Determining the Strongest Predictor of FAST Aerobic Fitness

by

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ABSTRACT

Ice hockey is a unique sport requiring a combination of well developed fitness capacities that can be generally referred to as 'ice hockey fitness'. To be successful at a representative level an ice hockey player must have exceptional aerobic and anaerobic fitness, in addition to excellent musculoskeletal fitness and a lean and large body composition. The primary objective of this study was to determine which laboratory measure of ice hockey fitness was the strongest predictor of VO_2max of the FAST (Faught Aerobic Skating Test). Fitness data were collected on the Thunder Bay Kings Minor Hockey Association Team, which was comprised of bantam-age, representative level, ice hockey players. Regression analysis was used to determine which laboratory measure was the strongest predictor of VO_2max of the FAST. Results showed that the Margaria-Kalamen power test was the strongest predictor of VO_2max of the FAST ($\beta = -0.008$, $p < 0.05$). It was concluded that coaches and trainers of bantam-age, representative level ice hockey teams can use the FAST and the Margaria-Kalamen power test to assess aerobic and/or anaerobic fitness in ice hockey players to determine those players with the greatest potential, and to monitor the development of 'ice hockey fitness' in response to various training programs. Further analysis helped to determine that the stature and fitness levels of participants were, generally, above average when compared to normative data for age and sex.

INTRODUCTION

Ice hockey is a physiologically taxing sport that requires participants to have a unique repertoire of performance capabilities. To be successful at a representative level of competition, a player must have well developed aerobic and anaerobic energy systems, in addition to musculoskeletal fitness and a large and lean body composition (Green, Pivarnik, Carrier, & Womack, 2006). Given the unique combination of fitness characteristics in elite ice hockey players, these characteristics can be generally referred to as 'ice hockey fitness'.

Research shows a general trend in elite ice hockey players to have excellent cardiovascular fitness and body composition. Carey, Drake, Pliego, and Raymond (2007) speculated that an enhanced aerobic capacity aids recovery ability between ice hockey shifts. However, there is debate whether high aerobic fitness is essential to ice hockey players (Carey et al., 2007). Additionally, elite ice hockey players tend to be taller, heavier, and have less fat mass than the general population according to normative data for age and sex (Cox, Miles, Verde, & Rhodes, 1995; Earle & Baechle, 2004; Montgomery, 2006; Quinney et al., 2008).

Since ice hockey is a complex sport requiring a unique combination of fitness capabilities, appropriate fitness tests must be conducted to accurately assess and predict ice hockey fitness. Fitness tests must be sport specific and able to elicit the energy systems used during actual play (Cox et al., 1995). Reliable laboratory and field fitness tests are essential to ice hockey for sport specificity; however, the most reliable and sport specific methods have been widely debated (Cox et al., 1995).

Young athletes can experience physiological adaptations as a result of their participation in physical training at an intense level, similar to that which has been demonstrated for adults (Bar-Or, 1995; Cox et al., 1995; Cunningham, Telford, & Swart, 1976). Furthermore, studies performed on young ice hockey athletes have revealed high VO_2max values; high ratios of lean body mass to fat mass; and increased muscular strength and bone mineral density compared to age matched controls (Nordström, Thorsen, Bergström, and Lorentzon, 1996; Cunningham et al., 1976).

In the present study, fitness data was collected on the Thunder Bay Kings Minor Hockey Association Team during the early ice hockey season. The fitness data included anthropometric, aerobic, anaerobic, and musculoskeletal measures relevant to ice hockey. The scores from these measures were analyzed in linear regression analysis to determine which measure was the strongest predictor of VO_2max of the FAST (Faught Aerobic Skating Test). Further analysis helped to determine how the participants' fitness compared to normative data for age and sex. The rationale for this study was that the FAST enables physiological parameters to be measured through a readily accessible field fitness test, which has shown to be valid and reliable.

Purpose

The primary purpose of this research is to determine which measure of early season laboratory ice hockey fitness best predicts VO_2max determined from the FAST.

Statement of the Problem

Currently, there is a lack of published literature that has examined the fitness capacities of bantam age representative ice hockey players in detail. Additionally, it is unknown whether VO_2max of the FAST can be predicted from laboratory measures of ice hockey fitness in this cohort.

Limitations

The limitations in this study are primarily the cohort being studied and the motivation of the participants. The cohort being studied is highly exclusive due to the age and athletic ability of participants. Results will not be generalized to the population because most people are not adolescent elite athletes. Additionally, low motivation levels of participants may negatively affect their performance on fitness tests.

Delimitations

The delimitations of this research allow results to be inferred to a highly exclusive population and a detailed physiological profile of ice hockey fitness to be assessed. Currently, there is a paucity of published literature regarding the fitness levels of ice hockey players for this cohort. This research will contribute to the body of literature that currently exists by providing a detailed physiological profile of the participants. Additionally, the FAST is a valid sport specific field fitness test that provides a reliable assessment of aerobic fitness in ice hockey players.

REVIEW OF RELATED LITERATURE

Ice Hockey Fitness

Generally, an ice hockey game consists of three periods of play and two intermissions of rest following the first and second periods (Cox et al., 1995). During play the athletes work in shifts characterized by intermittent bouts of high-intensity exercise lasting 45-60 seconds, which are then followed by periods of rest (work to rest ratio is commonly 1:2) (Carey et al., 2007; Houston & Green, 1976). Due to its unique energy requirements, this sport requires a diverse repertoire of physical fitness that can be generally referred to as 'ice hockey fitness'. At this level of play, ice hockey fitness can be improved and maintained through general fitness training, as well as refining ice hockey-specific skills via organized practice and competition.

At a representative level of ice hockey, a successful player needs to have exceptional anaerobic and aerobic energy systems, in addition to a large and lean body composition, with a well developed musculoskeletal fitness (Cox et al., 1995; Green et al., 2006). Attaining these physical attributes promotes efficient skating techniques, puck handling skills, the ability to, at times, manage aggressive physical contact from other players, and offset fatigue from the rigorous practice and game schedules often associated with a representative level of ice hockey (Cox et al., 1995; Green et al., 2006; Quinney et al., 2008).

Due to the high energy demands of ice hockey and the characteristics of a particular shift, players use a unique combination of intense glycolytic activity coupled with aerobic metabolism (Cox et al., 1995; Green & Houston, 1975). Anaerobic metabolism, consisting of the adenosine triphosphate phosphocreatine (ATP-PC) system and glycolysis, is the predominant energy system being utilized in ice hockey, which, when adequately trained, can produce large quantities of energy in a short amount of time (Green & Houston, 1975). During short-term, high intensity exercise lasting less than five seconds (rapidly accelerating down the ice rink during a break away) the ATP-PC system is stimulated (Powers & Howley, 2004). The ATP-PC system provides rapid amounts of energy through simple one-enzyme reactions; however, energy stores become depleted quickly (Powers & Howley, 2004). Glycolysis is the second step in anaerobic metabolism that produces energy during longer periods of play (Powers & Howley, 2004). During rest, energy stores for the ATP-PC system and glycolysis are replenished through aerobic metabolism between shifts and periods or while the player is coasting on the ice between plays (Burr et al., 2008; Carey et al., 2007).

At the representative level, an ice hockey player should ideally have a large frame to manage physical contact from other players while skating and handling the puck (Cox et al., 1995; Green et al., 2006). The average height and weight of a healthy, adult male between the ages 18-35 years is approximately 176 cm and 74-80 kg, respectively (Earle & Beachle, 2004). Interestingly, results from longitudinal studies of National Hockey League (NHL) players have shown that height and weight has increased over time. These increases in height and weight over the years predict a trend that these measures will continue to increase in NHL players (Montgomery, 2006). Through secondary analysis of fitness data, Montgomery (2006) analyzed the height and weight of NHL players from 1917-2003 who played for the Montreal Canadiens. Results showed that from 1917-2003 average height increased from 175 cm to 185 cm, and average weight increased from 75 kg to 92 kg. Montgomery speculated that these gains in weight appeared to be primarily from a gain in muscle tissue and not from fat mass. Quinney et al. (2008) examined the anthropometric measures of NHL players over a 26 year period from 1979-2005. Results showed that the average height and weight for these players was 184 cm and 89.2 kg, respectively. Furthermore, height and weight also increased over the 26 years in this study. Cox et al. (1995) gathered height and weight data on NHL players from 1980 to 1991. Results showed an increase in height and weight during the 11 years. In 1991, the average height and weight was 185.5 cm and 88.4 kg, respectively. Burr et al. (2008) assessed height and weight in ice hockey players eligible to be drafted into the NHL between 1998 and 2006. The average height and weight of players was 186 cm and 87.5 kg, respectively. Even though all participants profiled in these studies either played in the NHL or were eligible to be drafted into the NHL, which is the highest level of representative ice hockey, these results suggest the necessity of having a large frame to be successful in all levels of highly competitive ice hockey.

The ideal body composition of a player involved in a representative level of ice hockey is a high ratio of lean body mass to fat mass (Cox et al., 1995). According to Anderson, Hall, and Martin (2005), some male athletes may acquire a body fat percentage as low as 3-5%. Literature shows that, generally, elite ice hockey players tend to have a low body fat percentage according to normative data. The average body fat percentage of a healthy adult male between the ages 18-35 years ranges from 14-21% (Earle & Baechle, 2004). Data on body fat percentage of NHL players were gathered from 1981-2003 and then assessed through secondary analysis by Montgomery (2006). Results showed little change in body fat percentage, even though increases in height and weight were observed, during the 22 years. Body fat values ranged, on average, between 8-12%. Quinney et al. (2008) measured the body fat percentage of NHL players from 1979-2005 and discovered that body fat measurements were low and remained relatively unchanged as well. Green and Houston (1975) determined the average body fat percentage of two Major Junior A ice hockey teams (ages 16-20) to be 9%, with values reaching as low as 6.7%. Additionally, Houston and Green (1976) measured body fat percentage in Major Junior A ice hockey teams (ages 16-20) and a University ice hockey team (ages 18-23). Results showed that the average body fat percentage was 10%. The body fat percentages of the players profiled in these studies were significantly lower than normative data, supporting the notion that an athlete needs to have a low body fat percentage to play at a representative level of ice hockey.

Accurately Assessing Ice Hockey Fitness

The laboratory and field fitness tests used to assess ice hockey fitness must: (i) accurately measure relevant physiological attributes of the sport; (ii) use established fitness tests that have shown to be valid and reliable; and (iii) be conducted on a regular schedule (Cox et al., 1995). Anaerobic function requires fitness tests that will measure power, speed, and strength relative to ice hockey; whereas, aerobic function requires fitness tests that will enable athletes to reach their full physiological potential. Furthermore, performance on fitness tests can indicate a player's physiological strengths and weaknesses and predict on-ice playing potential (Burr et al., 2008; Cox et al., 1995; Green et al., 2006).

Literature shows a general trend in the fitness tests used to assess performance in elite ice hockey players of all ages. The Wingate 30-second cycling test, vertical jump, and the Margaria-Kalamen power test are commonly used to assess anaerobic capacities (Burr et al., 2008; Cox et al., 1995; Mastrangelo et al., 2004; Watson & Sargeant, 1986). Maximal oxygen uptake (VO_2max) is widely accepted as the most accurate and reliable method to determine cardiovascular fitness (Cunningham et al., 1976; Earle & Baechle, 2004; Lockwood, Yoder, & Deuster, 1997). The method, however, to assess aerobic function is widely debated. In the absence of a skating treadmill, a graded test on a cycle ergometer has shown to be the most sport specific laboratory method due to the biomechanics of ice skating being comparable to those of cycling (Cox et al., 1995). Gledhill and Jamnik (as cited in Cox et al., 1995) list a battery of tests and anthropometric measures that should be conducted when determining overall fitness of elite ice hockey players. These tests include standing height, body mass, body fat percentage, the Wingate 30-second cycling test, grip strength, benchpress, curl-ups, flexibility, and a graded cycle ergometer protocol using direct gas analysis to assess aerobic capacity.

Field tests are the epitome of sport specific fitness testing; however, field tests tend to lack a standardized protocol and therefore, often suffer low reliability and validity during test-retest trials (Cox et al., 1995; Petrella et al., 2007). Petrella et al. (2007) have validated the Faught Aerobic Skating Test (FAST), which is a quick and versatile ice hockey field fitness test to predict maximum aerobic power (VO_2max). The FAST consists of an on-ice continuous skating protocol on a standard length ice hockey surface. An audio CD of beep signals paces the skater to cross the boundary line at each end of the course. Petrella et al. (2007) assessed the aerobic capacities of ice hockey players consisting of males and females between the ages of 9 to 25 years who played a level of competition from Atom 'A' to University varsity calibre. All participants completed the FAST and a laboratory aerobic running treadmill test that directly measured VO_2max. The most significant finding of this study was the establishment of a regression model that incorporated results from performance on the FAST (number of lengths completed), height, body mass, and age to predict VO_2max (Equation 1)

$$VO_2max = 34.119h - 0.244m + (0.757 \text{ x No. of F lengths}) - (0.975 \text{ x age}) - 3.285$$

where h is the participant's height in meters and m is the participant's body mass in kilograms.

Since aerobic capacity has proven to be important to the success of elite ice hockey players a field test that accurately and reliably assesses aerobic fitness is welcomed. Furthermore, the FAST was shown to be safe and reliable for use with a wide range of ages for both sexes.

Aerobic Fitness and Ice Hockey

Ice hockey players require unique cardiovascular and respiratory systems to sustain their energy during an intense shift of game play and then to rapidly recover during periods of rest (Cox et al., 1995). A successful player needs to develop well-rounded anaerobic and aerobic fitness to compete at a high level of ice hockey (Burr et al., 2008; Cox et al., 1995; Green et al., 2006). Some researchers propose that successful anaerobic ice hockey performance may be reliant on aerobic capacity (Cox et al., 1995; Green and Paterson [as cited in Watson & Sargeant, 1986]). An elite ice hockey player must develop an aerobic capacity of approximately 50-60 ml-kg^{-1}-min^{-1} to thrive in a high level of competition (Petrella et al., 2007). According to Tomlin and Wenger (as cited in Carey et al., 2007) a high aerobic fitness aids recovery time, increases lactate removal, and improves ATP-PC restoration during high-intensity exercise lasting for short durations, such as a shift of ice hockey.

A common trend found in studies that examine the aerobic capacities of elite ice hockey players is high VO_2max. Cox et al. (1995) reported an average VO_2max of 62.0 ml-kg^{-1}-min^{-1} in NHL players in 1991; Green et al. (2006) studied the physiological profiles of NCAA Division I ice hockey players and results showed that players had, on average, a VO_2max of 59.0 ml-kg^{-1}-min^{-1}. Houston and Green (1976) found that Major Junior A and University ice hockey players had, on average, a VO_2max of 54.7 ml-kg^{-1}-min^{-1}; Burr et al. (2008) determined that the average VO_2max in amateur ice hockey players eligible to be drafted into the NHL was 57.4 ml-kg^{-1}-min^{-1}. It is evident from this literature that ice hockey players who compete in a high level of competition have superior aerobic capacity. The average healthy adult male between the ages 20-29 has a VO_2max of 42.5 ml-kg^{-1}-min^{-1}, which is significantly lower than the elite ice hockey players profiled in these studies (Earle & Baechle, 2004). It can be speculated that aerobic fitness is either necessary to or a result of competing at a high level of ice hockey.

However, some papers have disputed the need for aerobic fitness in high-intensity intermittent exercise, such as ice hockey (Carey et al., 2007). The rest periods between shifts and during intermissions may be ample time for ATP replenishing regardless of aerobic capacity (Bishop, 2004; Hoffman, Epstein, Einbinder, & Weinstein [as cited in Carey et al., 2007]). Furthermore, Hoffman et al. (as cited in Carey et al., 2007) proposed that there is a minimum level of aerobic fitness required to improve removal of metabolic wastes and ATP-PC replenishing, above which no increased benefit is observed.

Green and Houston (1975) determined the effect of a 5 month season of high intensity ice hockey on aerobic and anaerobic metabolism. Participants consisted of Major Junior A ice hockey players who played 70+ games a season (approximately 3 per week) and practiced on most non-playing days. Pre-season testing was conducted prior to regular season play and final testing was conducted at the end of the regular season (5 months later). Aerobic capacity was assessed by spirometry, and anaerobic capacity was assessed by various anaerobic fitness tests and blood analysis. Results showed no change in aerobic function during the course of the ice hockey season. A proposed explanation for the lack of improvement in aerobic function was that the ice hockey players' initially had high VO_2max values during the preseason testing (56.4 ml-kg^{-1}-min^{-1}), which was only maintained by the 5 months of training. Anaerobic capacities, however, did show a marked improvement during the season, which is expected due to the anaerobic systems being constantly galvanized during game play and practices.

Carey et al. (2007) researched the correlation between maximal oxygen uptake (VO_2max) and fatigue in female collegiate ice hockey players. The objective of this study was to determine if high aerobic capacity was linked to recovery ability from high-intensity intermittent exercise. On-ice training for these ice hockey players consisted of repeated short sprints to reproduce game-like conditions and off-ice training consisted of weight lifting twice per week. Very little training was aerobically based; however, the average VO_2max of these participants (50.3 $ml\text{-}kg^{-1}\text{-}min^{-1}$) was above the 90^{th} percentile for their sex and age, which indicated superior aerobic capacity. Aerobic capacity was analyzed by a graded treadmill test (modified Bruce protocol) and gas analyzers; fatigue was assessed by an anaerobic repeat sprint skating test, which consisted of skating five laps around the ice rink as fast as possible with 30 seconds of rest between each lap. Results showed that skating times increased from lap 1 to lap 5 indicating fatigue; however, there was no significant relationship between aerobic capacity and recovery ability ($r=-0.42$). These results suggest that an enhanced aerobic capacity is irrelevant to recovery time during short bursts of high intensity exercise. However, the researchers hypothesized that the non-significant results may have occurred due to the homogeneity of participants. VO_2max results and skating times were very similar for all participants which can reduce the chance of producing significant results. Further research is required to determine whether a relationship exists between high aerobic function and an enhanced ability to recover between bouts of exercise in ice hockey.

Physiological Adaptations/Responses to Exercise in Children and Adolescents

Children and adolescents adapt and respond to exercise differently than adults (Bar-Or, 1995). Since few pediatric research scientists are willing to test young athletes through invasive measures, such as obtaining muscle biopsies, inserting catheters into arteries, using radioactive materials, or performing experiments in extreme cold or heat, there is limited knowledge regarding their physiological adaptations to exercise (Bar-Or, 1995; Powers & Howley, 2004).

Children, adolescents, and adults may experience similar physiological responses to exercise; however, certain responses are exclusive to children and adolescents (Bar-Or, 1995). For example, young athletes experience a lower oxygen deficit at the onset of exercise, which results in attaining steady-state more quickly than adults (Bar-Or, 1995). Additionally, weight lifting can increase muscular strength in young athletes as a result of neuromuscular 'learning' rather than muscle hypertrophy (increase in muscle *size*) (Committee on Sports Medicine and Fitness, 2001).

Children can recover more quickly than adults from supra-maximal exercise lasting short durations (Bar-Or, 1995). Previous work by Bar-Or (1995) compared recovery ability on the Wingate anaerobic cycling test in young athletes (9-12 year old boys) to that of adults. The young athletes performed two consecutive Wingate Anaerobic tests with two minutes of rest between bouts. Results showed that the athletes were able to reproduce 100% of performance during the second bout of exercise; whereas, the adults were unable to reproduce a full performance on the second test after ten minutes of rest.

Compared to sedentary children, active children – such as athletes - tend to have higher VO_2max scores, are generally taller, and have less body fat (Committee on Sports Medicine and Fitness, 2000; Maffulli & Helms, 1988). Ortega, Ruiz, Hurtig-Wennlöf, and Sjöström (2007) studied adolescents (ages 14-16) to determine whether meeting the current physical activity guidelines (≥60 min/day of moderate-vigorous activity) resulted in an improved cardiovascular fitness (CVF). An accelerometer, worn on the lower back, measured the frequency and intensity of physical activity participation that each child participated in every day. Cardiovascular fitness (CVF) was assessed during a maximal cycle-ergometer test in which VO_2max was measured. Results indicated that adolescents who participated in the recommended amount of daily physical activity were up to 8 times more likely to have a healthy cardiovascular system than adolescents who did not meet the recommendations.

Intensive training programs in young athletes may ideally alter the dimensional and functional capacities of maximal aerobic power (Cunningham et al., 1976). A study by Seliger, et al. (as cited in Cunningham et al., 1976) determined that athletically trained boys experienced a marked increase in VO_2max from ages 12 to 18 compared to boys of the same age who were untrained. The untrained boys did not experience a significant increase in VO_2max from the ages of 12 to 18.

In a study by Häkkinen, Mero, and Kauhanen (1989), the training effects in prepubescent elite athletes were followed for one year and then compared to a sedentary control group of the same age. Participants were 11-13 year old male endurance, sprint, or weight lifting athletes. Various tests were conducted pre- and post-season to determine the endurance, sprint, and strength capabilities of these athletes. Maximal oxygen uptake (VO_2max) was measured to assess cardiovascular fitness (CVF); electromechanical dynamometers were used to measure muscular strength in the lower body; a vertical jump test and a maximal squat-lift test assessed power. The most significant outcome was the 21.4% increase in the strength of the weight lifters in one year; no significant increases in strength were observed in the other athlete groups or the control group. There was no significant change in VO_2max in any of the athletes which may be attributed to the fact that children do not experience the same gains in cardiorespiratory fitness as adults do (Earle & Baechle, 2004). However, the endurance athletes had a significantly higher VO_2max than the other athlete groups and the control group throughout the year. According to the Cooper Institute (as cited in Ortega et al., 2007), the recommended 'healthy fitness zone' for male adolescents is a VO_2max of 42 ml-min^{-1}-kg^{-1}. The endurance athletes in this study had an average VO_2max of 66.5 ml-min^{-1}-kg^{-1} which indicates superior CVF. The results from this study delineate the effects of highly specified training in young athletes. Since the weight lifters trained for strength, a significant increase in strength was observed; similarly, as the endurance athletes trained for aerobic power they exhibited significant gains in VO_2max compared to the other athlete and the control groups. Results showed that even young athletes competing at a high level of sport can achieve physiological adaptations to exercise as a result of highly specified training.

Young athletes can develop an 'athlete's heart' which is a layman's term to describe the morphological changes in cardiac dimensions due to intense training in elite sport commonly seen in adult athletes (Kervancioglu & Hatipoglu, 2007). Athletes tend to have thicker ventricular walls, larger cardiac cavities, and enhanced venous return which generates improved ventricular filling, ventricular contraction, and stroke volume during intense exercise (Kervancioglu & Hatipoglu, 2007). Ayabakan et al. (2006) studied the effect of high intensity endurance training on cardiac function and dimensions in prepubescent male elite swimmers compared to a sedentary control group of the same age. Cardiac function (systole, and velocity and duration of blood flow) was assessed by M-Mode and Doppler waves; cardiac dimensions (ventricular thickness and cavity size) were assessed by M-Mode and echocardiography. Results showed that the swimmers had larger ventricular wall thicknesses compared to controls; however, there were no significant differences in cardiac function between the two groups. One interesting discovery in the swimmers was that they did not have larger ventricular cavity diameters during diastole compared to controls. A larger cavity is a common occurrence in adult elite swimmers. These results support the notion that child physiology adapts differently to exercise than adults'.

Adolescent Aged Ice Hockey Athletes

Playing ice hockey at a representative level provides children and adolescents with an opportunity to improve their ice hockey related fitness. The section below summarizes research relating the number of hours spent training, practicing, and playing games in ice hockey athletes to improvements in anaerobic and aerobic capacities, increases in bone mineral density, and promotion of an ideal body composition with a high ratio of lean body mass to fat mass.

Cunningham et al. (1976) determined the aerobic capacities of 10 year old ice hockey players competing at a representative level that played 60 games and practiced 40 times during the season. Aerobic capacity was measured by gas analyzers during an incremental cycle ergometer protocol where participants were required to pedal until exhaustion. Results showed that these athletes achieved, on average, a VO_2max of 56.6 $ml\text{-}kg^{-1}\text{-}min^{-1}$. Compared to the average VO_2max of school children, aged 10-14 years, determined by Rodrigues, Perez, Carletti, Bissoli, and Abreu, (2006), the participants in the Cunningham et al. (1976) study have significantly enhanced aerobic capacity. In the Rodrigues et al. (2006) study, male participants had, on average, a VO_2max between 43.4-47.9 $ml\text{-}kg^{-1}\text{-}min^{-1}$; superior aerobic capacities were classified as VO_2max values above 52.3 $ml\text{-}kg^{-1}\text{-}min^{-1}$.

A study by MacNab (1979) followed a team of boys who played a high level of competitive ice hockey for five years from the ages of 8 to 12 to determine their fitness and performance measures. These results were compared to the fitness and performance measures of a control group of boys who played a less competitive level of ice hockey for two years from the age of 10 to 12. The competitive ice hockey group played, on average, 66 games a year and practiced twice a week; whereas, the control group played, on average, 25 games a year and practiced once a week. The fitness and performance measures consisted of: 50 yard dash, 300 yard run, sit ups, flexed arm hang, shuttle run, standing broad jump, physical working capacity, grip strength, height and weight, skating agility tests, and two puck control tests. The competitive group had significantly better scores on most of the fitness and performance tests than the control group. Comparing scores between the ages of 10 to 12 for both groups, the results showed that, on average, the competitive group performed significantly better in the following tests: the backwards skating agility test; the forwards skating agility test; both puck control tests; the 300 yard run; the standing broad jump; the flexed arm hang; and the sit ups.

An interesting discovery was made in a study by Nordström et al. (1996), which compared bone mass, muscle strength, and various anthropometric parameters in adolescent males who participated in a representative level of ice hockey to a reference group of adolescent males who participated in a moderate level of physical activity. Both groups were 15-16 years old. In addition to games, the ice hockey group trained 7-10 hours per week on-ice plus 2 hours per week was devoted to high impact and weight training exercises. The reference group participated in three hours or less of moderate exercise per week. Bone mineral density (BMD), fat mass (FM), and lean body mass (LBM) was determined from a total body scan; muscle strength was measured in Newton meters (Nm) using a Biodex isokinetic dynamometer on the left quadriceps femoris and hamstrings muscles; height and body weight were measured in stocking feet using standardized equipment and protocol. Results showed no significant difference in height and weight between the two groups; however, the ice hockey group had less FM and more LBM in addition to a significantly higher BMD and muscular strength. The greatest accumulation of bone mineral content in the ice hockey group was seen in the femur and, remarkably, in the humerus. This finding may be due to the constant loading of high magnitude forces exerted on the humerus in an unusual, yet unique, pattern during shooting and body checking in ice hockey (Nordström et al., 1996). Other findings in this study suggest that the repeated force and stress put upon the skeletal system while playing ice hockey can increase total BMD and promote a high ratio of lean body mass to fat mass. Children and adolescents who increase BMD at a young age can prevent osteoporosis in adulthood and ice hockey has proven, through this study, to be a supporting factor in bone growth (Nordström et al., 1996).

Ice hockey athletes, at all ages, have been shown to be more physically fit than the general population. Certain physiological attributes related to participating in representative ice hockey are anticipated, such as having high anaerobic fitness, a low body fat percentage and being taller and heavier than average. However, ice hockey athletes have also shown to exhibit physiological attributes that are less expected, such as high aerobic fitness and increased bone mineral density in the humerus. Ice hockey is a complex sport that has been shown to confer athletes with complex, yet unique, fitness capacities.

METHODOLOGY

All fitness testing took place in Thunder Bay, Ontario at either Lakehead University in the Human Performance Laboratory at C. J. Sanders Fieldhouse or at the Fort William First Nation hockey arena. At least two trained test conductors (Lakehead University kinesiology undergraduate or graduate students) and at least one supervising Lakehead University kinesiology professor were present during the testing.

Participants

Participants (n=16) were 13-14 year old males who played for the Thunder Bay Kings Minor Hockey Association Team, which was a representative level of ice hockey (triple 'A'). At this level of play, the ice hockey season lasts approximately six months (October-March) with 2-4 games played every week during the regular season (The Official Site of the Thunder Bay Kings AAA Hockey Organization, 2008). The athletes practice on almost all non-playing days (approximately 4-5 times a week) with each practice lasting 1-1.5 hours (M. Sutherland, personal communication, January 19, 2009). The nature of the study was explained to the participants and their parents/guardians. Written consent to participate in this study was obtained from the parents/guardians and the participants were given a PAR-Q prior to fitness testing to screen for injuries or chronic cardiovascular and respiratory conditions.

Statistical Analysis

Data were analyzed using *Statistical Analysis System* (SAS). Descriptive statistics were calculated for all variables of interest. Linear regression analysis was used to determine which measure of laboratory ice hockey fitness could best predict VO_2max of the FAST.

ESTABLISHING BASELINE MEASUREMENTS

Baseline measurements consisted of resting heart rate, resting blood pressure, standing height, weight, waist to hip ratio, and skinfold thickness. These measurements are essential in determining an individual's level of health and safety prior to participating in strenuous exercise and to identify any existing conditions such as hypertension (Anderson et al., 2005). Heart rate and blood pressure were measured prior to each fitness test and the participants' heart rate and blood pressure had to return to resting levels after exercising before they left the testing area. Height and weight were also measured at the beginning of each testing session.

Resting Heart Rate

Heart rate (HR) is the frequency at which the heart beats and is calculated as the number of beats in one minute expressed as 'beats per minute' (bpm) (Klentrou, Montelpare, & Faught, 2000). Average resting HR ranges from 60 to 100 bpm in adults; however, resting HR can vary between individuals depending on age, sex, lifestyle, and genetics (Earle & Baechle, 2004). A resting HR less than 60 bpm is termed 'bradycardia', and more than 100 bpm is termed 'tachycardia' (Earle & Baechle, 2004).

Protocol for Resting Heart Rate

Resting HR was determined using one of two methods: (i) pulse palpitation (manual) or (ii) HR monitor. Manual calculation was performed by lightly placing the first two fingers over the carotid *or* radial artery and counting the number of beats felt for 10 seconds and then multiplying that number by 6 to determine bpm (Klentrou et al., 2000). When using the HR monitor (*Polar T31* or *T34*) it was placed one inch below the line of the nipples with the electrode slightly to the left of the midline of the body. For better transmission, a small amount of water was placed on the electrode, and the watch was placed on or near the body. Participants rested in a seated position for at least five minutes prior to measuring resting HR.

Resting Blood Pressure

According to Earle and Baechle (2004, p. 25) blood pressure (BP) is "the pressure exerted against the arterial walls" and determining BP is important to help reveal cases of hypertension, which is a contraindication for exercise. BP is an umbrella terms that is comprised of *systolic* BP and *diastolic* BP. Systolic BP is measured from blood that is forcefully ejected during ventricular contraction (*systole*); whereas, diastolic BP is measured from blood in the vessels during the rest phase of the cardiac cycle (*diastole*) (Earle & Baechle, 2004).

***Protocol for Resting Blood Pressure*[1]**

A sphygmomanometer (which includes a stethoscope and blood pressure cuff) was used to measure BP. When measuring BP, the participant was seated with the arm that was going to be measured resting on a table. The participant rested in a seated position for at least five minutes prior to measuring resting BP.

1. The participant was asked to extend one arm with hand supinated (palm up), and to open and close fist about ten times. Opening and closing the hand increases the gradient of pressure and volume between the blood vessels in the arm and forearm.

2. The cuff was applied securely to the upper arm and the centre of the cuff bladder was placed directly over the brachial artery. This is where *Korotkoff Sounds* (blood pressure measurement) are loudest.

3. The diaphragm of the stethoscope was placed under the cuff, directly over the brachial artery. Korotkoff Sounds are produced by an abrupt distention of the arterial wall from blood pushing through to the distal artery under a constricting cuff.

4. The cuff was inflated as rapidly as possible to about 180 mmHg. If Korotkoff Sounds were present the cuff was pumped up another 20 mmHg and listened to again. Pumping was continued until no Korotkoff Sounds were heard.

5. The cuff was deflated at a rate of 5 mmHg/sec until the first Korotkoff Sounds were heard; this is the systolic pressure. The systolic pressure was read to the nearest 2 mmHg (e.g. 120, 122).

6. *Pulses alternans* was listened for. This is a condition where a double beat is present and is often associated with heart damage or disorders.

7. The cuff was deflated further until muffling was heard, then until the Korotkoff Sounds disappeared. The point at which the Korotkoff Sounds disappear is the diastolic pressure. The diastolic pressure was read to the nearest 2 mmHg.

Height and Weight

Height and weight provide basic anthropometric measurements that can be compared to standard growth charts to determine how the individual compares to the general population for the same sex and age (Earle & Baechle, 2004)

Protocol for Height and Weight

To measure height the participant stood in stocking feet with his back against a wall with a tape measure on it. Height was recorded to the nearest 0.5 of a centimeter (cm). To measure weight the participant removed shoes or heavy articles of clothing and stood on a standard weight scale. Weight was recorded to the nearest 0.5 of a kilogram (kg).

Waist to Hip Ratio

Waist to hip ratio (WHR) provides a simple method to determine fat distribution; only a partner and a soft tape measure are required to assess WHR. Individuals who store more fat in the abdomen are shown to have a greater risk of developing heart and metabolic diseases (Earle & Baechle, 2004).

Protocol for Waist to Hip Ratio[2]

1. The participant was asked to stand relaxed with feet together.
2. A non-elastic tape measure was placed around the smallest girth of the abdomen (waist).
   a. Value was recorded to the nearest 0.5 of a cm.
3. Next, the largest girth of the buttocks (hip) was measured.
   a. Value was recorded to the nearest 0.5 of a cm.
4. The waist circumference was divided by the hip circumference, which gives the WHR.
5. A WHR less than 0.83 is low risk, and greater than 0.94 is very high risk.

Skinfold Thickness

When performed by trained individuals, skinfold (SKF) thickness provides an accurate estimation of subcutaneous fat tissue (Earle & Baechle, 2004). An equation adapted from Earle & Baechle (2004, p. 244) relative to the individual's sex and age is used to convert the SKF values into an over all percentage of subcutaneous fat (body fat percentage). The average body fat percentage of male children and adolescents (age 6-17) ranges between 11-25%; a body fat percentage greater than 30% is considered 'obese' and poses a greater risk of developing cardio-vascular and metabolic diseases, such as hypertension and diabetes (Earle & Baechle, 2004).

Protocol for Skinfold Thickness[3]

Body fat (BF) percentage was determined by measuring the SKF thickness of subcutaneous fat at the triceps, biceps, subscapular, suprailium, and medial calf sites with SKF calipers. It should be noted that the equation used to calculate body fat percentage for adolescents only takes into account the SKF measurements for the triceps and medial calf. All SKF measurements were taken on the right side of the body with the participant standing up.

1. To begin, the skinfold sites were marked with an 'x' to indicate exactly where to measure.

   a. Triceps: this is a vertical fold located on the posterior midline of the upper arm, halfway between the acromion and olecranon processes; the elbow was extended and relaxed.
   b. Medial calf: this is a vertical fold located at the largest girth of the calf on the midline of its medial border; the leg was placed on a bench/chair with the knee flexed to 90 degrees.

2. After pinching the fold with thumb and finger, the caliper was placed directly on the skin surface, 1 cm away from the thumb and finger, perpendicular to the skinfold, and halfway between the crest and the base of the fold.

3. The pinch was maintained for 1-2 seconds before reading the caliper.

4. Each fold was measured twice by repeating steps 2 and 3. SKF thickness was recorded to the nearest 0.1 of a millimeter (mm).

5. The average of the two measurements was recorded. If there was more than a 2 mm discrepancy between the two measurements then the SKF was measured a third time.

6. Body fat percentage for male adolescents was calculated from the following equation:[4]
   BF% = 0.735(triceps SKF + medial calf SKF) + 1.0

MUSCULOSKELETAL FITNESS

Tests of muscular endurance and flexibility were used to assess musculoskeletal fitness. Muscular endurance was determined from curl ups and right angle push ups, and flexibility was assessed from the sit and reach test. Muscular endurance is essential for an athlete because it allows submaximal force to be exerted over an extended period of time (Earle & Baechle, 2004). Furthermore, enhanced flexibility decreases the risk of injury and musculoskeletal disorders in athletes (Earle & Baechle, 2004).

Curl Ups

Curl ups measure abdominal strength and endurance. Only a stopwatch and a partner are required to administer this fitness test (The President's Challenge, 2007)

Protocol for Curl Ups[5]

1. To execute a proper curl up the participant laid on his back with knees flexed and feet placed 30 cm from the buttocks.

2. A partner lightly anchored the participant's feet by placing both hands on top of the feet.

3. The arms were crossed over the chest and the participant curled the trunk up to touch elbows to thighs and then lowered back down again as fast as possible for one minute.

4. The shoulders *must* touch the ground before curling back up – an incorrect trial was not counted.

5. The total number of successfully executed curl ups was recorded.

Right Angle Push Ups

Right angle push ups assess upper body strength and more specifically, triceps strength. A stopwatch, a partner, and a metronome are required to administer this fitness test (The President's Challenge, 2007).

Protocol for Right Angle Push Ups[6]

1. To begin a right angle push up the participant lies face down on a mat in the push up position with hands placed under the shoulders and toes supporting the feet.

2. The participant extended the arms while keeping the back, buttocks, and legs in a straight line (the buttocks must not droop or be pushed up, and the back must not arch) until arms were fully extended.

3. The participant then lowered the body until the elbows were flexed to 90 degrees. Elbows had to be kept close to the body – this isolates the triceps muscles. A partner placed his hand under the shoulder of the participant to indicate the point of 90 degree flexion.

4. Push ups were performed in rhythm to a metronome; one push up was completed every three seconds, until the participant could not perform anymore *or* three consecutive unsuccessful trials occurred.

5. Incorrect trials were not counted and the total number of successfully executed push ups was recorded.

Sit and Reach

Sit and reach measures the flexibility of the lower back and hamstrings and only a tape measure and a partner are required to administer this fitness test.

Protocol for Sit and Reach[7]

1. A measuring tape was placed on the floor and, after removing shoes, the participant sat with feet 8-12 inches apart on either side of the tape; the participant's feet should line up with the '0' point on the measuring tape.
2. Hands were placed on top of each other with palms facing down.
3. With the legs held flat by a partner, the participant inhaled deeply and on exhalation reached forward with both hands as far as possible along the tape.
4. The participant must hold the peak of reach for a count of three.
5. The participant may not bounce the hands forward and legs must remain flat on the floor with toes pointing toward the ceiling.
6. After three practice trials the fourth trial was recorded to the nearest 0.5 of an inch.
7. A reach that does not pass the feet will receive a negative score and a reach that does pass the feet will receive a positive score.

ANAEROBIC MEASUREMENTS

Anaerobic fitness enables an athlete to sprint fast, to accelerate quick, to jump high, and throw far (Montelpare, 2008c). Anaerobic measurements consisted of the vertical jump, Maragaria-Kalamen power test, and the Wingate anaerobic bicycle test. Anaerobic activity, which lasts 30 seconds to two minutes, requires working muscles to rely on finite amounts of blood glucose and muscle glycogen as a source of energy (Power & Howley, 2004).

Vertical Jump

The vertical jump assesses explosive athletic performance by measuring the power generated by the legs from jumping vertically upwards (Sayers, Harman, Frykman, & Rosenstein, 1999).

Protocol for Vertical Jump[8]

1. To begin, the stand and reach height was determined from a measuring tape attached to the wall.

2. Standing perpendicular to the wall, the participant reached as high as possible along the tape using the arm closest to the wall with fingers extended and palm facing towards the wall. Feet remained flat on the floor and the stand and reach height was recorded to the nearest 0.5 of a cm.

3. The participant then moves a safe distance away from the wall (with hand on hip the elbow should barely touch the wall).

4. The participant began in a semi-squat position with arms extended behind the body. The participant paused momentarily in the semi-squat position (to minimize pre-jump) and then brought the arms forward and upward jumping as high as possible while touching the measuring tape at the peak of the jump.

5. There is no pre-jump or run up allowed and the arms must remain behind the body in the starting position so momentum is produced from the legs and not the arms.

6. The better of two trials was recorded to the nearest 0.5 of a centimeter.

7. The stand and reach height was subtracted from the jump height, which gave the actual jump height. Power in watts (W) was calculated from the following equation:[9] W = 60.7(actual jump height [cm]) + 45.3(body mass [kg]) – 2055

Margaria-Kalamen Power Test

A fitness test to measure performance during a short burst of maximal activity was originally designed by Margaria et al. (1966). This test was designed so it could be easily administered and no particular skill was required on behalf of the test conductor or the participant (Margaria et al., 1966). The only equipment needed was a set of stairs with at least six steps that were 17.5 cm tall each and a watch sensitive to 0.01 seconds. In 1968, Kalamen modified this fitness test and it was renamed the Margaria-Kalamen power test (Montelpare, 2008c).

Protocol for the Margaria-Kalamen Power Test[10]

1. The participant stood six meters from the bottom of a flight of twelve steps that have a rise of 18-20 cm each.

2. When ready, the participant would run at full speed up the stairs stepping on the 3rd, 6th, and 9th steps.

3. Two test conductors timed the trials with stopwatches. The clock was started when the participant's foot hit the 3rd step and it was stopped when the participant's foot hit the 9th step.

4. If there was a difference between the two times an average time was determined.

5. Each participant performed the test until three successful trials were completed and the best time was recorded to the nearest 0.01 of a second.

6. Power in watts (W) was calculated from the following equation:[11] W = (body mass [kg])(distance travelled [m])(9.81) / time (s)

Wingate Anaerobic Cycling Test

The Wingate anaerobic cycling test was first introduced in 1974 and is used to measure anaerobic power and anaerobic capacity (Bar-Or, 1987; Klentrou et al., 2000). This fitness test is simple to administer and does not require a particular skill on behalf of the test conductors (Bar-Or, 1987). According to Bar-Or (1987), this test is non-invasive and, therefore, safe and reasonable to use on children and adolescents. It is recommended that two test conductors administer this test for maximum efficiency (Klentrou et al., 2000).

Protocol for the Wingate Anaerobic Cycling Test [12]

The Wingate anaerobic cycling test consists of a standardized warm up and a 30 second 'all out' test followed by a cool down. A stationary bicycle (*Monark Ergomedic 824 E*) equipped with a cradle for weights and a sensor that records pedal revolutions determined power generated during the test.

1. Resistance needed during the warm up and during the test was calculated from multiplying body weight (kg) by 0.02 and 0.07, respectively.

2. Seat height was determined when there was a slight bend in the knee at the bottom of the pedal stroke. Handle bars were adjusted according to the participant's preference.

3. The participant wore a heart rate monitor (*Polar T31* or *T34*) during the warm up, test, and cool down.

4. The warm up consisted of cycling for five minutes against the warm up resistance at the participant's desired cadence. Then, at the 2 minute, 3 minute, and 4 minute mark of the warm up the full test resistance was added for ten seconds. The participant was encouraged to pedal fast and hard during this sprint.

5. Once the warm up was completed the participant either pedaled slowly to no resistance or stopped pedaling and rested for three minutes.

6. To begin the test, a countdown of 5 seconds was verbalized during which, the participant was instructed to pedal as quickly as possible with no resistance.

7. Once the countdown was completed the full test resistance was 'dropped' and the participant pedaled 'all out' for 30 seconds.

8. The peak, average, and minimum power generated were determined in watts (W) from the wheel revolutions detected by a sensor, which were then calculated by a computer program.

9. To cool down, the participant pedaled slowly with the warm up resistance for at least five minutes.

AEROBIC FITNESS TESTING

The ability of the cardiovascular and respiratory systems to supply blood and oxygen to working muscles is referred to as 'cardio-respiratory' (aerobic) fitness (Powers & Howley, 2004). These systems require oxygen to produce ATP during strenuous exercise lasting two or more minutes (Powers & Howley, 2004). The most valid method of measuring aerobic fitness is determining how well the body can transport and utilize oxygen during maximal exercise (Powers & Howley, 2004). Maximal oxygen consumption (VO_2max [$ml{-}kg^{-1}{-}min^{-1}$]) is reached when there is a leveling off of oxygen uptake even if work rate increases. In this study, aerobic fitness was assessed directly by a laboratory method (Åstrand maximal cycling test) and through prediction by a field method (Faught Aerobic Skating Test [FAST]).

Åstrand Maximal Cycling Test

For this test, the participant exercises on a bicycle ergometer until exhaustion. The pedal resistance is increased at timed stages during the test while the participant keeps a constant pedaling cadence.

Protocol for the Åstrand Maximal Cycle Test[13]

1. To begin, the participant warmed up for five minutes on a bicycle ergometer (*Monark Ergomedic 828 E*) at a low speed and resistance.

2. The seat height and handle bars were adjusted for riding efficiency and comfort for each participant. Proper seat height was determined when there was a slight bend in the knee at the bottom of the pedal stroke. Handle bars were adjusted according to the participant's preference.

3. The participant wore a heart rate monitor (*Polar T31* or *T34*) during the warm up, the exercise test, and the cool down.

4. Oxygen uptake (VO_2 [$ml{-}kg^{-1}{-}min^{-1}$]) was measured during the exercise test and cool down by one of two breath-by-breath gas analyzers (COSMED Fitmate Pro; Sensormedics VMAX Series 29).

5. Pedaling was set at a cadence of 50 rpm with the help of a metronome.

6. The participant began pedaling at a resistance of 2 kiloponds (kp). The resistance was increased by 1 kp every two minutes to a maximum of 7 kp. The participant was encouraged to pedal as long as possible at the required cadence while staying seated.

7. The test was terminated due to one of the following events:
    a) The participant's own volition due to fatigue.
    b) The participant was unable to maintain proper cadence.
    c) The test conductor decided the participant was in cardiac or respiratory distress.
    d) The participant reached their VO_2max determined by a plateau in their VO_2 even if work rate increased. If a plateau in VO_2 was *not* reached then maximal oxygen consumption was called '*peak* VO_2'.

8. Once the test stopped, the resistance was reduced and the participant cooled down on the bicycle for at least five minutes.

9. The VO_2max ($ml\text{-}kg^{-1}\text{-}min^{-1}$), the maximum heart rate (bpm) reached during the exercise test, and the amount of time it took to complete the exercise test (mm:ss) was recorded.

Faught Aerobic Skating Test

The FAST is an incremental on-ice skating fitness test that was validated by Petrella et al. (2007) to measure aerobic capacity in ice hockey players. This test is an inexpensive alternative to laboratory testing, which requires little equipment and set up, and is simple to administer. This test consists of continuous skating lengths on a standard size ice rink (approximately 61 m in length). An audio CD of beep signals played in a portable stereo or on the arena sound system paces the participant to cross the line at each end of the rink to begin a new length. The time between each beep signal becomes shorter causing the participant to increase skating speed.

***Protocol for the FAST*[14]**

Up to 8 participants can comfortably and safely perform this test at one time and they were required to wear ice-skates, hockey gloves, a helmet, and carry a hockey stick.

1. 6 pylons, 3 at either end of the ice rink, were placed 48.8 m apart (or 24.4 m from centre ice).

2. Prior to the test, participants warmed up for 5 minutes by skating around the ice rink at their preferred pace.

3. Two test conductors skated with the participants during the initial lengths of the test until the participants became comfortable with the pace. The test conductors then stood at either end of the ice rink by the pylons to notify the participants if they violated any rules of the test. Violations occurred when a participant failed to remain behind the pylons before the beep signal or if he failed to reach the pylons before the beep signal.

4. Participants were required to skate the full 48.8 m distance during the allotted time for each length. The initial lengths took 15 seconds each to complete and decreased by 0.5 seconds every three lengths.

5. The test was terminated due to one of the following events:
   a) Volitional stoppage due to fatigue
   b) Two consecutive violations
   c) The maximum number of lengths was reached (60).

6. The last full length completed was recorded as the participant's score. The participant's heart rate was measured immediately after the test and again five minutes later by measuring the number of heart beats at the carotid artery to determine bpm.

7. To predict VO_2max ($ml\text{-}kg^{-1}\text{-}min^{-1}$) from the FAST the following equation was used:[15]
   $VO_{2max} = 34.119(\text{height [m]}) - 0.244(\text{weight [kg]}) + 0.757(\text{\# lengths}) - 0.975(\text{age}) - 3.285$

PROTOCOL

Fitness testing took place during the early ice hockey season (November 2007) and it lasted four days due to the number of fitness tests performed. One day was devoted to assessing performance on the Wingate anaerobic cycling test and the Margaria-Kalamen power test; a second day was devoted to assessing performance on the Åstrand maximal cycling test; a third day was devoted to assessing performance on the FAST; and a fourth day was devoted to assessing waist to hip ratio, skinfold thickness, vertical jump, curl ups, push ups, and flexibility. Height, weight, resting heart rate, and resting blood pressure were measured at the beginning of each testing day. If there were differences in these measures throughout the testing session an average value was obtained and recorded for data analysis.

RESULTS

Descriptive Statistics

Table 1 presents the number of observations (N), means, standard deviations (SD), minimum values, maximum values, standard errors (SE), and 95% confidence intervals ($CI_{95\%}$) for anthropometry (height, weight, resting heart rate, resting blood pressure, waist to hip ratio, and body fat percent) and measures of physical fitness (curl ups, sit and reach flexibility, and push ups) during the early ice hockey season. Average height was 176.1 ± 7.84 cm; average weight was 71.3 ± 11.77 kg; and average body fat was 15.2 ± 3.10 %.

Table 1
Early season measures of anthropometry and physical fitness

Variable	N	Mean	SD	Min	Max	SE	$CI_{95\%}$
Ht	16	176.1	± 7.84	166.5	193.0	1.96	± 3.84
Wt	16	71.3	± 11.77	51.5	93.5	2.94	± 5.76
R HR	16	72.2	± 7.12	60	82	1.78	± 3.49
R SBP	16	124.1	± 6.31	114	136	1.58	± 3.10
R DBP	16	75.8	± 7.37	65	94	1.84	± 3.61
WHR	16	0.84	± 0.03	0.76	0.89	0.01	± 0.02
BF	16	15.2	± 3.10	11.4	20.6	0.77	± 1.51
C Up	16	40	± 4.84	33	50	1.21	± 2.37
Flex	16	5.1	± 8.14	-18.0	17.0	2.03	± 3.98
P Up	16	20.2	± 4.96	11	27	1.24	± 2.43

Note. Ht = height (cm); Wt = weight (kg); R HR = resting heart rate (bpm); R SBP = resting systolic blood pressure (mmHg); R DBP = resting diastolic blood pressure (mmHg); WHR = waist to hip ratio; BF = body fat percent; C Up = # of curl ups; Flex = sit and reach flexibility (cm); P Up = # of right angle push ups.

Table 2 presents the number of observations (N), means, standard deviations (SD), minimum values, maximum values, standard errors (SE), and 95% confidence intervals ($CI_{95\%}$) for aerobic (the Åstrand maximal cycling test and the FAST) and anaerobic (the Margaria-

Kalamen power test, the Wingate cycling test, and vertical jump) measures of fitness during the early ice hockey season. Average VO_2max on the Åstrand maximal cycling test was 54.1 ± 7.04 $ml\text{-}kg^{-1}\text{-}min^{-1}$; average number of FAST lengths completed was 41.6 ± 4.52; and average predicted VO_2max from the FAST was 57.5 ± 3.73 $ml\text{-}kg^{-1}\text{-}min^{-1}$.

Table 2
Early season measures of aerobic and anaerobic fitness

Variable	N	Mean	SD	Min	Max	SE	$CI_{95\%}$
MK	14	1253.4	± 223.01	970	1676	59.60	± 116.82
Bk VO_2	14	54.1	± 7.04	41.7	65.5	1.88	± 3.68
Bk Tm	14	10.4	± 1.56	7.0	12.3	0.42	± 0.82
Win Pk	15	683.0	± 125.54	481	919	32.41	± 63.52
Win Avg	15	546.9	± 93.61	393	742	24.17	± 47.37
Win Min	15	400.7	± 73.01	299	555	18.85	± 36.95
FAST L	15	41.6	± 4.52	28	46	1.17	± 2.29
FAST VO_2	15	57.5	± 3.73	46.2	61.6	0.96	± 1.88
FAST PEHR	15	171.1	± 18.23	132	198	4.71	± 9.23
FAST 5PEHR	15	96.4	± 18.90	66	132	4.88	± 9.56
VJ Ht	15	44.0	± 5.71	34.5	56.0	1.47	± 2.88
VJ W	15	3811.7	± 670.46	2562	4696	173.11	± 339.30

Note. MK = Margaria-Kalamen power test (watts); Bk VO_2 = VO_2max on the Åstrand ($ml\text{-}kg^{-1}\text{-}min^{-1}$); Bk Tm = total cycling time in the Åstrand (min); Win Pk = peak Wingate power (watts); Win Avg = average Wingate power (watts); Win Min = minimum Wingate power (watts); FAST L = # of FAST lengths; FAST VO_2 = predicted VO_2max from the FAST ($ml\text{-}kg^{-1}\text{-}min^{-1}$); FAST PEHR = FAST post exercise heart rate (bpm); FAST 5PEHR = FAST 5 min post exercise heart rate (bpm); VJ Ht = vertical jump height (cm); VJ W = vertical jump power (watts).

The results from descriptive statistics help to explain how the measures of anthropometry and ice hockey fitness compare to normative data and to the findings of previous studies. Additional explanations of the results are presented.

DISCUSSION

Comparison of Present Results to Data from the Published literature

According to growth charts, the average height of participants was above the 90th percentile (Centers for Disease Control and Prevention [CDC], 2001). Interestingly, the height of the shortest participant (166.5 cm) was still above the 90th percentile ranking, indicating that the athletes on this ice hockey team are all taller than average for their age and sex. These findings are similar to previous work by McLaren (2006) that assessed anthropometric and fitness measures in a triple 'A' bantam-age male ice hockey team; results showed that the mean height of participants was also above the 90th percentile; however, not all participants' height was above the 90th percentile.

Similar to height, mean weight for these athletes was above the 90th percentile as well (CDC, 2001). This finding is similar to the results in the McLaren (2006) study, where results showed that the mean weight of participants was above the 90th percentile. In the present study weight varied greatly between participants; the lightest individual weight (51.5 kg) was below the 50th percentile and the heaviest individual weight (93.5 kg) was above the 95th percentile. This difference in weight between players is consistent with the findings of a previous study that also found a large difference in weight between players on a bantam-age male ice hockey team (Brust, Leonard, Pheley, & Roberts, 1992). .

Compared to normative values, the participants' mean body fat percent was 'leaner than average' (Earle & Baechle, 2004, p. 246). The lowest individual body fat percent (11.4%) was 'very lean' (and not recommended for this age group), and the highest individual body fat percent (20.6%) was 'average'.

The findings for height, weight, and body fat in this study were consistent with previous research that found elite ice hockey players to be taller, heavier, and have less body fat than the average population (Cox, 1995; Earle & Baechle, 2004; Montgomery, 2006; Quinney et al., 2008).

The mean number of FAST lengths was above the 70th percentile according to normative data (Petrella et al., 2007). However, there was a wide range in the number of FAST lengths the participants completed; the lowest number of FAST lengths (28) was below the 20th percentile and the highest number of FAST lengths (46) was above the 90th percentile. In the McLaren study, the minimum number of FAST lengths completed was 37 and the maximum number of FAST lengths completed was 51. This may indicate that the participants in the McLaren study had, on average, better aerobic fitness characterized by the number of FAST lengths completed. In the present study, the mean VO_2max from the FAST was above the 50th percentile (Petrella et al., 2007). However, similar to the number of FAST lengths, there was a wide range in scores on VO_2max from the FAST; the lowest predicted VO_2max from the FAST (46.2 $ml\text{-}kg^{-1}\text{-}min^{-1}$) was below the 20th percentile and the highest predicted VO_2max from the FAST (61.6 $ml\text{-}kg^{-1}\text{-}min^{-1}$) was above the 80th percentile.

Linear Regression Analysis

Backwards linear regression analysis was used to determine which measure was the strongest predictor of VO_2max of the FAST from the following independent variables: height, weight, resting heart rate, resting blood pressure, waist to hip ratio, body fat percent, vertical jump height, vertical jump power, the Margaria-Kalamen power test, VO_2max on the Åstrand maximal cycling test, total cycling time in the Åstrand maximal cycling test, the Wingate cycling test, the number of curl ups, sit and reach flexibility, and the number of right angle push ups.

Table 3 presents the model and the variable (Predictors) that was shown to be the most significant ($p < 0.09$) predictor of VO_2max of the FAST, in addition to the beta co-efficient (β), significance of the beta co-efficient (p), and the R-squared for the significant predictor (R^2). The results showed that the Margaria-Kalamen stair test ($\beta = -0.008$, $p < 0.05$) was the strongest predictor of VO_2max of the FAST.

Table 3
Results from the regression analysis

Model	Predictors	β	p	R^2
MK + Bk VO_2+ Win Min + VJ Ht + VJ W	Intercept	67.903	< 0.01	0.372
	MK	-0.008	< 0.05	

Note. β with $p > 0.09$ not included; MK = Margaria-Kalamen power test (watts); Bk VO_2 = VO_2max on the Åstrand ($ml\text{-}kg^{-1}\text{-}min^{-1}$); Win Min = minimum Wingate power (watts); VJ Ht = vertical jump height (cm); VJ W = vertical jump power (watts).

Results from the regression analysis showed that the strongest predictor of VO_2max of the FAST was the Margaria-Kalamen power test. These results are interesting since the Margaria-Kalamen power test is a measure of anaerobic power, whereas the FAST measures aerobic fitness. However, these findings support results from previous research by Petrella et al. (2007) that found the FAST to be a good measure of overall ice hockey fitness.

The Assessment of Ice Hockey Fitness and Its Meaning

The findings from the present research provide a detailed physiological profile of the anthropometry and fitness capacities of a representative level, bantam-age ice hockey team. Additionally, the results from the present study were compared to the findings of previous research and to normative data to determine where the participants rank in the general population.

Compared to normative data, the participants from this study are 'above average' regarding stature and aerobic fitness levels. Having a large frame is not only ideal when participating in representative ice hockey, it is a necessity. Coaches and scouts generally recruit ice hockey athletes with large frames because these players tend to have the advantage when confronted with the need for controlling the puck or during physical body contact with other players (Burr et al., 2008; Montgomery, 2006). Aerobic fitness has been proven in the literature to be an essential part of success in representative ice hockey, primarily because it improves recovery between shifts of play (Carey et al., 2007; Petrella et al., 2007). Therefore, it was not unexpected that these participants would, on average, have better aerobic fitness compared to normative data.

Fitness data from the early ice hockey season was used in the regression analysis to predict VO_2max of the FAST because motivation of participants was believed to be highest during this time. Therefore, a true assessment of ice hockey fitness was obtained to achieve the most accurate and valid results possible. To reduce multi-collinearity the appropriate statistical procedures were conducted in addition to exploring various combinations of variables in the regression analysis.

Results from the regression analysis showed that the Margaria-Kalamen power test was the strongest predictor of VO_2max of the FAST when VO_2max from the Åstrand maximal cycling test, minimum Wingate power, vertical jump height, and vertical jump power were also included in the model. Overall ice hockey fitness consists of aerobic and anaerobic fitness, musculoskeletal fitness, and a large and lean body composition (Green et al., 2006). Previous research by Petrella et al. (2007) found that the FAST does not just measure aerobic fitness, it is also a good measure of overall ice hockey fitness. The finding that the Margaria-Kalamen power test was the strongest predictor of VO_2max of the FAST supports the research conducted by Petrella et al. (2007): a participant's score on the FAST can indicate abilities in other areas of ice hockey fitness. More importantly, the Margaria-Kalamen power test, similar to the FAST, is a quick and easily administered fitness test. This allows coaches and trainers of ice hockey teams to assess the fitness of their players without the need of expensive equipment or trained test conductors. Furthermore, both the FAST and the Margaria-Kalamen power test have shown to assess both aerobic *and* anaerobic fitness. This suggests that an ice hockey team can save time by performing just one of these fitness tests, and yet still achieve an accurate assessment of overall ice hockey fitness.

It was unexpected that VO_2max from the Åstrand maximal cycling test was not the strongest predictor of VO_2max of the FAST since both of these fitness tests measure aerobic fitness. Interestingly, the VO_2max from the Åstrand maximal cycling test was a significant predictor only when total cycling time in the Åstrand maximal cycling test was included in the regression model. However, results from statistical analysis showed that including both measures from the Åstrand maximal cycling test resulted in multicollinearity of these variables. Therefore, it was decided to remove total cycling time from the regression model and to keep the VO_2max variable since it was a direct measure of aerobic power.

No other research was found that conducted a study to determine which measure of laboratory ice hockey fitness could best predict VO_2max of the FAST; therefore, it was not possible to compare the findings from the present study directly with another study. However, there were some previous studies that used similar protocols and had results that showed noteworthy relevance to the present study.

Burr et al. (2008) determined which measures of laboratory ice hockey fitness could predict hockey playing potential in elite players as determined by entry draft selection order into the NHL. Results showed that measures of anthropometry (height, body fat percent, and physical development) and peak Wingate power were significant predictors of playing potential. It was unexpected that no measures of anthropometry were shown to significantly predict VO_2max of the FAST in the present study since these measures are commonly used by trained professionals to assess and predict an individual's health and fitness (Earle & Baechle, 2004). Even though peak Wingate power was not a significant predictor in the present study, the Margaria-Kalamen power test, which is also a measure of anaerobic fitness, was shown to predict VO_2max of the FAST. Furthermore, results from the Burr et al. study did not find that aerobic power (VO_2max) had a significant influence on performance, which is similar to the findings in the present study. According to Hoffman et al. (as cited in Carey et al., 2007), there is a minimum level of aerobic fitness required in an elite ice hockey player above which there are no increased benefits. This suggests that better aerobic fitness does not necessarily result in better performance in ice hockey players. Conversely, results from a study by Green et al. (2006) determined that a significant amount of the variance in on-ice hockey performance was explained by a laboratory measure of aerobic fitness.

The results from the regression analysis are vitally consistent with the findings in previous work by Petrella et al. (2007): performance on the FAST has shown to be a good measure of over all ice hockey fitness. Previous research has shown that ice hockey fitness is multi-dimensional and that it is necessary for successful elite ice hockey athletes to have proficient aerobic and anaerobic systems (Green et al., 2006). Therefore, coaches and trainers of bantam-age, representative level ice hockey teams can use the FAST and the Margaria-Kalamen power test to assess aerobic and/or anaerobic fitness in ice hockey players to determine those players with the greatest potential, and to monitor the development of 'ice hockey fitness' in response to various training programs.

CONCLUSION

This study analyzed the relationship between laboratory measures of ice hockey fitness and VO_2max from the FAST, in addition to creating a physiological profile and comparing the participants' fitness test results to normative data. Results were supportive of previous research that showed representative ice hockey players tend to be taller, heavier, and have less fat mass than the average person. Furthermore, results from the regression analysis showed that the Margaria-Kalamen power test was the strongest predictor of VO_2max of the FAST.

Future research can provide supplementary information about the fitness capabilities of this cohort in addition to revealing the reliability of the Margaria-Kalamen to predict VO_2max of the FAST.

The FAST and the Margaria-Kalamen are established sport specific fitness tests that have shown to be valid and reliable in assessing ice hockey fitness. They are readily accessible fitness test that ice hockey coaches and trainers can use to determine the fitness abilities of their players without requiring complicated or expensive laboratory methods.

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ENDNOTES

[1] The protocol for resting blood pressure was taken from Klentrou, et al. (2000).

[2] The protocol for waist to hip ratio was taken from Earle and Baechle (2005) and Montelpare (2008a).

[3] The protocol for measuring skinfold thickness was taken from Earle and Baechle (2004) and Montelpare (2008a).

[4] The equation to calculate body fat percentage from skinfold measures was taken from Earle and Baechle (2004, p. 244).

[5] The protocol for curl ups was taken from The President's Challenge (2007).

[6] The protocol for right angle push ups was taken from Montelpare (2008b) and The President's Challenge (2007).

[7] The protocol for sit and reach was taken from The President's Challenge (2007).

[8] The protocol for vertical jump was taken from Montelpare (2008c).

[9] The equation to calculate power from the vertical jump was taken from Sayers, et al. (1999).

[10] The protocol for the Margaria-Kalamen was taken from Margaria et al. (1966) and Montelpare (2008c).

[11] The equation to calculate power from the Margaria-Kalamen was taken from Montelpare (2008c).

[12] The protocol for the Wingate anaerobic bicycle tests was taken from Bar-Or (1987) and Montelpare (2008c).

[13] The protocol for the Åstrand VO_2max bicycle test was taken from Heyward (2006) and Siconolfi, Cullinane, Carleton, and Thompson (1982).

[14] The protocol for the FAST was taken from Petrella et al. (2007).

[15] The equation to calculate VO_2max from the FAST was taken from Petrella et al. (2007).

APPENDIX A

SAS Program and Output

```
data session_1;
infile '/export/home/vemorris/session_1.dat';
input ID 1-10 Age 12-13 Ht 15-19 Wt 21-24 R_HR 26-27 R_SBP 29-31 R_DBP 33-34 MK 36-39 Bk_VO2 41-
44 Bk_Tm 46-49 Win_Pk 51-53 Win_Avg 56-58
Win_Min 60-62 FAST_L 64-65 FAST_VO2 67-70 FAST_PEHR 72-74 FAST_5PEHR 76-78 WHR 80-83 BF 85-88
VJ_Ht 90-93 VJ_W 95-98 C_Up 100-101 Flex 103-107 P_Up
109-110;
label
Name        ='Participant Name'
Age         ='Participant Age (years)'
Ht          ='Height(cm)'
Wt          ='Weight(kg)'
R_HR        ='Resting Heart Rate (bpm)'
R_SBP       ='Resting Systolic Blood Pressure (mmHg)'
R_DBP       ='Resting Diasolic Blood Pressure (mmHg)'
MK          ='Margaria-Kalamen (watts)'
Bk_VO2      ='Astrand VO2max (ml/kg/min)'
Bk_Tm       ='Astrand Bike Time (min)'
Win_Pk      ='Wingate Peak Power (watts)'
Win_Avg     ='Wingate Average Power (watts)'
Win_Min     ='Wingate Minimum Power (watts)'
FAST_L      ='FAST Lengths'
FAST_VO2    ='FAST VO2max (ml/kg/min)'
FAST_PEHR   ='FAST Post Exercise Heart Rate (bpm)'
FAST_5PEHR='FAST 5 min Post Exercise Heart Rate (bpm)'
WHR         ='Waist to Hip Ratio'
BF          ='Body Fat Percent'
VJ_Ht       ='Vertical Jump Height (cm)'
VJ_W        ='Vertical Jump Power (watts)'
C_Up        ='Curl Ups'
Flex        ='Sit and Reach (cm)'
P_Up        ='Right Angle Push Ups'
;
title 'Fitness Scores from Session 1';
proc sort data=session_1 noequals; by ID;
proc print data=session_1;
proc means data=session_1 n min max mean std stderr;
title 'Descriptive Statistics for Session 1';

proc sort data=session_1 noequals; by ID;
proc reg data=session_1;
 model FAST_VO2=MK Bk_VO2 Win_Min VJ_Ht VJ_W/selection=backward collin vif;
 title 'Multiple Regression of Aerobic and Anaerobic Measures to Predict FAST_VO2';

run;
endsas;
```

Descriptive Statistics for Session 1 10:15 Tuesday, July 21, 2009 2

The MEANS Procedure

Variable	Label	N	Minimum	Maximum	Mean	Std Dev	Std Error
ID		16	1.0000000	16.0000000	8.5000000	4.7609523	1.1902381
Age	Participant Age (years)	16	13.0000000	14.0000000	13.8125000	0.4031129	0.1007782
Ht	Height(cm)	16	166.5000000	193.0000000	176.0625000	7.8440529	1.9610132
Wt	Weight(kg)	16	51.5000000	93.5000000	71.2937500	11.7732164	2.9433041
R_HR	Resting Heart Rate (bpm)	16	60.0000000	82.0000000	72.1875000	7.1201007	1.7800252
R_SBP	Resting Systolic Blood Pressure (mmHg)	16	114.0000000	136.0000000	124.1250000	6.3126856	1.5781714
R_DBP	Resting Diasolic Blood Pressure (mmHg)	16	65.0000000	94.0000000	75.7500000	7.3711148	1.8427787
MK	Margaria-Kalamen (watts)	14	970.0000000	1676.00	1253.43	223.0149061	59.6032408
Bk_VO2	Astrand VO2max (ml/kg/min)	14	41.7000000	65.5000000	54.1071429	7.0355651	1.8803339
Bk_Tm	Astrand Bike Time (min)	14	7.0000000	12.3000000	10.3571429	1.5569765	0.4161195
Win_Pk	Wingate Peak Power (watts)	15	481.0000000	919.0000000	683.0000000	125.5394076	32.4141357
Win_Avg	Wingate Average Power (watts)	15	393.0000000	742.0000000	546.8666667	93.6130841	24.1707944
Win_Min	Wingate Minimum Power (watts)	15	299.0000000	555.0000000	400.6666667	73.0094580	18.8509610
FAST_L	FAST Lengths	15	28.0000000	46.0000000	41.6000000	4.5166359	1.1661904
FAST_VO2	FAST VO2max (ml/kg/min)	15	46.2000000	61.6000000	57.4533333	3.7349444	0.9643585
FAST_PEHR	FAST Post Exercise Heart Rate (bpm)	15	132.0000000	198.0000000	171.1333333	18.2321015	4.7075084
FAST_5PEHR	FAST 5 min Post Exercise Heart Rate (bpm)	15	66.0000000	132.0000000	96.4000000	18.9012471	4.8802810
WHR	Waist to Hip Ratio	16	0.7600000	0.8900000	0.8387500	0.0340343	0.0085086
BF	Body Fat Percent	16	11.4000000	20.6000000	15.2187500	3.0995094	0.7748773
VJ_Ht	Vertical Jump Height (cm)	15	34.5000000	56.0000000	44.0333333	5.7054694	1.4731459
VJ_W	Vertical Jump Power (watts)	15	2562.00	4696.00	3811.67	670.4621718	173.1125884
C_Up	Curl Ups	16	33.0000000	50.0000000	40.0000000	4.8442406	1.2110601
Flex	Sit and Reach (cm)	16	-18.0000000	17.0000000	5.0625000	8.1360822	2.0340205
P_Up	Right Angle Push Ups	16	11.0000000	27.0000000	20.1875000	4.9560569	1.2390142

Multiple Regression of Aerobic and Anaerobic Measures to Predict FAST_VO2 3
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The REG Procedure
Model: MODEL1
Dependent Variable: FAST_VO2 FAST VO2max (ml/kg/min)

Number of Observations Read	16
Number of Observations Used	11
Number of Observations with Missing Values	5

Backward Elimination: Step 0

All Variables Entered: R-Square = 0.5500 and C(p) = 6.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	29.35327	5.87065	1.22	0.4155
Error	5	24.01219	4.80244		
Corrected Total	10	53.36545			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	77.10921	18.03647	87.77509	18.28	0.0079
MK	-0.01676	0.01101	11.11853	2.32	0.1886
Bk_VO2	-0.13474	0.14017	4.43719	0.92	0.3806
Win_Min	0.00553	0.01706	0.50482	0.11	0.7589
VJ_Ht	0.03984	0.34495	0.06405	0.01	0.9126
VJ_W	0.00121	0.00380	0.48572	0.10	0.7633

Bounds on condition number: 15.256, 167.92

Backward Elimination: Step 1

Variable VJ_Ht Removed: R-Square = 0.5488 and C(p) = 4.0133

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	29.28921	7.32230	1.82	0.2430
Error	6	24.07624	4.01271		
Corrected Total	10	53.36545			

Multiple Regression of Aerobic and Anaerobic Measures to Predict FAST_VO2 4
10:15 Tuesday, July 21, 2009

The REG Procedure
Model: MODEL1
Dependent Variable: FAST_VO2 FAST VO2max (ml/kg/min)

Backward Elimination: Step 1

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	78.67175	10.90276	208.93051	52.07	0.0004
MK	-0.01757	0.00771	20.86626	5.20	0.0628
Bk_VO2	-0.13484	0.12813	4.44440	1.11	0.3331
Win_Min	0.00460	0.01376	0.44923	0.11	0.7493
VJ_W	0.00160	0.00157	4.17776	1.04	0.3469

Bounds on condition number: 4.5516, 49.445

Backward Elimination: Step 2

Variable Win_Min Removed: R-Square = 0.5404 and C(p) = 2.1069

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	28.83998	9.61333	2.74	0.1226
Error	7	24.52548	3.50364		
Corrected Total	10	53.36545			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	77.28137	9.41876	235.87494	67.32	<.0001
MK	-0.01628	0.00623	23.93636	6.83	0.0347
Bk_VO2	-0.11607	0.10764	4.07426	1.16	0.3166
VJ_W	0.00178	0.00138	5.80909	1.66	0.2388

Bounds on condition number: 3.4049, 22.932

Backward Elimination: Step 3

Variable Bk_VO2 Removed: R-Square = 0.4641 and C(p) = 0.9553

The REG Procedure
Model: MODEL1
Dependent Variable: FAST_VO2 FAST VO2max (ml/kg/min)

Backward Elimination: Step 3

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	24.76572	12.38286	3.46	0.0825
Error	8	28.59974	3.57497		
Corrected Total	10	53.36545			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	68.11726	4.10242	985.61036	275.70	<.0001
MK	-0.01329	0.00563	19.89534	5.57	0.0460
VJ_W	0.00162	0.00139	4.90051	1.37	0.2754

Bounds on condition number: 2.7278, 10.911

Backward Elimination: Step 4

Variable VJ_W Removed: R-Square = 0.3722 and C(p) = -0.0243

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	19.86521	19.86521	5.34	0.0462
Error	9	33.50024	3.72225		
Corrected Total	10	53.36545			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	67.90340	4.18193	981.37678	263.65	<.0001

MK	-0.00804	0.00348	19.86521	5.34	0.0462

Bounds on condition number: 1, 1

All variables left in the model are significant at the 0.1000 level.

The REG Procedure
Model: MODEL1
Dependent Variable: FAST_VO2 FAST VO2max (ml/kg/min)

Summary of Backward Elimination

Step	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	VJ_Ht	Vertical Jump Height (cm)	4	0.0012	0.5488	4.0133	0.01	0.9126
2	Win_Min	Wingate Minimum Power (watts)	3	0.0084	0.5404	2.1069	0.11	0.7493
3	Bk_VO2	Astrand VO2max (ml/kg/min)	2	0.0763	0.4641	0.9553	1.16	0.3166
4	VJ_W	Vertical Jump Power (watts)	1	0.0918	0.3722	-0.0243	1.37	0.2754

The REG Procedure
Model: MODEL1
Dependent Variable: FAST_VO2 FAST VO2max (ml/kg/min)

Number of Observations Read	16
Number of Observations Used	11
Number of Observations with Missing Values	5

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	19.86521	19.86521	5.34	0.0462
Error	9	33.50024	3.72225		
Corrected Total	10	53.36545			

Root MSE	1.92931	R-Square	0.3722
Dependent Mean	58.33636	Adj R-Sq	0.3025
Coeff Var	3.30722		

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	67.90340	4.18193	16.24	<.0001	0
MK	Margaria-Kalamen (watts)	1	-0.00804	0.00348	-2.31	0.0462	1.00000

Collinearity Diagnostics

Number	Eigenvalue	Condition Index	--Proportion of Variation- Intercept	MK
1	1.99028	1.00000	0.00486	0.00486
2	0.00972	14.30816	0.99514	0.99514