2 %	12 %	7 %	5 %
EARLY	3 %	-3 %	6 %	2 %	4 %

FIGURE 35. Relative change between groups in CMJ. (* = significant difference between groups at $p < 0.05$)



	Competitive season	Preparatory period	Competitive period
LATE	6 %	-1 %	8 %
EARLY	0 %	-3 %	3 %

FIGURE 36. Relative change between groups in 5-times jump test. (* = significant difference between groups at $p < 0.05$)

TABLE 9. 5-times jump, 30m sprint run and CMJ results in both groups.

			PRE	MID	POST
5-TIMES JUMP (m)	**EARLY**	MEAN	12,17	11,86	12,21
		SD	0,53	0,53	0,72
	LATE	MEAN	11,72	11,56	12,51
		SD	0,74	0,73	0,41
30M SPRINT (s)	**EARLY**	MEAN	4,41	4,51	4,45
		SD	0,17	0,18	0,17
	LATE	MEAN	4,45	4,53	4,34
		SD	0,13	0,13	0,10
CMJ (cm)	**EARLY**	MEAN	37,70	36,30	38,20
		SD	5,60	4,00	3,40
	LATE	MEAN	37,80	36,60	40,80
		SD	5,80	3,80	4,10

8.2.6. Muscle endurance

Mid body muscle endurance increased significantly ($p<0.05$) during the whole and competitive seasons. During the off ice training season, the result stayed at the same level (Table 10). Upper body muscle endurance increased significantly ($p<0.05$) during the whole and competitive season. A slight decrease occurred during the first half of the competitive season.

TABLE 10. Muscle endurance test results.

		PRE	MID1	MID2	POST
SIT UPS (N=22)	**MEAN**	44,4	44,1	47,4*	49*#
	SD	8,1	7,4	7,6	6,8
PULL UPS (N=20)	**MEAN**	9,8	11,4*	10,9	12,6*#
	SD	2,9	3,2	2,4	3,4

* = (P<0.05) Significant difference to earlier measurement

\# = (P<0.05) Significant difference to PRE measurement

8.2.7. Maximal aerobic power

Peak power (W) in the graded maximal bicycle ergometer test increased significantly ($p<0.05$) from PRE to POST (from 282,9±26 W to 298±26 W). There was a slight increase troughout the whole competitive season in peak aerobic power, but the increase was not statistically significant ($p<0.05$) (figure 37.). The relative change in peak power (W) during the competitive season was significant ($p<0.05$). An increase of 2% occurred during the preparatory period and that of 3 % during the competitive period (figure 38.). When calculated VO2max relative to body weight (ml/kg/min) no significant changes were found during the competitive season.

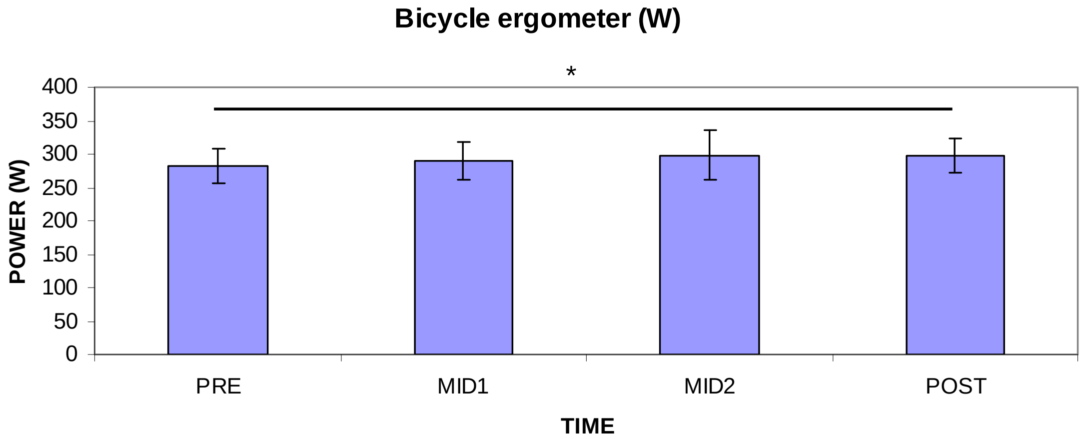


FIGURE 37. Maximal aerobic power (W) changes during competitive season. *= significant change at $p<0.05$

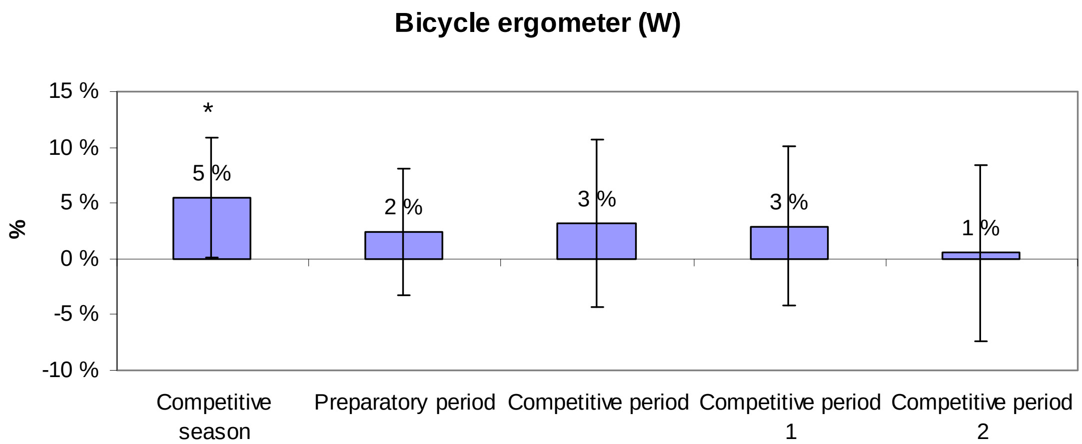


FIGURE 38. Relative change during different training periods. *= significant change at $p<0.05$

In the graded bicycle ergometer test the early matured group had significantly ($p<0.05$) higher peak power than the late matured group in every measurement. Both groups improved peak power in every measurement (figure 39). No significant differences was found in relative change between groups. The late matured group increased peak power 7% and the early matured group 5 % during the competitive season. In calculated VO2max (ml/kg/min) no statistically significant ($p<0.05$) between group differences were found. The late matured group had slightly higher values at MID1 and POST and the early matured had better values in PRE and MID2. Peak aerobic power (W) correlated significantly ($p < 0.01$) with maximal isometric leg press in every time point. A significant ($p < 0.05$) correlation was also found between peak aerobic power (W) and estimated rate of puberty (figure 40).

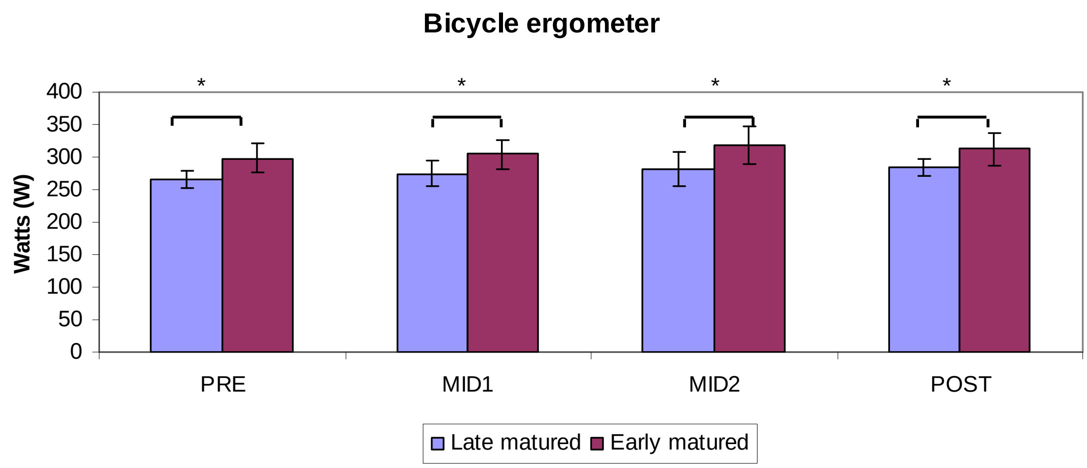


FIGURE 39. Between group difference in graded bicycle ergometer test. Results are peak power in watts (W). * = statistically significant difference between groups (p<0.05)

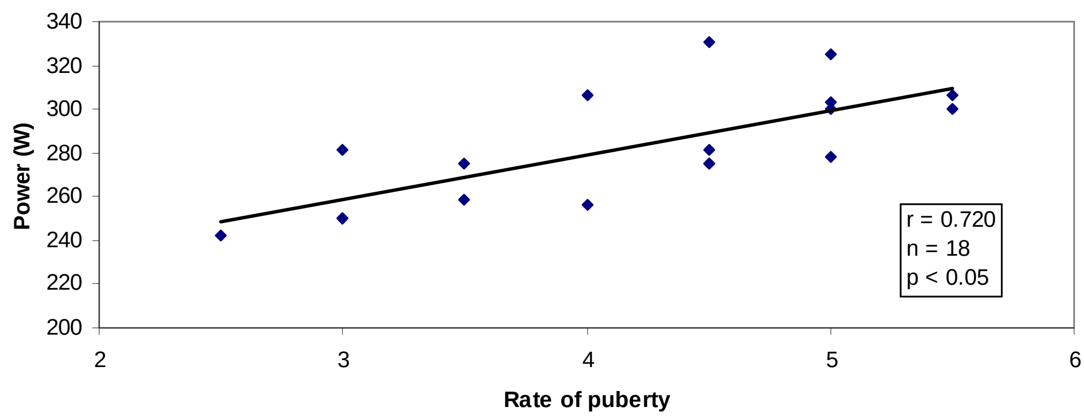


FIGURE 40. Relationship between estimated rate of puberty and maximum aerobic power (W)

8.2.8. Performance on ice

Skating skill test time increased significantly during the off-ice training season (from PRE 35.7±0.9 to MID1 36.5±1 seconds), but shortened significantly during the competitive season (MID1 36.5±1 to POST 34.2±0.9 seconds) and during the whole season (PRE 35.7±0.9 to POST 34.2±0.9 seconds).

In the stickhandling test, a significant ($p<0.05$) decrease in time was found between PRE to POST an MID to POST. Between PRE to POST, time improved from 20.1 ± 0.9 seconds to 19.4 ± 0.6 seconds, and between MID to POST measurement from 20.2 ± 0.9 seconds to 19.4 ± 0.6 seconds.

In the on ice tests no statistically significant differences were found between the groups. Both groups improved their results during the competitive season. A slight increase in time occurred after the off ice training period. In skating skill test (figure 41.) the early matured group had better time in PRE and the late matured group in MID and POST. In stickhandling test (figure 42.) the early matured group had better result in PRE and MID and late matured group had better time in POST.

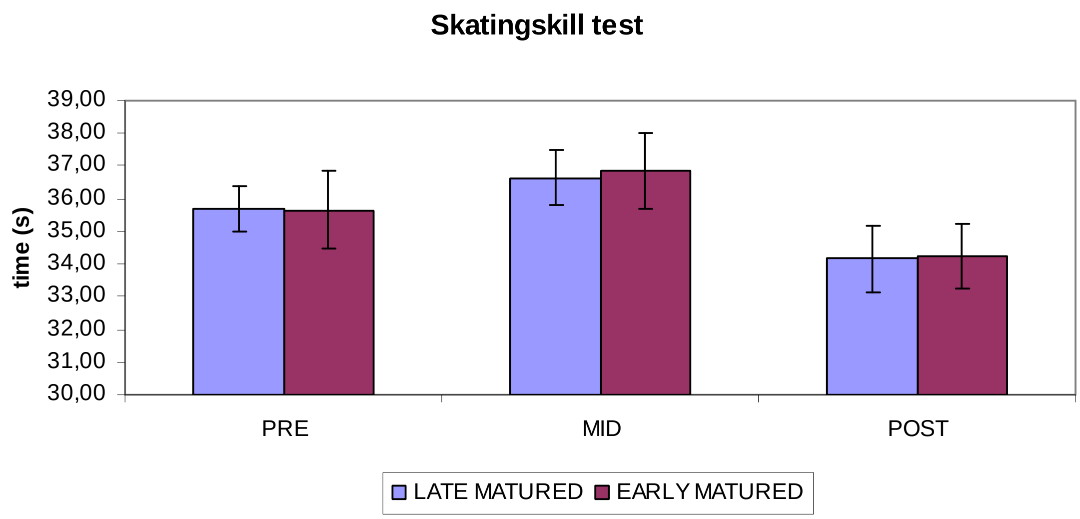


FIGURE 41. The early and late matured group results during competitive season.

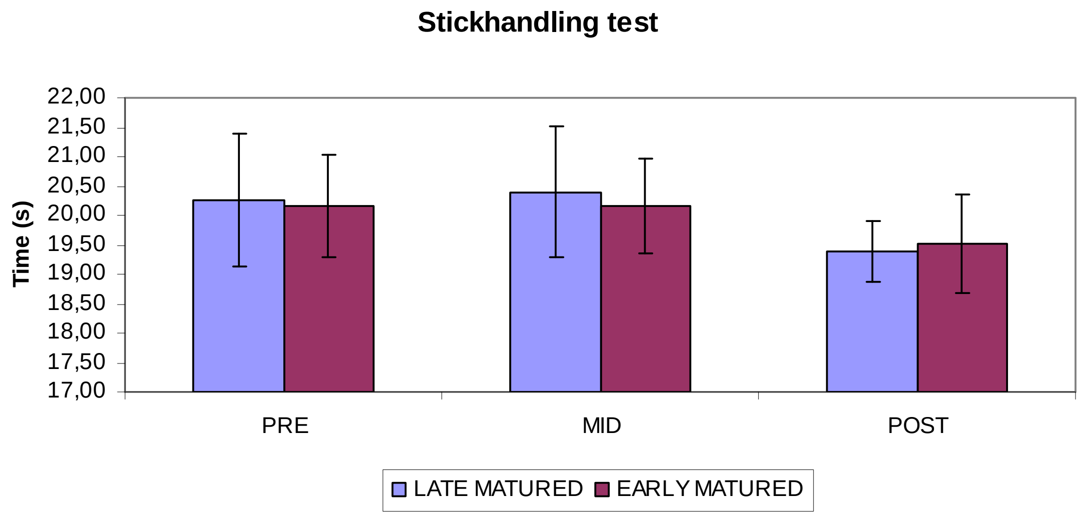


FIGURE 42. The early and late matured group results during competitive season.

9. DISCUSSION

9.1. Major findings

The main findings of this study were that subjects was able to improve their physical fitness level (strength and endurance) throughout the season. The maturation level was quite a strong predictor of maximal strength and peak aerobic power during the whole season. On ice skill tests, no differences were found between the early and late matured groups. These results suggest that early matured players are bigger and stronger compared to late matured players, but in the on ice skill there are no differences. Based on these results, at this age group, bigger and stronger players may have an advantage compared to smaller and weaker players. If players skill level is the same, and when considering the nature of ice hockey as a contact sport with one on one battles, a player who is stronger and bigger, and has same skills, might get an advantage. The relative change in neuromuscular and cardiorespiratory performance suggests that the late matured group was increasing results more than the early matured group. According to these results it is important to take into consideration players biological age. This would give more information about the level of growth, and help coaches to consider what may be good for each individual.

In this study total training volume increased from the off ice preparatory period to the first part of the competitive season, but decreased slightly to the later part of the competitive season. One answer for the increase during the first part of the competitive season is the start of the ice practice in the end of the summer. Players were still on holiday from schools a couple of weeks, and there was a chance to train several times a day. That may explain the increase. The reason for the decrease in the later part of the competitive season may be the lighter training in the last weeks of the season. The team prepared for the playoffs and the goal was to be physically and mentally as prepared as possible.

The amount of training was only collected from team practices and games. Training that happened outside of the team practices, was not taken into calculation for the amount of practices. This may have affected to some of the results.

9.2. Performance profile

9.2.1. Anthropometry

In comparison to Finnish national team players, this team was lighter and shorter than U-16 (years 1997, 1998 and 2000) and U-17 teams (years 1997-1999 and 2012). Fat percentage were about at the same level. A statistically significant ($p<0.05$) correlation was found between isometric leg press and weight in all measurements. Between leg press and height there was a significant ($r = 0.574$) correlation at the PRE measurement. In the literature, body weight have been shown to correlate highly with maximal force during pubertal years and diminishing during adolescent years. The correlation with height should be at the moderate level during the puberty, and diminishing after that. (Carron & Bailey 1974, Clarke 1971, Blimkie 1980) This information suggests that subjects of this study were at their late pubertal growth phase of their growth.

The early matured players were significantly heavier than the late matured players. The early matured players were also taller and had slightly higher fat percentage than late matured players, but no statistically significant differences were found. The differences in weight and fat percentage stayed at the same level through whole season. This means that the difference in weight comes from a higher amount of muscle mass in the early matured subjects. According to these results, it could be thought that early matured players have an advantage at the game situation because of their higher body mass.

9.2.2. Neuromuscular performance

In maximal strength of the lower extremities, the largest increase occurred during the preparatory period and the increase continued through the competitive season. A slight decrease in strength occurred during the first part of the competitive season. This decrease is interesting, because the training volume decreased after that measurement point, and still maximal force improved at the second part of the competitive season. There might be a couple of explanations for this decrease. One might be that there were too few days off before the MID2 measurements, and that is why maximal force level decreased. The other may be that training intensity increased after MID2 and force level increased.

Kauhanen & Savolainen (1995) reported a same kind of maximal isometric force at this age group in their study, but they didn't report any absolute values or knee angles. Cameron et. al. (1996) reported probable results in the later training phase of adolescent athletes (10 % increase). Comparison to that, 12 % increase sounds quite a reliable increase through the competitive season in maximal bilateral leg extension.

Between the group comparison the early matured group was significantly ($p<0.05$) stronger in maximum bilateral isometric leg press than the late matured group only in the PRE measurements. The early matured were also stronger than the late matured in other measurements but not significantly. That kind of trend was found only in the force measurement of the lower extremities. In trunk extension and flexion, the difference between the groups was significant through the whole season, and in isometric bench press, the significant difference was found at the PRE, MID 1 and MID 2 measurements. The difference of change from significant to insignificant shows that the late matured group had improved strength more than the early matured group. In the relative change of force, no significant differences between the groups were found, but the late matured group seemed to increased force more than the early matured group. The interesting thing is that why the gap is closing faster in the lower extremities than in the upper body or trunk? Cameron et. al. (1996) reported a bigger improvement during the early training phase in adolescent athletes than the later training phase. That might be one reason to "closing the gab" between the early and late matured groups. Another thing might be the lack of intensity for the early matured group, compared to the late matured group. The difference in muscle mass stayed at the same level through the season, so this suggests that closing the gab between the groups in strength may be due to improved neural activation of the muscles.

In trunk extension and flexion, the largest increase occurred also during the preparatory period. A slight decrease occurred during the first part of the competitive season. The increase in strength occurred during the whole competitive season. The early matured subjects were significantly ($p<0.05$) stronger than the late matured subjects in trunk extension and flexion.

Maximal force of the upper body, measured by isometric bench press, maintained at the same level through the competitive season. The slight decrease in force occurred during the preparatory period. The preparatory period training focused highly on lower extremities and seems that the amount of training has been too low to maintain the upper body strength level. According to Cameron et. al. (1996), a decrease after a detraining period affects to neuromuscular activation and motor skills, more than the muscle hypertrophy at the adolescent athletes.

In explosive performance and speed, there was a slight decrease in countermovement jump and increase in 30-meter sprint time during the preparatory period. These results may occur because of the preparatory period training. The MID1 measurements were done before the speed and speed strength training period started, and effort to maintain these capabilities during the preparatory period did not happen because of too low volume of that type of training. According to Twist (1997) lower body power helps a player to manage in 1 on 1 situations during the game.

When looking at the training volumes of the different training periods, speed and speed strength volume stayed almost at the same level during the whole season in the off ice training. This suggests that ice practice is in the major role at the improvement of speed and speed strength, because the improvement occurred during the competitive season. More emphasis should be put to the maintenance of speed and speed strength during the preparatory training period, because these qualities are essential in ice hockey. Jump height increased during the competitive season and 30-m sprint time decreased during the competitive season.

9.2.3. Cardiorespiratory performance

Maximum aerobic power increased throughout the season in the graded bicycle ergometer test. Estimated VO2max (ml/kg/min) didn’t increase during the season. The largest increase in aerobic peak power occurred during the competitive season (3 %). These results may be due to subjects increased body weight, which affects to both results. The results are quite similar that Tikka (2000) and FIHA (2012) reported for U-16 and U-17 national teams. In most of those national team average results, peak power were higher, but the teams were also heavier. In the estimated oxygen uptake (VO2max (ml/kg/min)), there was the same trend between subjects of this study and the national team players that it was with peak power. According to these results, the physical level of the team in this study was almost at the same level that it is/has been at the national team. Between the groups comparison the early matured group had significantly higher power (W) in all measurements. Estimated VO2max (ml/kg/min) was at the same level in all timepoints. Both groups increased aerobic power throughout the competitive season.

9.2.4. On ice performance and field tests

On ice test times increased during the preparatory period and shortened during the competitive period. The increase in time is propably caused by the preparatory season training, which happened only at the off ice. No significant differences were found between the early and late matured group in on ice tests. This results suggests that skill level, without contact, is quite similar between early and late matured subjects.

Stickhandling track correlated significantly with 5-times jump test at the post measurement timepoint (r = -0.521). This suggests that explosive performance and on ice speed and skill have a positive relationship. The correlation wasn’t significant between 5-times jump and skating skill test. This might be because of time it took to skate the skill test. Times were over 30 seconds and anaerobic glycolysis and aerobic energy has more emphasis at this performance, and ATP and PCr systems are having smaller emphasis. (McArdle, 1996; Twist & Rhodes, 1993)

9.3. Conclusions

In this study subjects were able to improve and maintain their performance level through the competitive season with a relatively same training volume and intensity for the whole group. This study does not offer information about whether this is the effective way to organize team training or not. According to differences between the early and late matured groups and improvements of different individuals, it seems that this training wasn’t as good as possible to different individuals. Naughton et. al. (2000) concluded in their review that the exercise prescription to produce the most desirable and long term benefits for adolescents requires dynamic and individual programming.

The early matured subjects were bigger and stronger compared to the late matured subjects. At on ice skill, off ice speed and explosiveness, no significant differences were found. This information suggests that early matured subjects have advantage at the game play situation, because of the contact nature of ice hockey. This also suggests to give time for late matured players, to grow and improve their level of physical profile. It is too early to judge player at this age, when physical growth is still going on. This information should be essential for coaches, and help them to understand and co-operate with players at the different level of growth.

In this study, all subjects trained relatively at the same volume and intensity. This type of training may not be ideal for all individuals, and more information is needed about physical training of different individuals at the different phases of growth. One suggestion to improve this study design, would be the third group, which would be training differently, compared to the early and late matured groups. This third group could be another early matured group, which would train with higher volume and intensity compared to two other groups. This would give more information about the effectiveness of the training.

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