THE ROLE FITNESS TESTING PLAYS IN TEAM SELECTION OF ELITE FEMALE ICE HOCKEY PLAYERS

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ABSTRACT

The purpose of this study was to determine the role physical and physiological testing plays in team selection of elite female ice hockey athletes. Testing results collected during pre-season for Hockey Canada Women's National Team between the years of 2005-2014 were analyzed and compared between athletes who were selected to the team (N=189) compared to athletes who were not selected (N=154). Basic descriptive statistics were calculated for the entire group and a logistic regression was run to determine the odds ratios for each testing measure. The odds of being selected to the elite team were significantly higher for age (OR = 1.27, 95% CI = 1.19-1.35), height (OR = 1.06, 95% CI = 1.02-1.10), fat percentage (OR = 0.91, 95% CI = 0.86-0.96), fat mass (OR = 0.94, 95% CI = 0.89-1.00), estimated maximum oxygen consumption (VO_2 max) from 20m shuttle run (OR = 1.11, 95% CI = 1.03-1.19), maximal aerobic power workload (OR = 1.01, 95% CI = 1.00-1.00), critical power workload (OR = 1.01, 95% CI = 1.01-1.02), bench press by 10 unit increase (OR = 1.19, 95% CI = 1.06-1.34), maximum fixed bar supinated grip chin-ups (OR = 1.15, 95% CI = 1.08-1.22), squat vertical jump by 10 unit increase (OR = 2.63, 95% CI = 1.61-4.28), countermovement vertical jump by 10 unit increase (OR = 2.33, 95% CI = 1.47-3.70), drop jump by 10 unit increase (OR = 2.47, 95% CI = 1.53-3.97). The results of this analysis suggest that improvements in aerobic fitness, upper body strength, and lower body power will increase a player's odds of being selected for the team. Off-ice training should focus on developing these areas so that female hockey players are placed in the best position for being selected for an elite team.

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REVIEW OF THE LITERATURE

Physical and Physiological Characteristics of Ice Hockey

The sport of ice hockey is characterized by participants repeatedly performing high-intensity, short-duration bursts of maximal power, while also needing to be able to perform at a consistently high level over the course of a 60-minute game[1]. For optimal performance, elite hockey athletes need to have well-rounded physical and physiological capabilities including anaerobic fitness[2], aerobic fitness[3], muscular strength, power, and endurance[4]. To be successful, athletes must be able to combine dynamic movement patterns with sport-specific skills such as skating, shooting, and passing of the puck[5].

From a physiological point of view, ice hockey players are expected to develop a well-rounded fitness profile including the ability to sprint repeatedly, have high level of aerobic fitness, and a high degree of muscle strength, power, and endurance to be able to continually perform at a high level and throughout a season[1]. In a time-motion analysis of a hockey game, Green *et al*. (1976) showed that forwards played on average 14 to 21 shifts per game and approximately 20 minutes total time on ice. The average shift length was 85 seconds, during which only 39 seconds of the shift was actual playing time. The intensity varied throughout the shift; however the average heart rate was approximately 80% of a player's maximal aerobic power[6]. Similar results were found by Montgomery (1988), in that even though variability on a per player basis exists during a shift, players recorded an average heart rate of 85% of their maximum heart rate while on the ice[7].

From an energetics perspective, ice hockey players rely heavily on their anaerobic system. Over the course of a game, it is estimated that an ice hockey athlete will rely on anaerobic glycolysis for 69% of their energy expenditure[8]. Due to the intermittent nature of the sport, the aerobic system plays a large role in the recovery of the energy systems between shifts and between periods[9]. A positive correlation has been shown between an ice hockey player's maximal aerobic oxygen consumption (VO_2 max) and on-ice success[10]. The aerobic system most likely plays a large role in allowing the athlete to recovery for repeat on-ice sprint bouts. It has been shown in previous research that ice hockey athletes should maintain a VO_2 max between 50-60 $ml \cdot kg^{-1} \cdot min^{-1}$ at the highest levels of male hockey[11]. This is supported by more recent literature of male international ice hockey players in which showed that elite level players had higher maximum oxygen uptake values when compared to junior hockey players within the same club system[12].

Ice hockey athletes need to have adequate levels of upper and lower body strength, power, and endurance to perform. Athletes who are stronger are able to skate faster and apply more force with each stride into the ice[13]. Athletes who exhibit an ability to produce large amounts of horizontal leg power have been shown to be able to skate and turn at higher velocities on the ice[14]. Likewise, it has been shown that athletes with a higher vertical jump score were deemed superior based on their draft round selection at the NHL Combine. It is hypothesized that the vertical jump best simulates the full-bodied coordinated movements needed to play hockey[15]. Upper body strength allows athletes to shoot the puck harder, as well as use their body for positioning and body contact[5]. Peyer *et al*. (2007) found that athletes with higher preseason scores in upper and lower body tests had a better plus/minus (+/-) at the end of the season[16]. This is a statistic hockey coaches use to measure a players impact on the game. When an even-strength goal or a shorthanded goal is scored, each player that is on the ice for the scoring team receives a "plus" score; the players on the opposing team that are on the ice when the goal is scored receive a “minus” score. The statistic is directly affected by overall team performance, influenced by both the offensive and defensive performance of the team as a whole.

Typical Fitness Tests for Hockey

Testing protocols are typically selected because they share biomechanical similarities to on-ice movements and demands placed on the players. This has led researchers and hockey coaches to modify valid and reliable off-ice tests to conform to on-ice procedures. One such example is the investigation of Buchheit *et al.* (2011) who created the “30-15 Intermittent Ice Test”. This test consists of 30 second shuttle skates of 40 metres, intersperse with 15 seconds of passive recovery at a pre-determined skating speed dictated by audible signal. Similar to the off-ice 30-15 intermittent test, it was found that the on-ice version was highly reliable in both maximum skating velocity and maximum heart rate values when compared to the off-ice protocol[17].

In both female and male ice hockey players, the use of an off-ice 40 yard sprint test has shown to be highly correlated with on-ice skating speed. Bracko and George (2001) performed a wide battery of tests on female hockey players including sit-and-reach flexibility, vertical jump, 40 yard sprint, and maximum push-ups. The strongest correlation they found between the off-ice measures and skating speed was the 40 yard sprint time, which they reported that this is because at top speed, skating requires horizontal leg power, which is easily replicated in sprinting[18]. Likewise, Krause *et al.* (2012) found that the 40 yard sprint was the best predictor of on ice speed, when compared to vertical jump and standing long jump[19]. The Wingate bike test has also been shown by researchers to have a strong correlation between skating speed and peak power[14,20]. The squat vertical jump, which consists of a pause at the bottom phase of the jump, has been strongly correlated to leg power ranking of elite hockey prospects[15].

It has been hypothesized that off-ice tests are unable to fully capture the physical and physiological capabilities needed for on-ice performance. Off-ice tests may not recruit the same muscle mass as skating[21]. This can be seen in jumping tests, where jumping protocols elicit the same underlying power production as skating; the movements are biomechanically different[22]. Jumping tests, while shown to have some correlation to on-ice success[14,15], might lack specificity to skating performance as skating mechanics rely heavily on impulse rather than the stretch shortening cycle[23].

In a recent literature review of both on-ice and off-ice hockey fitness testing, Nightingale (2013) has suggested that to make the most accurate estimation of on-ice ability through fitness testing it needs to include both on-ice and off-ice tests. The selected testing battery should measure acceleration, speed, anaerobic and aerobic power, upper body and lower body strength, change of direction ability, and body composition[24]. On-ice tests should measure acceleration, speed, aerobic power, and change of direction ability include 6.1 meter skate[25], 35 meter sprint and Cornering "S" test[14], and the 30-15 Intermittent Test[17]. Off-ice tests would reflect the remaining qualities, anaerobic power through the vertical jump, and typical strength tests for upper body and lower body strength such as the bench press and front squat.

Testing to Predict Team Success and Team Selection

At the highest level of male hockey, it has been shown that physiological tests are associated with certain indicators of success. Burr *et al.* (2008) showed that percent body fat and performance in the Wingate cycle test for peak power and fatigue index were important physical attributes for draft round selection in the National Hockey League Combine (formerly known as the Entry Draft)[3].

Over the course of a season, performance in certain off-ice tests measured in the preseason has been positively associated to on-ice success. Male ice hockey players with higher scores in a repeat 110 meter sprint test, leg press test, maximum chin-up test, and bench press test had a higher end of season plus/minus ranking than their teammates[16]. In a study by Green *et al.* (2006) they found that athletes who have a higher VO_2 max had increased scoring chances over the course of a season[10]. Theoretically, the more scoring chances a team has over the course of the season, the greater chance of success they would have to win game(s). It is hypothesized that the higher level of aerobic fitness allowed these athletes to have a greater amount of involvement in the overall game play, thus resulting in more scoring opportunities due to their ability to recover and repeat high intensity bouts as needed.

To the author's knowledge, no study has investigated the role that physical and physiological fitness testing plays in team selection in hockey. When investigating the role of fitness testing in other sports, it has been shown that the physiological characteristics do play a role in team selection in rugby. Professional rugby players selected to play in in the National Rugby League were older, had faster 10 meter and 40 meter sprint times, and jumped higher than athletes not selected to the professional teams[26].

Physical fitness testing scores and anthropometric data have successfully been used in team selection in Australian Rules Football. In a unique study by Keogh (1999), he showed that by using a discriminant analysis equation, he could successfully predict 75.9% of the selected to the team, 90.9% of the players not selected, and 80% of all the players[27]. Forty Australian Rules Football (ARF) players attending a selection camp an Under 18 ARF elite team were put through a fitness testing battery that included measures of estimated VO2 max, upper body strength, flexibility, and counter movement vertical jump, along with some anthropometric measures of height, and body mass. Through a comparison of the athletes selected versus not selected to the team, selected athletes were significantly taller, stronger, and exhibited higher lower body power.

Female Ice Hockey Characteristics and Participation

At the international level, elite female hockey consists of the countries that participate in the International Ice Hockey Federation (IIHF) Women's World Championship tournament or the Winter Olympic Games. The IIHF has hosted 15 championships during non-Olympic years, with Canada winning 10 times[28]. Women's hockey has appeared in the Winter Olympic Games since 1998, Canada has won 4 out of 5 gold medals during this time[29]. The highest level of female hockey within Canada is the National Women's Team, chosen yearly to represent Canada at either the IIHF World Championship or the Olympic Winter Games either annually or quadrennially respectively.

From a grassroots level, female hockey has seen a large growth over the last twenty years. Participation in women's hockey in North America has grown over 900%, from approximately 6,000 in 1990 to 67,230 in 2014 in the USA and from 8,146 in 1990 to 86,612 in 2014 in Canada[30,31]. It has been speculated that while there is no true professional hockey league for females, the number of opportunities are increasing due to increased exposure of international tournaments, most notably the Olympics[32]. On an international scale, the participation of female ice hockey is growing, with 36 countries applied to the IIHF for inclusion into their World Championship program[33]. Women's hockey is represented in every part of the world and there are teams in North America, Europe, Asia, Oceania, Africa and Latin America.

Elite Female Ice Hockey Definition in Literature

There is a lack of consistency in the terminology surrounding the classification of elite female ice hockey athletes. When performing a search for literature on “elite female ice hockey”, the definition of elite is inconsistent and varied. Some authors considered Canadian University players as elite ice hockey players[25,34]. While University hockey is played at a high level, it is not a true representation of elite athletes. Of all the female hockey players selected to represent Canada at the Sochi Winter Olympics, 3 players had competed in the Canadian Interuniversity Sport league[31]. Only two studies used the terminology “elite female ice hockey players” in reference to international-caliber athletes. Ransdell and Murray (2011) published the fitness testing data from the pre-competition period of American female ice hockey players preceding the Vancouver Olympics[4]. Similarly, Ransdell *et al*. (2013) studied the physical fitness characteristics of elite female hockey teams at an international camp. This study analyzed the results by comparing athletes from countries with continued success in female hockey (Canada and United States of America) versus all other countries that are still developing women’s hockey[35].

Physical and Physiological Profile of Elite Female Ice Hockey Player

To date, there are few studies that have investigated the physical and physiological profiles of elite female athletes playing hockey at the international level. A recent study by Ransdell and Murray (2011), examined the profiles of twenty-three female ice hockey players who were invited to compete for a spot to represent the United States of America at the Vancouver Olympics based upon their preseason fitness testing outcomes. From this data, they reported that elite female hockey player’s body composition, lower leg power, and muscular strength were comparable to other previously studied female athletes from multiple sports[4]. Similarly, in another study Ransdell and colleagues (2013) showed that players from countries with the best international records in female ice hockey were in better physical condition and displayed higher levels of upper body strength and lower body power[35].

Rationale and Objective

Canada has been one of the most successful countries in the sport of female ice hockey. It is important to investigate if the physical and physiological fitness tests play a role in athletes being selected to represent Canada on the international ice hockey stage. Furthermore, with the worldwide growth of female hockey, having normative testing data from one of the top countries in the world can help other countries better tailor their fitness testing and team selection as they train and evaluate their female hockey players.

The main objective of this study was to determine which physical and physiological fitness variables are associated with being selected to compete at the highest level of international female ice hockey competition. Within this objective, we will compare the testing results between athletes who were successfully selected to the team compared with athletes who were not selected.

Chapter 2

METHODS

Study Participants

The Hockey Canada Women's National Team physical and physiological fitness testing database was used for analysis. This database consists of historical physical and physiological fitness testing results collected from athletes invited to try-out for the Women's National Hockey team. Between the years 2005 and 2013, 343 female athletes were invited to complete a physical and physiological fitness testing battery as part of a pre-season try-out camp. This camp is typically held in August or September and the outcomes of the testing battery are critical to Hockey Canada's selection of the team who will be competing at the Women's World Championships or Winter Olympic Games for the upcoming year.

This analysis compares athletes who were selected to represent Canada at the World Championship or Olympics between 2006 and 2014 to those athletes who were not selected to the team. The names of the athletes were removed and replaced with an assigned number for identification to ensure confidentiality. The study was reviewed and approved under the research ethics protocols by the Human Participants Review Subcommittee at York University, Toronto, Canada.

Procedure

Physical and physiological fitness testing data collected between the years of 2005 and 2013 were analyzed for this study. To ensure validity of the data, fitness testing was performed by qualified Exercise Physiologists and/or Certified Strength and Conditioning Coaches. This information includes data and testing results such as: age, body mass (kg), height (cm), fat percentage (%), muscle percentage (%), fat mass (kg), muscle mass (kg), fat-to-muscle ratio, estimated VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$), maximal aerobic power workload (W), critical power workload (W), Wingate peak power ($W \cdot kg^{-1}$) and mean power ($W \cdot kg^{-1}$), 4 rep-maximum bench press (lb), maximum fixed bar supinated grip chin-ups (#), standing long jump (cm), squat vertical jump (cm), counter-movement vertical jump (cm), drop jump (cm), and first repeat

(FRT) (sec) and drop-off (DO) (sec) during the 40 meter Repeated High Intensity Endurance Test (RHIET).

Test Protocols

Anthropometric

Anthropometric information was measured and collected according to the protocol outlined by the International Standards for Anthropometric Assessment manual created by the International Society for the Advancement of Kinanthropometry[36]. A full anthropometric profile was recorded for each subject. The full profile consists of 39 measurements divided into 5 broad categories: basic, skinfolds, girths, lengths, and breadths. Using the measurements of the full profile, additional calculations allow for estimates of relative body fat, bone, muscle, and residual masses to measure ratio fat to muscle. All skinfold data was measured using Harpenden skinfold calipers. The 5 categories are outlined below:

Basic: body mass, height, sitting height.

Skinfolds: triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf.

Girths: head, neck, arm, forearm, wrist, chest, waist, gluteal, thigh, calf, ankle.

Lengths: acromiale-radiale, radiale-stylion, midstylion-dactylion, iliospinale height, trochanterion height, trochanterion-tibiale laterale, tibiale laterale height, tibiale laterale sphyrion tibiale.

Breadths: biacromial, biiliocristal, foot length, transverse chest, anterior-posterior chest depth, humerus, femur.

Estimated Maximal Oxygen Consumption (VO_2) Max Test via 20m shuttle run

The Australian Institute of Sport 20 meter shuttle run consists of running back and forth in a gymnasium or running track at a running speed controlled by audio signals. The signals control the running speed, at a rate of 0.5 km/h each minute. At every sound signal, subjects must reach the 20m line, pivot, and get back to the other line by the next audio signal. The test is terminated when a subject fails to reach within 1 meter of the end line two consecutive times. Scores are a product of the level and the number of successful shuttles completed for that level. The estimation of VO_2 max is refined from maximal running speed[37].

Maximal Aerobic Power Workload

The test is performed on an electronically braked cycle ergometer. The subject begins the test at a workload of 55W and 90 rpm. The workload increases 25W every three minutes. Blood lactates are measured using a Lactate Pro analyzer at the end of each workload, up to a blood lactate greater than 6.0mmol. Once 6.0mmol is reached the workload is increased 25W every minute up to maximal effort. Maximal aerobic power workload is considered the last workload the subject completes without a 15rpm drop.

Critical Power 2.5 Workload

This is a maximal constant load test performed on an electronically braked cycle ergometer. The subject pedals between 80-90rpms with a load determined by the slope and intercept of values derived from maximal aerobic power workload, and Wingate power. The subject is instructed to maintain constant revolutions per minute. The test is terminated when a decrease of 15rpms occurs from the maintained pace. Critical power workload is determined by the y-intercept[38].

Wingate Peak Power and Mean Power

The Wingate test is performed on a Monark cycle ergometer with a load of 8.5% body weight. Subjects are instructed to complete a 5-minute warm-up on the cycle ergometer between 60-100rpms. The test requires a 30-second maximum effort bout on the bike. Peak power is determined by the highest mechanical power generated during any 5 second interval of the test. Mean power is the total amount of work performed over the 30 second trial, without normalizing for a full minute.

The equation for Peak Power is[39]: (W) = avg. of highest 5s revs$\cdot$min^{-1}*6 m$\cdot$rev^{-1}*0.1635 W$\cdot$(kgm$\cdot$min^{-1})$^{-1}$

The equation for Mean Power is[39]: (W) = Total work (J) / Time (s) and then represented as a relative mean anaerobic power expressed as W$\cdot$kg^{-1}.

Repeated High Intensity Endurance Test (RHIET)

The test is performed in a gymnasium or track surface long enough to allow for safe acceleration and deceleration zones. A distance of 40m is measured with electronic timing lights placed at 5 meter and 35 meter. The test involved a full 40m sprint followed by a stop, pivot, and sprint return to the starting line. The timing lights record each 30m interval – as the subject crosses the 5m line and the 35m line and then again as the subject returns from the 35m line back to the 5m line. A total of 6 sprints are performed at 30 second intervals, with each interval beginning at time 0, 30 seconds, 60 seconds, 90 seconds, 120 seconds, 150 seconds. Time is recorded 5m to 35m and 35m to 5m. The first sprint time is the sum of the first full down and back sprint time recorded by the electronic timing lights and the drop off is calculated as the sum of the sixth sprint trial subtracted by the sum of the first sprint trial[40].

Upper Body Strength – 4 repetition maximum Bench Press

The subject sets up on a standard bench press with feet flat on ground, and a medium grip on the bar. Keeping their back flat on the bench, the subject moves through a full range of motion from full arm extension, touching the bar to the chest, and back to full extension of the arms. A four repetition maximum weight is recorded and the subject is encouraged to attempt this weight on their fourth set. If completed the weight is increased until a four repetition maximum is reached.

Upper Body Strength – Fixed bar supinated grip chin-ups

The pull-up bar is grasped with hands approximately shoulder-width apart, using a supinated grip. The test begins from a freely hanging position with arms extended. The subject must pull up until the chin is above or level with the pull-up bar without using any hip motion. The arms must return to full extension without hyperextending at the bottom. One pull-up is complete when the subject returns to the start position. Each subject completes as many repetitions as possible.

Squat Vertical Jump

The squat vertical jump is performed by having the subject squat down to 90 degrees hip flexion with their hands on their hips. After a 2 second pause, the subject performs 1 maximal vertical jump with no counter-movement before the jump. This is repeated three times consecutively with a 20 second rest between successive trials. Jump height is recorded for the highest jump using the Opto Jump infrared timing system.

Counter-movement Vertical Jump

The counter-movement vertical jump is performed by having the subject start in a standing position with their hands on their hips. The subject then moves down as fast as possible to 90 degrees hip flexion then maximally jumps. There is no pause at the bottom of the jump. This is repeated three times with a 20 second rest between successive trials. Jump height is recorded for the highest jump using the Opto Jump infrared timing system.

Drop Jump

The drop jump is performed by having the subject stand on a 42cm box. The subject steps off the box, drops to 90 degree hip flexion, and then maximally jumps. This is repeated three times with a 20 second rest between successive trials. Jump height is recorded for the highest jump using the Opto Jump infrared timing system.

Standing Long Jump

The subject stands behind a line marked on the ground with feet slightly apart. A two-foot takeoff and landing is required, with swinging of the arms and bending of the knees and trunk allowed to provide forward drive. The subject jumps out as far as possible, landing on both feet without falling forwards or backwards. This is repeated three times with a brief rest between successive trials. The distance is recorded from the starting line to the back of the heels.

Data Analysis

Data were collected yearly, and the athletes were coded on their success or failure at making the team. Not every test was included in the testing battery each year; therefore the number of entries varies across the database. The variable with the greatest number of study participants is age (n = 343) and the variable with the fewest number of study participants is maximal aerobic power workload (n = 177).

For ease of interpretation of odds ratios (OR) during the logistic regression step, certain results were re-coded by 10 unit groupings. The variables selected for recoding were bench press, standing long jump, squat vertical jump, counter-movement vertical jump, and drop jump. These scores were all divided by a value of 10 to better reflect marked improvement between subjects. For example, if an athlete recorded a squat vertical jump of 37.9cm, her score in the Squat Vertical Jump_10 variable field would be 3.79.

All statistical analyses were conducted using IBM SPSS statistical software version 22. Basic descriptive statistics were calculated for the entire group, the athletes selected to the team, and the athletes that were not selected. Variables shown to be significant were further analyzed on a yearly basis to investigate trends between the two groups.

Descriptive analysis was performed to analyze yearly changes and trends in testing performance. Trend analysis was used to represent any change in the fitness parameters over the time period for athletes selected to the team. To do this, a trend line for each significant fitness variable was generated and the coefficient of determination (R^2) values reported for each trend line, as well as a percentage change was calculated comparing the first year of data to the last year. Note that some of the players were selected to the team for more than 1 year, and are represented in the data set for each year they were selected. A binary logistic regression was run to determine the odds ratio for each variable separately with the dependent variable of being selected compared to those not selected. Finally, various multivariate logistic regression models were conducted to analyze the relationships among the variables to show success of making the team.

Chapter 3

MANUSCRIPT

THE ROLE FITNESS TESTING PLAYS IN TEAM SELECTION OF ELITE FEMALE ICE HOCKEY PLAYERS

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ABSTRACT

The purpose of this study was to determine the role physical and physiological testing plays in team selection of elite female ice hockey athletes. Testing results collected during pre-season for Hockey Canada Women's National Team between the years of 2005-2014 were analyzed and compared between athletes who were selected to the team (N=189) compared to athletes who were not selected (N=154). Basic descriptive statistics were calculated for the entire group and a logistic regression was run to determine the odds ratios for each testing measure. The odds of being selected to the elite team were significantly higher for age (OR = 1.27, 95% CI = 1.19-1.35), height (OR = 1.06, 95% CI = 1.02-1.10), fat percentage (OR = 0.91, 95% CI = 0.86-0.96), fat mass (OR = 0.94, 95% CI = 0.89-1.00), estimated maximum oxygen consumption (VO_2 max) from 20m shuttle run (OR = 1.11, 95% CI = 1.03-1.19), maximal aerobic power workload (OR = 1.01, 95% CI = 1.00-1.00), critical power workload (OR = 1.01, 95% CI = 1.01-1.02), bench press by 10 unit increase (OR = 1.19, 95% CI = 1.06-1.34), maximum fixed bar supinated grip chin-ups (OR = 1.15, 95% CI = 1.08-1.22), squat vertical jump by 10 unit increase (OR = 2.63, 95% CI = 1.61-4.28), countermovement vertical jump by 10 unit increase (OR = 2.33, 95% CI = 1.47-3.70), drop jump by 10 unit increase (OR = 2.47, 95% CI = 1.53-3.97). The results of this analysis suggest that improvements in aerobic fitness, upper body strength, and lower body power will increase a player's odds of being selected for the team. Off-ice training should focus on developing these areas so that female hockey players are placed in the best position for being selected for an elite team.

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BACKGROUND

The sport of ice hockey is characterized by participants repeatedly performing high-intensity, short-duration bursts of maximal power, while also needing to be able to perform at a consistently high level over the course of a 60-minute game[1]. For optimal performance, elite hockey athletes need to have well-rounded physical and physiological capabilities including anaerobic fitness[2], aerobic fitness[3], muscular strength, power, and endurance[4].

From a physiological point of view, ice hockey players are expected to develop a well-rounded fitness profile including the ability to sprint repeatedly, have high level of aerobic fitness, and a high degree of muscle strength, power, and endurance to be able to continually perform at a high level and throughout a season[1,5–7]. Previous research has reported an association between several off-ice performance measures with on-ice performance ranging from playing performance measures as well as on-ice specific tests[8–13].

At the highest level of male hockey, it has been shown that physiological tests are associated with certain indicators of success. Burr *et al.* (2008) showed that percent body fat and performance in the Wingate cycle test for peak power and fatigue index were important physical attributes for draft round selection in the National Hockey League Combine (formerly known as the Entry Draft)[3]. Green and colleagues also found a positive relationship between anaerobic fitness and minutes played, as well as between VO_2 max and scoring chances over the course of a season[14].

To date, there are few studies that have investigated the physical and physiological profiles of elite female athletes playing hockey at the international level. A recent study by Ransdell and Murray (2011) examined the profiles of twenty-three female ice hockey players who were invited to compete for a spot to represent the United States of America (USA) at the Vancouver Olympics based upon their preseason fitness testing outcomes. From this data, they reported that elite female hockey player's body composition, lower leg power, and muscular strength were comparable to other previously studied female athletes from multiple sports[4]. Similarly, in another study Ransdell and colleagues showed that players from countries with the best international records in female ice hockey were in better physical condition and displayed higher levels of upper body strength and lower body power[15].

At the international level, elite female hockey consists of the countries that participate in the International Ice Hockey Federation (IIHF) Women's World Championship tournament or the Winter Olympic Games. The IIHF has hosted 15 championships during non-Olympic years, with Canada winning 10 times[16]. Women's hockey has appeared in the Winter Olympic Games since 1998, 4 out of 5 Winter Olympic gold medals have been won by Canada[17]. The highest level of female hockey within Canada is the National Women's Team, chosen yearly to represent Canada at either the IIHF World Championship or the Olympic Winter Games either annually or quadrennially respectively.

The purpose of this study is to determine which physical and physiological fitness variables are associated with being selected to compete at the highest level of international female ice hockey competition. Within this objective, we will compare the testing results between athletes who were successfully selected to the team compared with athletes who were not selected.

METHODS

Subjects

The Hockey Canada Women's National Team physical and physiological fitness testing database was used for analysis. This database consists of historical physical and physiological fitness testing results collected from athletes invited to try-out for the Women's National Hockey team. Between the years 2005 and 2013, 343 female athletes were invited to complete a physical and physiological fitness testing battery as part of a pre-season try-out camp. This camp is typically held in August or September and the outcomes of the testing battery are critical to Hockey Canada's selection of the team who will be competing at the Women's World Championships or Winter Olympic Games for the upcoming year.

This analysis compares athletes who were selected to represent Canada at the World Championship or Olympics between 2006 and 2014 to those athletes who were not selected to the team. The names of the athletes were removed and replaced with an assigned number for identification to ensure confidentiality. The study was reviewed and approved under the research ethics protocols by the Human Participants Review Subcommittee at York University, Toronto, Canada.

Procedure

Physical and physiological fitness testing data collected between the years of 2005 and 2013 were analyzed for this study. To ensure validity of the data, fitness testing was performed by qualified Exercise Physiologists and/or Certified Strength and Conditioning Coaches. This information includes data and testing results such as: age, body mass (kg), height (cm), fat percentage (%), muscle percentage (%), fat mass (kg), muscle mass (kg), fat-to-muscle ratio, estimated VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$), maximal aerobic power workload (W), critical power workload (W), Wingate peak power ($W \cdot kg^{-1}$) and mean power ($W \cdot kg^{-1}$), 4 rep-maximum bench press (lb), maximum fixed bar supinated grip chin-ups (#), standing long jump (cm), squat vertical jump (cm), counter-movement vertical jump (cm), drop jump (cm), and first repeat (FRT) (sec) and drop-off (DO) (sec) during the 40 meter Repeated High Intensity Endurance Test (RHIET). A brief description of the tests and testing protocols are contained in Table 1.

Data were collected yearly, and the athletes were coded on their success or failure of being selected to the team. Not every test was included in the testing battery each year; therefore the number of entries varies across the database. The variable with the greatest number of study participants is age (n = 343) and the variable with the fewest number of subjects is maximal aerobic power workload (n = 177).

For ease of interpretation of odds ratios (OR) during the logistic regression step, certain results were re-coded by 10 unit groupings. The variables selected for recoding were bench press, standing long jump, squat vertical jump, counter-movement vertical jump, and drop jump. These scores were all divided by a value of 10 to better reflect marked improvement between study participants. For example, if an athlete recorded a squat vertical jump of 37.9cm, her score in the Squat Jump_10 variable field would be 3.79.

Data Analysis

All statistical analyses were conducted using IBM SPSS statistical software version 22. Basic descriptive statistics were calculated for the entire group, the athletes selected to the team, and the athletes that were not selected. A binary logistic regression was run to determine the odds ratio for each variable separately with the dependent variable of being selected compared to those not selected. Finally, various multivariate logistic regression models were conducted to analyze the relationships among the variables to show success of being selected to the team.

RESULTS

Of the 343 elite female ice hockey players invited to participate to compete for a position to represent Canada at either the International Ice Hockey Championships or Olympic Winter Games between 2005-2014, 189 players were successful in being selected to the team. Characteristics of those athletes selected to try-out for the team are represented in Table 2.

The association between physical and physiological fitness test scores and success at being selected for the team are presented in Table 3. The odds of being selected to the team were significantly higher for some variables, including: age (OR = 1.27, 95% CI = 1.19-1.35), height (OR = 1.06, 95% CI = 1.02-1.10), fat percentage (OR = 0.91, 95% CI = 0.86-0.96), fat mass (OR = 0.94, 95% CI = 0.89-1.00), estimated VO_2 Max (OR = 1.11, 95% CI = 1.03-1.19), maximal aerobic power workload (OR = 1.01, 95% CI = 1.00-1.00), critical power workload (OR = 1.01, 95% CI = 1.01-1.02), bench press by 10 unit increase (OR = 1.19, 95% CI = 1.06-1.34), maximum fixed bar supinated grip chin-ups (OR = 1.15, 95% CI = 1.08-1.22), squat vertical jump by 10 unit increase (OR = 2.63, 95% CI = 1.61-4.28), countermovement vertical jump by 10 unit increase (OR = 2.33, 95% CI = 1.47-3.70), and drop jump by 10 unit increase (OR = 2.47, 95% CI = 1.53-3.97).

The results of the multivariate logistic regressions were inconclusive. No multivariate model fit the data. It is suspected that this is due to the high multicollinearity within the data set.

DISCUSSION

The findings of this investigation provide a unique examination of the role that information related to physical and physiological fitness testing can play in the selection of a National team. To the best of our knowledge, this is the first study to describe anthropometric and physiological performance characteristics in the context of an athlete's odds of being selected to a team.

From a descriptive perspective, athletes that made the team were older and taller than athletes who did not make the team. For every year increase in age, athletes had a 27% greater chance of being selected to the team (OR = 1.27, 95% CI = 1.19-1.35). Similarly, for every centimeter increase in height, athletes had a 6% greater chance at being selected (OR 1.06 = 1.02-1.10). When comparing age and height means of the groups selected and not selected, athletes selected to the team were older (25.79 ± 4.39) and taller (171.01cm ± 5.53) than those not selected (21.90 ± 3.84 and 169.11 ± 5.71 respectively). These results are similar to results published by Ransdell and Murray (2011). They found that athletes from the United States Women's Ice Hockey team who were invited to try out of the team that would compete in the 2010 Winter Olympics had a mean age of 24.7 ± 3.1 years and height of 169.7cm ± 6.9[4].

Similar comparisons can be made in upper body strength and leg power between those athletes that have historically competed for Canada versus the athletes from the USA who attended the try-out camp in 2009[4]. When comparing upper body strength, athletes from the USA had a one-repetition maximum of 65.3kg ± 12.2. Our results are displayed as a 4 repetition maximum, but when converted using a one repetition maximum conversion equation[18], would give a one repetition maximum of 66.9kg ± 8.65. For leg power, Team Canada athletes had a similar standing long jump 220.21cm ± 15.96 compared to the USA hockey group at 214.8cm ± 10.9[4].

Athletes with a higher aerobic fitness had increased odds of being selected. For every unit increase in estimated VO_2 max athletes had an 11% increased chance of being selected (OR 1.11, 95% CI = 1.03-1.19). Significance was also shown with maximal aerobic power workload

(OR 1.01, 95% CI = 1.00-1.00) and critical power workload (OR 1.01, 95% CI = 1.01-1.02) between the two groups. This is consistent with research by Green who showed that athletes with a higher VO_2 max were more successful at producing positive scoring chances during the course of a season [14]. More recently, it has been shown that aerobic capacity for elite hockey players is important due to the repeated sprint demands placed on them during the course of a game[19]. Players with higher aerobic fitness levels are able to delay the onset of fatigue and recover more quickly between shifts than players with lower levels[20]. It is important to note that no significant association was found between Wingate peak power or mean power and an athlete's success at being selected to the team. This is in contrast to research by Burr *et al.* (2008) who showed that performance in select Wingate test variables were important physical attributes for draft round selection in elite male hockey players[3]. This variance could be attributed to the differences in game play of male and female ice hockey.

In comparison to the men's hockey game, the female game is non-contact wherein body checking is not allowed. However, the game is very physical and body contact is allowed during play. As such, upper body strength is important. For every 10 lb increase in bench press performance, athletes from this study had a 19% increased chance of being selected to the team (OR = 1.19, 95% CI = 1.06-1.34). Supinated grip chin-ups are reflective of upper body strength and muscular endurance and showed significance in team selection (OR = 1.15, 95% CI 1.08-1.22). Upper body strength plays a dual role, both in on-ice performance but also in injury prevention; muscular strength training has been shown to reduce sport injuries by 31.5%[21].

Lower body power assessment has been shown to have a significant association with being selected to the team. All three of the vertical jumping protocols performed were associated with increased odds of selection to the team, whereas there was no significance for standing long jump or sprinting speed. Vertical jump testing results are predictive of peak power, which has a strong correlation to skating speed[22,23]. When evaluating hockey potential based on off-ice fitness tests, the squat vertical jump has been shown to correlate higher with selection order in the NHL Combine[24]. However, research by Farlinger *et al.* (2007) showed that horizontal power, evidenced through sprinting and horizontal hopping test, are highly correlated to skating performance[10].

The purposes of this investigation are to present up-to-date physical and physiological fitness testing data on elite female ice hockey players and to explore the association between fitness testing scores and team selection. Hockey Canada has demonstrated success in the female hockey game, therefore this study might help other countries select and tailor their training and testing as it relates to on-ice success. This is the first article to have access to the fitness testing data. The primary limitation is that team selection is multi-factorial, and is heavily weighted on on-ice performance. At the elite level, skill plays a large role in team selection as the fittest athletes are not always selected to the team. Further limitations of this study include that there was no consideration of improvements within each yearly cohort. As athletes increase in training age, so too should the improvement in fitness test outcomes. The female hockey game has increased in popularity over the last ten years, with increased enrollment and improvements in athlete training methods[25], which could skew the collective means when viewed across all ten years. Due to the multicollinearity of the testing variables, this study was unable to show a true multivariate model. Future research could work to eliminate this with further statistical analysis and perhaps create a predictive model on probability of being selected to the team based on certain fitness testing scores.

CONCLUSION

This study presents a physical and physiological profile of elite female hockey players that has not been previously reported. The physical and physiological fitness testing results of female ice hockey players from one of the most successful countries can be used as a reference to Strength and Conditioning coaches as they prepare other female hockey players for national or international competition. This study can provide guidance and targets for other countries as they train and evaluate their athletes. The results of this analysis suggest that improvements in aerobic fitness, upper body strength, and lower body power, elite female ice hockey athletes will increase a player's odds of being selected for the team. Off-ice training should focus on developing these areas so that female hockey players are placed in the best position for being selected for an elite team.

Table 1. Descriptions of Hockey Canada National Women's Team physical and physiological fitness testing battery.

Test	Description
Anthropometric	
Body Mass Height, Body Fat Percentage, Muscle Percentage, Fat Mass, Muscle Mass, Ratio Fat:Muscle	Methodology outlined by the International Society for the Advancement of Kinanthropometry (ISAK)[26].
Energy Systems Tests	
Estimated VO_2 Max ($ml \cdot kg^{-1} \cdot min^{-1}$)	20m Shuttle Run as outlined by Australian Sports Commision[27].
Maximal Aerobic Power Workload (W)	Cycle ergometer graded exercise test using incremental loading (Starts at 55W with 90 rpm, then increase 25W every 3 minutes until 6.0mmol, then 25W each minute to maximal effort). Maximal aerobic power workload is considered the last workload the subject completes without a 15rpm drop.
Critical Power Workload (W)	3 minute all-out cycling test[28]. Relationship between power and inverse of time, where critical power is equivalent to y-intercept. Resistance is determined by slope and intercept of values derived from 30-second Wingate and Maximal Aerobic Power Workload.
Wingate Peak Power ($W \cdot kg^{-1}$) and Mean Power ($W \cdot kg^{-1}$)	Standard 30-s Wingate Test on cycle ergometer with a resistance set at 0.085 x body mass (kg). Peak Power is the highest mechanical power generated during any 5 second interval. Mean Power is the total amount of work performed over the 30 second trial, without normalizing for a full minute; converted to watts (1W = 1 J/s).
Repeated High Intensity Endurance Test	40m shuttle repeat sprint test[29].
Strength Tests	
Bench Press (lb)	Submaximal strength testing, tested at 4 repetition maximum.
Fixed bar supinated grip chin-ups	Maximum consecutive repetitions from full extension of arms to full flexion of arms.
Jump Testing for Power	
Squat Vertical Jump (cm)	No counter movement allowed, squat depth to 90 degree knee flexion. Jump height recorded from Opto Jump infrared timing system. Highest jump of three trials.
Counter-movement Vertical Jump (cm)	Jump height recorded from Opto Jump infrared timing system. Highest jump of three trials.
Drop Jump (cm)	Drop from 42cm box. Jump height recorded from Opto Jump infrared timing system. Highest jump of three trials.
Standing Long Jump (cm)	Counter-movement allowed. Athlete must land under control without falling forward. Longest jump of three trials.

Table 2. Characteristics of Elite Female Ice Hockey Players selected by Hockey Canada from 2005-2013.

VARIABLE	Selected to team			Not selected to team			Total		
	N	MEAN	SD	N	MEAN	SD	N	MEAN	SD
Age	189	25.78	4.39	154	21.90	3.84	343	24.04	4.58
Body Mass (kg)	189	70.35	6.90	153	69.14	7.40	342	69.81	7.15
Height (cm)	189	171.01	5.53	153	169.11	5.71	342	170.16	5.68
Body Fat Percentage (%)	185	18.33	4.07	148	19.87	3.86	333	19.01	4.04
Muscle Percentage (%)	180	42.65	2.50	120	42.19	2.88	300	42.47	2.66
Fat Mass (kg)	185	13.06	3.75	148	13.90	3.82	333	13.43	3.80
Muscle Mass (kg)	180	29.94	2.96	120	29.34	3.45	300	29.70	3.18
Ratio Fat:Muscle	180	434.21	116.75	120	480.29	119.83	300	452.64	119.94
Estimated VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$)	177	51.33	3.14	143	50.29	3.29	320	50.87	3.24
Maximal Aerobic Power workload (W)	119	301.29	34.53	58	286.98	36.80	177	296.60	35.82
Critical Power workload (W)	147	338.47	38.76	92	320.60	35.81	239	331.59	38.57
Wingate Peak Power ($W \cdot kg^{-1}$)	126	11.81	0.99	67	11.63	1.02	193	11.75	1.00
Wingate Mean Power ($W \cdot kg^{-1}$)	126	56.61	4.18	67	55.92	4.99	193	56.37	4.47
Bench Press 4 rep max (lb)	173	130.08	19.04	146	122.48	18.74	319	126.60	19.25
Fixed bar supinated grip Chin-ups	173	8.39	3.58	146	6.51	3.84	319	7.53	3.81
Standing Long Jump (cm)	111	220.21	15.96	93	215.77	17.97	204	218.19	17.01
Squat Vertical Jump (cm)	175	35.48	4.63	144	33.30	4.90	319	34.50	4.87
Counter-movement Vertical Jump (cm)	175	36.91	4.69	143	34.91	5.14	318	36.01	4.99
Drop Jump (cm)	173	37.24	4.55	143	35.13	5.19	316	36.29	4.96
Repeated High Intensity Endurance Test First Repeat (sec)	147	8.98	0.39	109	9.06	0.48	256	9.01	0.44
Repeated High Intensity Endurance Test Drop Off (sec)	115	2.48	0.83	85	2.64	1.21	200	2.55	1.01

Table 3. Association between physical and physiological fitness test scores and success at being selected for the team.

VARIABLE	Odds Ratio (95% CI)
Age	1.27 (1.19-1.35)
Body Mass	1.02 (0.99-1.06)
Height	1.06 (1.02-1.10)
Body Fat Percentage	0.91 (0.86-0.96)
Muscle Percentage	1.07 (0.98-1.17)
Fat Mass	0.94 (0.89-1.00)
Muscle Mass	1.06 (0.99-1.14)
Ratio Fat:Muscle	1.00 (1.00-1.00)
Estimated VO_2 max	1.11 (1.03-1.19)
Maximal Aerobic Power workload	1.01 (1.00-1.00)
Critical Power workload	1.01 (1.01-1.02)
Wingate Peak Power	1.21 (0.90-1.63)
Wingate Mean Power	1.04 (0.97-1.11)
Bench Press_10	1.19 (1.06-1.34)
Fixed bar supinated grip chin up	1.15 (1.08-1.22)
Standing Long Jump_10	1.01 (0.91-1.11)
Squat Vertical Jump_10	2.63 (1.61-4.28)
Counter-movement Vertical Jump_10	2.33 (1.47-3.70)
Drop Jump_10	2.47 (1.53-3.97)
Repeated High Intensity Endurance Test First Repeat	0.65 (0.36-1.15)
Repeated High Intensity Endurance Test Drop Off	0.86 (0.65-1.14)

REFERENCES

1. Cox MH, Miles DS, Verde TJ, Rhodes EC. Applied physiology of ice hockey. *Sports Med*. 1995;19(3):184-201.

2. Wilson K, Snydmiller G, Game A, Quinney A, Bell G. The development and reliability of a repeated anaerobic cycling test in female ice hockey players. *J Strength Cond Res*. 2010;24(2):580-584.

3. Burr JF, Jamnik RK, Baker J, Macpherson A, Gledhill N, McGuire EJ. Relationship of physical fitness test results and hockey playing potential in elite-level ice hockey players. *J Strength Cond Res*. 2008;22(5):1535-1543.

4. Ransdell LB, Murray T. A physical profile of elite female ice hockey players from the USA. *J Strength Cond Res*. 2011;25(9):2358-2363.

5. Glaister M. Multiple sprint work : physiological responses, mechanisms of fatigue and the influence of aerobic fitness. *Sports Med*. 2005;35(9):757-777.

6. Lau S, Berg K, Latin RW, Noble J. Comparison of active and passive recovery of blood lactate and subsequent performance of repeated work bouts in ice hockey players. *J Strength Cond Res*. 2001;15(3):367-371.

7. Seliger V, Kostka V, Grusová D, Kovac, J, Machovcova J, Pauer M, Pribylova A., Urbankova R. Energy expenditure and physical fitness of ice-hockey players. *Int Z Angew Physiol*. 1972;30(4):283-291.

8. Behm DG, Wahl MJ, Button DC, Power KE, Anderson KG. Relationship between hockey skating speed and selected performance measures. *J Strength Cond Res*. 2005;19(2):326-331.

9. Bracko MR, George JD. Prediction of ice skating performance with off-ice testing in women's ice hockey players. *J Strength Cond Res*. 2001;15(1):116-122.

10. Farlinger CM, Kruisselbrink LD, Fowles JR. Relationships to skating performance in competitive hockey players. *J Strength Cond Res*. 2007;21(3):915-922.

11. Peyer KL, Pivarnik JM, Eisenmann JC, Vorkapich M. Physiological characteristics of National Collegiate Athletic Association Division I ice hockey players and their relation to game performance. *J Strength Cond Res*. 2011;25(5):1183-1192.

12. Krause DA, Smith AM, Holmes LC, Klebe CR, Lee JB, Lundquist KM, Eischen JJ, Hollman H. Relationship of off-ice and on-ice performance measures in high school male hockey players. *J Strength Cond Res*. 2012;26(5):1423-1430.

13. Gilenstama KM, Thorsena K, Henriksson-larséna KB. Physiological correlates of skating performance in women ' s and men ' s ice hockey. *J Strength Cond Res*. 2011;25:2133-2142.

14. Green MR, Pivarnik JM, Carrier DP, Womack CJ. Relationship between physiological profiles and on-ice performance of a National Collegiate Athletic Association Division I hockey team. *J Strength Cond Res*. 2006;20(1):43-46.

15. Lynda B. Ransdell, Teena M. Murray and YG. Off-Ice Fitness of Elite Female Ice Hockey Players by Team Success, Age, and Player Position. 2013;27(4).

16. IIHF. Women's World Championship Gold Medal. :- http://www.iihf.com/iihf-home/history/all-medall.

17. IIHF. Women's Hockey Gold Medalist Winter Olympic Games. http://www.iihf.com/de/iihf-home/history/all-medallists/olympics/women.

18. Baechle T, Earle R. *Essentials of Strength Training and Conditioning*. NSCA-National Strength and Conditioning Association; 2008:656.

19. Peterson BJ, Fitzgerald JS, Dietz CC, Ziegler, KS, Ingraham, SJ, Baker, SE, Snyder, EM. Aerobic Capacity is Associated with Improved Repeated Shift Performance in Hockey. *J Strength Cond Res*. 2015.

20. Arnett M. Effects of Specificity of Training on the Recovery Process during Intermittent Activity in Ice Hockey. *J Strength Cond Res*. 1996;10(2):124-126.

21. Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries : a systematic review and meta-analysis of randomised controlled trials. 2013:1-8.

22. Bracko MR, Fellingham GW. Prediction of ice skating performance with off-ice testing in youth hockey players. *Med Sci Sports Exerc*. 1997;29:S172.

23. Mascaro T, Seaver BL, Swanson L. Prediction of Skating Speed with Off-Ice Testing in Professional Hockey Players. *J Orthop Sport Phys Ther*. 1992;15(2).

24. Burr JF, Jamnik RK, Dogra S, Gledhill N. Evaluation of jump protocols to assess leg power and predict hockey playing potential. *J Strength Cond Res*. 2007;21(4):1139-1145.

25. Hockey Canada. Annual Report 2014. 2014.

26. International Society for the Advancement of Kinanthropometry. *International Standards for Anthropometric Assessment*. The International Society for the Advancement of Kinanthropometry; 2001:139.

27. Australian Sports Commision. *20m Shuttle Run Test: A Progressive Shuttle Run Test for Measuring Aerobic Fitness*.; 1999.

28. Vanhatalo, A, Doust, J., and Mark Burnley. "Determination of critical power using a 3-min all-out cycling test." *Medicine and science in sports and exercise* 39.3 (2007): 548-555.

29. Spencer M, Fitzsimons M, Dawson B, Bishop D, Goodman C. Reliability of a repeated sprint test for field hockey. *J Sci Med Sport.* 2006:5-8.

Chapter 4

RESULTS

Descriptive Results

Of the 343 elite female ice hockey players invited to participate to compete for a position to represent Canada at either the International Ice Hockey Championships or Olympic Winter Games between 2005-2014, 189 players were successful in being selected to the team. Characteristics of those athletes selected to try-out for the team are represented in Table 2.

Figures 1 through 9 show the changes across both groups within selected variables over time. These variables were selected based off the significance shows in the logistic regression analysis. It is interesting to note that there is a general trend of improvement over time; however there is less than 5% change between athletes selected in 2005 and those selected in 2014 in most of the variables. The variables with the largest percent change are squat vertical jump (15% change from 2005-2014), countermovement vertical jump (9% change from 2005-2014), and fixed bar supinated grip chin ups (9% change from 2005-2014). The only variable with a performance decrease was drop jump with a -7% change between athletes selected to the team in 2005 to those athletes selected in 2014. Based off the trend line analysis, the greatest improvement over time was evident in height (R^2 = 0.96) and VO_2 max (R^2 = 0.80). Upper body strength, both bench press strength or maximum fixed bar supinated grip chin-ups, and body fat percentage remained relatively unchanged over the 10 year period (R^2 = 0.00 and R^2=0.03 respectively).

Logistic Regression

The association between physical and physiological fitness test scores and success at being selected for the team are presented in Table 3. The odds of being selected to the team were significantly higher for some variables, including: age (OR = 1.27, 95% CI = 1.19-1.35), height (OR = 1.06, 95% CI = 1.02-1.10), fat percentage (OR = 0.91, 95% CI = 0.86-0.96), fat mass (OR = 0.94, 95% CI = 0.89-1.00), estimated VO_2 Max (OR = 1.11, 95% CI = 1.03-1.19), maximal aerobic power workload (OR = 1.01, 95% CI = 1.00-1.00), critical power workload (OR = 1.01, 95% CI = 1.01-1.02), bench press by 10 unit increase (OR = 1.19, 95% CI = 1.06-1.34), maximum fixed bar supinated grip chin-ups (OR = 1.15, 95% CI = 1.08-1.22), squat vertical jump by 10 unit increase (OR = 2.63, 95% CI = 1.61-4.28), counter-movement vertical jump by 10 unit increase (OR = 2.33, 95% CI = 1.47-3.70), and drop jump by 10 unit increase (OR = 2.47, 95% CI = 1.53-3.97).

The results of the multivariate logistic regressions were inconclusive. No multivariate model fit the data. It is suspected that this is due to the high multicollinearity within the data set.

Chapter 5

DISCUSSION

The findings of this investigation provide a unique examination of the role that information related to physical and physiological fitness testing can play in the selection of an elite team. To the best of our knowledge, this is the first study to describe anthropometric and physiological performance characteristics in the context of an athlete’s odds of being selected to a team.

Generalizability of Results

Athletes who were selected to the team had higher physical and physiological testing scores in the pre-season than their counterparts who were not selected to the team. This is evident in the yearly comparisons of testing means. A noticeable trend is that it appears the athletes' ramp up their training during an Olympic year, which is followed by a plateau or slight drop in testing performance for the following year. This could be due to two factors: Hockey Canada centralizes their athletes in one location for the year leading up to the Olympic Games in an attempt to create the best training environment possible. After such a year, it is not uncommon for athletes to take a step back to avoid possible burn out and to take some time away from the game due to the overloaded schedule of the previous year. This is clearly noticed when comparing the testing results in 2009-2010 (preceding the Vancouver Olympic Games) and 2010-2011, the year following the games. Selected athletes had a body fat percentage higher than athletes not selected. Also in the year 2010-2011, selected athletes scored a slightly lower estimated VO_2 max than non-selected athletes. This is the only year of where the non-selected athletes had favourable scores over the athletes selected. This could also be a factor in the difference between the percentage change from 2005 to 2014 and the overall trend line of the time period. The fluctuation of years following the Olympics could account for the lower coefficient of determination for bench press, fixed bar supinated grip chin ups, and body fat percentage.

The fitness testing variable with the greatest improvement when strictly comparing the athletes tested in 2005 to the athletes tested in 2013 was evidenced in measures of lower body power. In the comparison of selected athletes tested in 2005 and 2014, they improved their squat vertical jump by 15% and their counter-movement vertical jump by 9%. This could be due to a change in training methodologies, as research has shown the importance of lower body power for hockey players, Strength and Conditioning coaches modified their training methods to reflect these changes. It should be noted that there was a 7% decrease in performance in the drop jump variable over time. One possibility is that as training methods for hockey became more aligned with research, training methodologies shifted from focusing less on the stretch-shortening response and more on the actual force-production impulse. In a study by Green (2000), he showed that skating is a skill that emphasizes impulse during the push-off phase[41]. Therefore the shift in training focus from drop jump, which relies on the stretch-shortening cycle, to the squat vertical jump and counter-movement vertical jump, is more suited to hockey players[23].

From a descriptive perspective, athletes selected to the team were older and taller than athletes not selected to the team. For every year increase in age, athletes had a 27% greater chance of being selected to the team (OR = 1.27, 95% CI = 1.19-1.35). Similarly, for every centimeter increase in height, athletes had a 6% greater chance at being selected (OR 1.06 = 1.02-1.10). When comparing age and height means of the groups selected and not selected, athletes selected to the team were older (25.79 ± 4.39) and taller (171.01cm ± 5.53) than those not selected (21.90 ± 3.84 and 169.11 ± 5.71 respectively). These results are similar to results published by Ransdell and Murray (2011). They found that athletes from the United States Women's Ice Hockey team who were invited to try out of the team that would compete in the 2010 Winter Olympics had a mean age of 24.7 ± 3.1 years and height of 169.7cm ± 6.9[4].

It has been shown that there are differences in the physical and physiological characteristics between forwards, defense, and goalies in both the male and female ice hockey game. In male hockey, when comparing forwards to defense players, forwards tend to be smaller in stature[6,42], have less body mass[43], lower levels of absolute strength[16], but show higher aerobic and anaerobic power[5]. When compared to forwards and defensemen, goalies tend to be shorter, have an increased body fat percentage, and lower VO2 max[44]. While this current study did not differentiate players by position, it has been shown that similar positional differences exist in the female ice hockey game. Geithner *et al.* (2006) found that forwards tended to have the lowest body composition amongst the three positions and goalies had the highest. Forwards were faster in the 40 yard off-ice sprint test and showed higher aerobic fitness as predicted by the 20 meter shuttle run when compared to defense and goalies[34].

Historical Trends in Physical Fitness

The concept of training age is important when studying the physical and physiological fitness of athletes over time. Training age refers to the number of years an athlete has been following a formalized strength and conditioning program[45]. When comparing rosters of the athletes that represented Canada at the Winter Olympics in 2006 and 2010, 14 athletes played in both tournaments. Of those 14 athletes, 6 of them represented Canada at the Sochi Winter Olympics in 2014. Twelve athletes played for Team Canada in both the 2010 Winter Olympics and the 2014 Winter Olympics. Each of these athletes would be considered at an advanced training age due to their longevity and exposure to advanced training methods[45].

In a four year study of elite rugby players, Baker and Newton (2006) found that athletes were able to make significant improvements in upper body strength. However, when compared to subelite athletes following a similar training program, the improvements for elite athletes was not at the same rate as the subelite group. This shows evidence that athletes with a higher training age can still make improvements with training, but not at the same rate of progress as developing athletes[46]. In a similar study, it was shown that elite rugby players experienced rapid strength gains in the first four years of training and then experienced small gains in strength and power in the remaining six years when tracked over a ten year period[47]. This is similar to the results found within the current study. There is very little fluctuation in the means of the fitness test results over time, indicating that athletes with a higher training age do not have the same rate of progress as athletes with younger training ages.

Montgomery (2006) compared physical and physiological fitness testing results collected from a professional male ice hockey team. Over a 22 year period, the largest changes in results is evidenced in height and body mass of the players. Upper body strength, as evidenced by a bench press test also improved[48]. These changes could be due to the improved knowledge of Strength and Conditioning professionals as well as a great awareness of physical preparation over the last ten years within the sport of hockey. The author noted a sharp increase in strength originating around the time that the team hired a full-time strength and fitness coach that prepared strength and conditioning programs for the athletes. In a similar study by Quinney *et al.* (2008), fitness testing results tracked over a 26 year period for a professional hockey team showed similar profile changes. The most significant trends were increases in body mass, height, body mass index, absolute VO2 peak, and grip strength[44]. Athletes from this current study showed a 5% and 9% improvement in bench press and fixed grip supinated grip chin-ups respectively. These strength improvements could be related to the increased focus on upper body strength for hockey players over the ten year period.

Comparison of Testing Variables to Performance

Similar comparisons can be made in upper body strength and leg power between those athletes that have historically competed for Canada versus the female ice hockey athletes from the USA who attended a try-out camp in 2009. When comparing upper body strength, athletes from the USA had a one-repetition maximum of 65.3kg ± 12.2[4]. Our results are displayed as a 4 repetition maximum, but when converted using a one repetition maximum conversion equation[49], would give a one repetition maximum of 66.9kg ± 8.65. For leg power Team Canada athletes had a similar standing long jump 220.21cm ± 15.96 compared to the USA hockey group at 214.8cm ± 10.9[4].

Athletes with a higher aerobic fitness had increased odds of being selected. For every unit increase in estimated VO_2 max, athletes had an 11% increased chance of being selected (OR 1.11, 95% CI = 1.03-1.19). Significance was also shown with maximal aerobic power workload (OR 1.01, 95% CI = 1.00-1.00) and critical power workload (OR 1.01, 95% CI = 1.01-1.02) between the two groups. This is consistent with research by Green who showed that athletes with a higher VO_2 max were more successful at producing positive scoring chances during the course of a season [10]. More recently, it has been shown that aerobic capacity for elite hockey players is important due to the repeated sprint demands placed on them during the course of a game[50]. Players with higher aerobic fitness levels are able to delay the onset of fatigue and recover more quickly between shifts than players with lower levels[51]. It is important to note that no significant association was found between Wingate peak power or mean power and an athlete's success at making the team. This is in contrast to research by Burr *et al.* (2008), who showed that performance in select Wingate test variables were important physical attributes for draft round selection in elite male hockey players[3]. This variance could be attributed to the differences in game play between male and female ice hockey.

In comparison to the men's hockey game, the female game is non-contact wherein body checking is not allowed. However, the game is very physical and body contact is allowed during play. As such, upper body strength is important. For every 10 lb increase in bench press performance, athletes from this study had a 19% increased chance of being selected to the team (OR = 1.19, 95% CI = 1.06-1.34). Supinated grip chin-ups are reflective of upper body strength and muscular endurance and showed significance in team selection (OR = 1.15, 95% CI 1.08-1.22). Upper body strength plays a dual role, both in on-ice performance but also in injury prevention; muscular strength training has been shown to reduce sport injuries by 31.5%[52].

Lower body power assessment has been shown to have a significant association with being selected to the team. All three of the vertical jumping protocols performed were associated with increased odds of team selection, whereas there was no significance for standing long jump or sprinting speed. Vertical jump testing results are predictive of peak power, which has a strong correlation to skating speed[13,43]. When evaluating hockey potential based on off-ice fitness tests, the squat vertical jump has been shown to correlate higher with selection order in the NHL Combine[15]. However, research by Farlinger *et al.* (2007) showed that horizontal power, evidenced through sprinting and horizontal hopping test, are highly correlated to skating performance[14].

Limitations

The purposes of this investigation are to present up-to-date physical and physiological fitness testing data on elite female ice hockey players and to explore the association between fitness testing scores and team selection. Hockey Canada has demonstrated success in the female hockey game, therefore this study might help other countries select and tailor their training and testing as it relates to on-ice success. This is the first article to have access to the fitness testing data. The primary limitation is that team selection is multi-factorial, and is heavily weighted on on-ice performance. At the elite level, skill plays a large role in team selection as the fittest athletes are not always selected to the team. Further limitations of this study include that there was no consideration of improvements within each yearly cohort. As mentioned previously, there is little turnover in athletes throughout the year. This homogeneity of the data pool could skew the data as athletes might have hit a ceiling within their physical and physiological development. The athlete pool was studied at a whole, with no consideration for playing position. Future research with this dataset could focus on positional differences and the characteristics of elite female ice hockey players by position. The female hockey game has increased in popularity over the last ten years, with increased enrollment and improvements in athlete training methods[31], which could skew the collective means when viewed across all ten years.

Due to the multicollinearity of the testing variables, this study was unable to show a true multivariate model. Future research could work to eliminate this with further statistical analysis and perhaps create a predictive model on probability of being selected to the team based on certain fitness testing scores.

Summary and Conclusion

Our results show that certain physical and physiological fitness testing variables play a role in team selection. Elite female athletes who are older, taller, leaner, with better aerobic fitness, greater upper body strength, and greater lower body power have an increased odds of being selected compared to their counterparts. While there is little comparative data to other published research on female ice hockey athletes, our results are similar to data on elite male hockey players.

This study presents a physical and physiological profile of elite female hockey players that has not been previously reported. The physical and physiological fitness testing results of female ice hockey players from one of the most successful countries can be used as a reference to Strength and Conditioning coaches as they prepare other female hockey players for national or international competition. This study can provide guidance and targets for other countries as they train and evaluate their athletes.

The results of this analysis suggest that improvements in aerobic fitness, upper body strength, and lower body power, elite female ice hockey athletes will increase a player's odds of being selected for the team. Off-ice training should focus on developing these areas so that female hockey players are placed in the best position for being selected for an elite team.

BIBLIOGRAPHY

1. Cox MH, Miles DS, Verde TJ, Rhodes EC. Applied physiology of ice hockey. *Sports Med*. 1995;19(3):184-201.

2. Wilson K, Snydmiller G, Game A, Quinney A, Bell G. The development and reliability of a repeated anaerobic cycling test in female ice hockey players. *J Strength Cond Res*. 2010;24(2):580-584.

3. Burr JF, Jamnik RK, Baker J, Macpherson A, Gledhill N, McGuire EJ. Relationship of physical fitness test results and hockey playing potential in elite-level ice hockey players. *J Strength Cond Res*. 2008;22(5):1535-1543.

4. Ransdell LB, Murray T. A physical profile of elite female ice hockey players from the USA. *J Strength Cond Res*. 2011;25(9):2358-2363.

5. Twist, Peter, Rhodes T. A physiological analysis of Ice Hockey positions. *Natl Strength Cond J*. 1993;15:44-46.

6. Green, H., Bishop, P., Houston, M., McKillop, R., Norman, R., Stothart P. Time Motion and physiological assessments of ice hockey performance. *J Appl Physiol*. 1976;40(2):159-163.

7. Montgomery D. Physiology of Ice Hockey. *Sport Med*. 1988;5(2):99-126.

8. Seliger V, Kostka V, Grusová D, Kovac J, Machovcova J, Pauer M, Pribylova A, Urbankova R. Energy expenditure and physical fitness of ice-hockey players. *Int Z Angew Physiol*. 1972;30(4):283-291.

9. Lau S, Berg K, Latin RW, Noble J. Comparison of active and passive recovery of blood lactate and subsequent performance of repeated work bouts in ice hockey players. *J Strength Cond Res*. 2001;15(3):367-371.

10. Green MR, Pivarnik JM, Carrier DP, Womack CJ. Relationship between physiological profiles and on-ice performance of a National Collegiate Athletic Association Division I hockey team. *J Strength Cond Res*. 2006;20(1):43-46.

11. Twist, Peter, Rhodes T. The bioenergetics and physiological demands of ice hockey. *Natl Strength Cond J*. 1993;15(5):68-70.

12. Hoff, J., Kemi, O.J., Helgerud J. Strength and endurance differences between elite and junior elite ice hockey players. The importance of allometric scaling. *Int J Sports Med*. 2005;26(7):537-541.

13. Mascaro T, Seaver BL, Swanson L. Prediction of Skating Speed with Off-Ice Testing in Professional Hockey Players. *J Orthop Sport Phys Ther*. 1992;15(2).

14. Farlinger CM, Kruisselbrink LD, Fowles JR. Relationships to skating performance in competitive hockey players. *J Strength Cond Res*. 2007;21(3):915-922.

15. Burr JF, Jamnik RK, Dogra S, Gledhill N. Evaluation of jump protocols to assess leg power and predict hockey playing potential. *J Strength Cond Res*. 2007;21(4):1139-1145.

16. Peyer KL, Pivarnik JM, Eisenmann JC, Vorkapich M. Physiological characteristics of National Collegiate Athletic Association Division I ice hockey players and their relation to game performance. *J Strength Cond Res*. 2011;25(5):1183-1192.

17. Buchheit, M., Lefebvre, B., Laursen, P.B., Ahmaidi S. Reliability, usefulness, and validity of the 30-15 Intermittent Ice Test in elite young ice hockey players. *J Strength Cond Res*. 2011;25(5):1457-1464.

18. Bracko MR, George JD. Prediction of ice skating performance with off-ice testing in women's ice hockey players. *J Strength Cond Res*. 2001;15(1):116-122.

19. Krause DA, Smith AM, Holmes LC, Klebe CR, Lee JB, Lundquist KM, Eischen JJ, Hollman JH. Relationship of off-ice and on-ice performance measures in high school male hockey players. *J Strength Cond Res*. 2012;26(5):1423-1430.

20. JeffreyPotteiger, Dean L. Smith, Mark L. Maier and TSF. Relationship between body composition, leg strength, anaerobic power, and on-ice skating performance in Division 1 Men's Hockey Athletes. *J Strength Cond Res*. 2010.

21. Durocher JJ, Guisfredi AJ, Leetun DT, Carter JR. Comparison of on-ice and off-ice graded exercise testing in collegiate hockey players. *Appl Physiol Nutr Metab*. 2010;35(1):35-39.

22. Matthews, Martyn, Comfort, Paul, Crebin R. Complex training in ice hockey: the effects of a heavy resisted sprint on subsequent ice-hockey sprint performance. *J Strength Cond Res*. 2010;24(11):2883-2887.

23. Behm DG, Wahl MJ, Button DC, Power KE, Anderson KG. Relationship between hockey skating speed and selected performance measures. *J Strength Cond Res*. 2005;19(2):326-331.

24. Nightingale, Steven, Miller, Stuart, Turner A. The usefullness and reliability of fitness testing protocols for Ice Hockey players: A Literature review. *J Strength Cond Res*. 2013;27(6):1742-1748.

25. Bracko, Michaerl R. On-ice performance characteristics of elite and non-elite Women's ice hockey players. *J Strength Cond Res*. 2001;15(1):42-47.

26. Gabbett TJ. Influence of physiological characteristics on selection in a semi-professional first grade rugby league team: a case study. *J Sports Sci*. 2002;20(5):399-405.

27. Keogh J. The use of physical fitness scores and anthropometric data to predict selection in an elite under 18 Australian Rules football team. *J Sci Med Sport*. 1999;2(2):125-133.

28. IIHF. Women’s World Championship Gold Medal. :- http://www.iihf.com/iihf-home/history/all-medall.

29. IIHF. Women’s Hockey Gold Medalist Winter Olympic Games. http://www.iihf.com/de/iihf-home/history/all-medallists/olympics/women.

30. USA Hockey. *USA Hockey 2014-2015 Annual Guide*.; 2014:1-348.

31. Hockey Canada. Annual Report 2014. 2014.

32. Theberg N. Physicality and the Production of Gender in Women’s Hockey. *Gend Soc*. 1997;11(1):69-87.

33. IIHF. Women’s Ice Hockey Participation. http://www.iihf.com//iihf-home/sport/women.

34. Geithner CA, Lee AM, Bracko MR. Physical and performance differences among forwards, defensemen, and goalies in elite women’s ice hockey. *J Strength Cond Res*. 2006;20(3):500-505.

35. Ransdell LB, Murray TM, Gao Y. Off-ice fitness of elite female ice hockey players by team success, age, and player position. *J Strength Cond Res*. 2013;27(4):875-884.

36. International Society for the Advancement Kinanthropometry. *International Standards for Anthropometric Assessment*. The International Society for the Advancement of Kinanthropometry; 2001:139.

37. Australian Sports Commision. *20m Shuttle Run Test: A Progressive Shuttle Run Test for Measuring Aerobic Fitness*.; 1999.

38. Vanhatalo, Anni, Doust, Jonathan, Burnley M. Determination of Critical Power Using a 3 minute All-Out Cycling Test. *Med Sci Sports Exerc*. 2007;39(3):548-555.

39. Beam, William, C., Adams, Gene M. Anaerobic Cycling. In: *Exercise Physiology Laboratory Manual*.; 2014:95-109.

40. Bishop D, Lawrence S, Spencer M. Predictors of repeated-sprint ability in elite female hockey players. *J Sci Med Sport*. 2003;6(2):199-209.

41. Green HJ. Fatigue and weakness in ice hockey: Mechanisms and management. In: Biasca, N., Montag, W.O., Gerber C, ed. *Safety in Ice Hockey*. Reinach, Switzerland: Multi-Press; 2000:122-130.

42. Agre J., Casal D., Leon AS, McNally C, Baxter TL, Serfass R. Professional ice hockey players: physiologic, anthropometric, and musculoskeletal characteristics. *Arch Phys Med Rehabil*. 1988;69:188-192.

43. Bracko MR, Fellingham GW. Prediction of ice skating performance with off-ice testing in youth hockey players. *Med Sci Sports Exerc*. 1997;29:S172.

44. Quinney, H.A., Dewart, Randy, Game, Alex, Snydmiller, Gary, Warburton, Darren, and Bell G. 1 26 year physiological description of a National Hockey League team. *Appl Physiol Nutr Metab*. 2008;33:753-760.

45. Lloyd, Rhondri, Oliver J. The youth physical development model: A new approach to long-term athletic development. *Strength Cond J*. 2012;34(3):61-72.

46. Baker, Daniel, and Newton R. Adaptations in upper-body maximal strength and power output resulting from long-term resistance training in experiences strength-power athletes. *J Strength Cond Res*. 2006;20(3):541-546.

47. Baker, Daniel G. 10-year changes in upper body strength and power in elite professional rugby league players - the effect of training age, stage, and content. *J Strength Cond Res*. 2013;27(2):285-292.

48. Montgomery D. Physiological profile of professional hockey players - a longitudinal comparison. *Appl Physiol Nutr Metab*. 2006;31:181-185.

49. Baechle T, Earle R. *Essentials of Strength Training and Conditioning*. NSCA-National Strength and Conditioning Association; 2008:656.

50. Peterson BJ, Fitzgerald JS, Dietz CC, Ziegler, KS, Ingraham, SJ, Baker, SE, Snyder, EM. Aerobic Capacity is Associated with Improved Repeated Shift Performance in Hockey. *J Strength Cond Res*. 2015.

51. Arnett M. Effects of Specificity of Training on the Recovery Process during Intermittent Activity in Ice Hockey. *J Strength Cond Res*. 1996;10(2):124-126.

52. Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries : a systematic review and meta-analysis of randomised controlled trials. 2013:1-8.

Table 1. Descriptions of Hockey Canada National Women's Team physical and physiological fitness testing battery.

Test	Description
Anthropometric	
Body Mass Height, Body Fat Percentage, Muscle Percentage, Fat Mass, Muscle Mass, Ratio Fat:Muscle	Methodology outlined by the International Society for the Advancement of Kinanthropometry (ISAK)[26].
Energy Systems Tests	
Estimated VO_2 Max ($ml \cdot kg^{-1} \cdot min^{-1}$)	20m Shuttle Run as outlined by Australian Sports Commision[27].
Maximal Aerobic Power Workload (W)	Cycle ergometer graded exercise test using incremental loading (Starts at 55W with 90 rpm, then increase 25W every 3 minutes until 6.0mmol, then 25W each minute to maximal effort). Maximal aerobic power workload is considered the last workload the subject completes without a 15rpm drop.
Critical Power Workload (W)	3 minute all-out cycling test[28]. Relationship between power and inverse of time, where critical power is equivalent to y-intercept. Resistance is determined by slope and intercept of values derived from 30-second Wingate and Maximal Aerobic Power Workload.
Wingate Peak Power ($W \cdot kg^{-1}$) and Mean Power ($W \cdot kg^{-1}$)	Standard 30-s Wingate Test on cycle ergometer with a resistance set at 0.085 x body mass (kg). Peak Power is the highest mechanical power generated during any 5 second interval. Mean Power is the total amount of work performed over the 30 second trial, without normalizing for a full minute; converted to watts (1W = 1 J/s).
Repeated High Intensity Endurance Test	40m shuttle repeat sprint test[29].
Strength Tests	
Bench Press (lb)	Submaximal strength testing, tested at 4 repetition maximum.
Fixed bar supinated grip chin-ups	Maximum consecutive repetitions from full extension of arms to full flexion of arms.
Jump Testing for Power	
Squat Vertical Jump (cm)	No counter movement allowed, squat depth to 90 degree knee flexion. Jump height recorded from Opto Jump infrared timing system. Highest jump of three trials.
Counter-movement Vertical Jump (cm)	Jump height recorded from Opto Jump infrared timing system. Highest jump of three trials.
Drop Jump (cm)	Drop from 42cm box. Jump height recorded from Opto Jump infrared timing system. Highest jump of three trials.
Standing Long Jump (cm)	Counter-movement allowed. Athlete must land under control without falling forward. Longest jump of three trials.

Table 2. Characteristics of Elite Female Ice Hockey Players selected by Hockey Canada from 2005-2013.

	Selected to team			Not selected to team			Total		
VARIABLE	N	MEAN	SD	N	MEAN	SD	N	MEAN	SD
Age	189	25.78	4.39	154	21.90	3.84	343	24.04	4.58
Body Mass (kg)	189	70.35	6.90	153	69.14	7.40	342	69.81	7.15
Height (cm)	189	171.01	5.53	153	169.11	5.71	342	170.16	5.68
Body Fat Percentage (%)	185	18.33	4.07	148	19.87	3.86	333	19.01	4.04
Muscle Percentage (%)	180	42.65	2.50	120	42.19	2.88	300	42.47	2.66
Fat Mass (kg)	185	13.06	3.75	148	13.90	3.82	333	13.43	3.80
Muscle Mass (kg)	180	29.94	2.96	120	29.34	3.45	300	29.70	3.18
Ratio Fat:Muscle	180	434.21	116.75	120	480.29	119.83	300	452.64	119.94
Estimated VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$)	177	51.33	3.14	143	50.29	3.29	320	50.87	3.24
Maximal Aerobic Power workload (W)	119	301.29	34.53	58	286.98	36.80	177	296.60	35.82
Critical Power workload (W)	147	338.47	38.76	92	320.60	35.81	239	331.59	38.57
Wingate Peak Power ($W \cdot kg^{-1}$)	126	11.81	0.99	67	11.63	1.02	193	11.75	1.00
Wingate Mean Power ($W \cdot kg^{-1}$)	126	56.61	4.18	67	55.92	4.99	193	56.37	4.47
Bench Press 4 rep max (lb)	173	130.08	19.04	146	122.48	18.74	319	126.60	19.25
Fixed bar supinated grip Chin-ups	173	8.39	3.58	146	6.51	3.84	319	7.53	3.81
Standing Long Jump (cm)	111	220.21	15.96	93	215.77	17.97	204	218.19	17.01
Squat Vertical Jump (cm)	175	35.48	4.63	144	33.30	4.90	319	34.50	4.87
Counter-movement Vertical Jump (cm)	175	36.91	4.69	143	34.91	5.14	318	36.01	4.99
Drop Jump (cm)	173	37.24	4.55	143	35.13	5.19	316	36.29	4.96
Repeated High Intensity Endurance Test First Repeat (sec)	147	8.98	0.39	109	9.06	0.48	256	9.01	0.44
Repeated High Intensity Endurance Test Drop Off (sec)	115	2.48	0.83	85	2.64	1.21	200	2.55	1.01

Table 3. Association between physical and physiological fitness test scores and success at being selected for the team.

VARIABLE	Odds Ratio (95% CI)
Age	1.27 (1.19-1.35)
Body Mass	1.02 (0.99-1.06)
Height	1.06 (1.02-1.10)
Body Fat Percentage	0.91 (0.86-0.96)
Muscle Percentage	1.07 (0.98-1.17)
Fat Mass	0.94 (0.89-1.00)
Muscle Mass	1.06 (0.99-1.14)
Ratio Fat:Muscle	1.00 (1.00-1.00)
Estimated VO_2 max	1.11 (1.03-1.19)
Maximal Aerobic Power workload	1.01 (1.00-1.00)
Critical Power workload	1.01 (1.01-1.02)
Wingate Peak Power	1.21 (0.90-1.63)
Wingate Mean Power	1.04 (0.97-1.11)
Bench Press_10	1.19 (1.06-1.34)
Fixed bar supinated grip chin up	1.15 (1.08-1.22)
Standing Long Jump_10	1.01 (0.91-1.11)
Squat Vertical Jump_10	2.63 (1.61-4.28)
Counter-movement Vertical Jump_10	2.33 (1.47-3.70)
Drop Jump_10	2.47 (1.53-3.97)
Repeated High Intensity Endurance Test First Repeat	0.65 (0.36-1.15)
Repeated High Intensity Endurance Test Drop Off	0.86 (0.65-1.14)

Figure 1. Mean age of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.

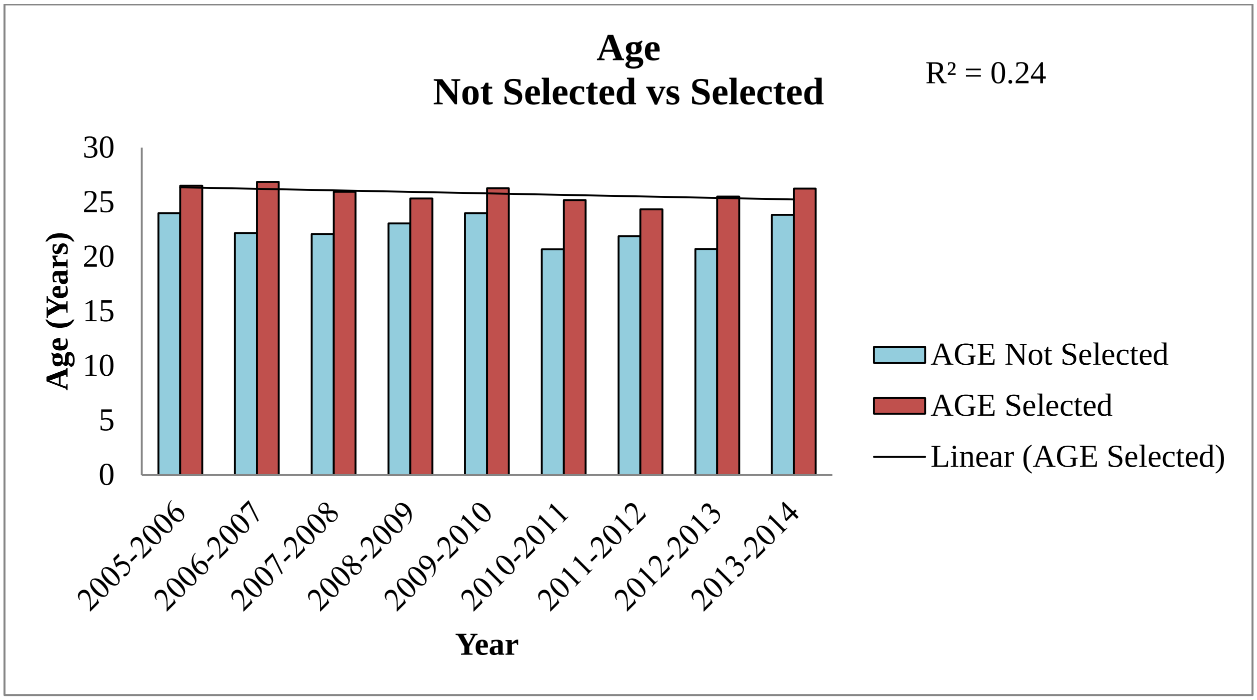

Figure 2. Mean height of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.

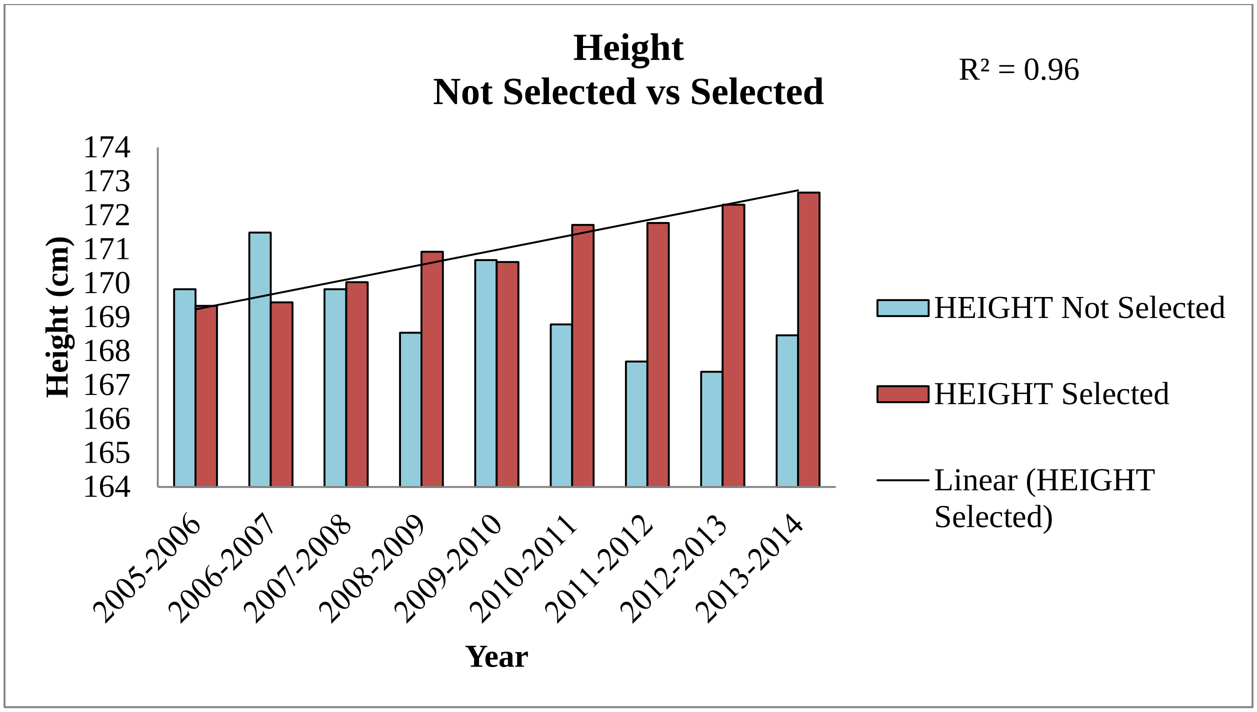

Figure 3. Mean body fat percentage of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.

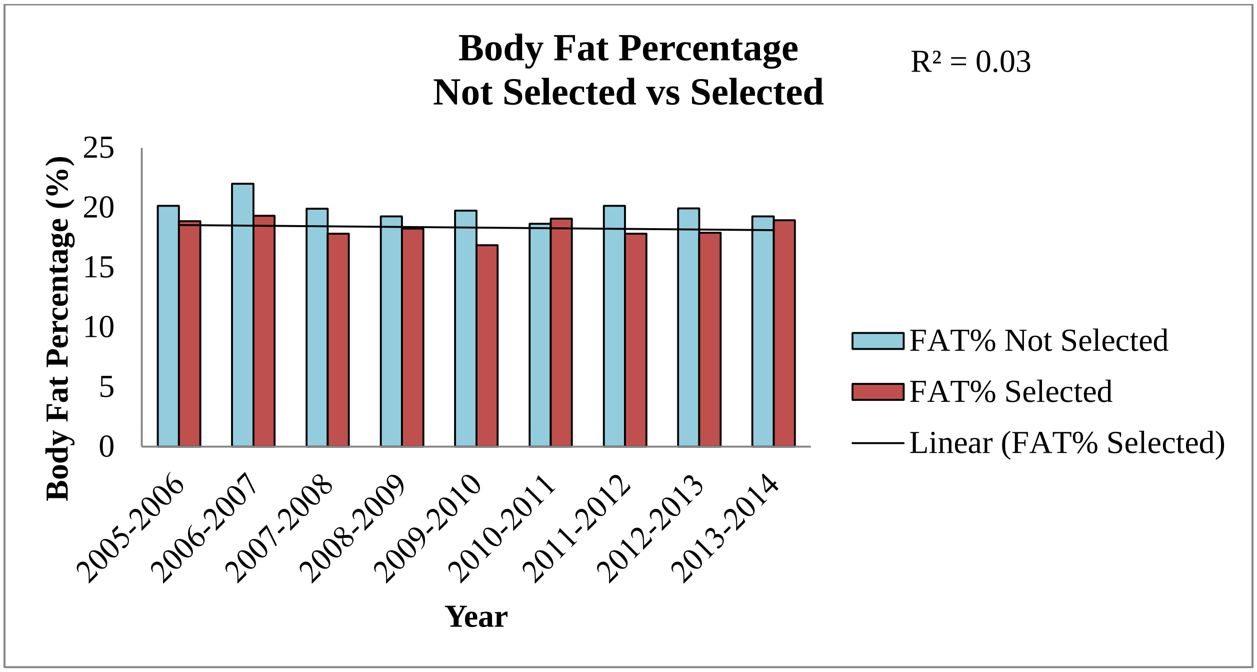

Figure 4. Mean estimated VO_2 max of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.

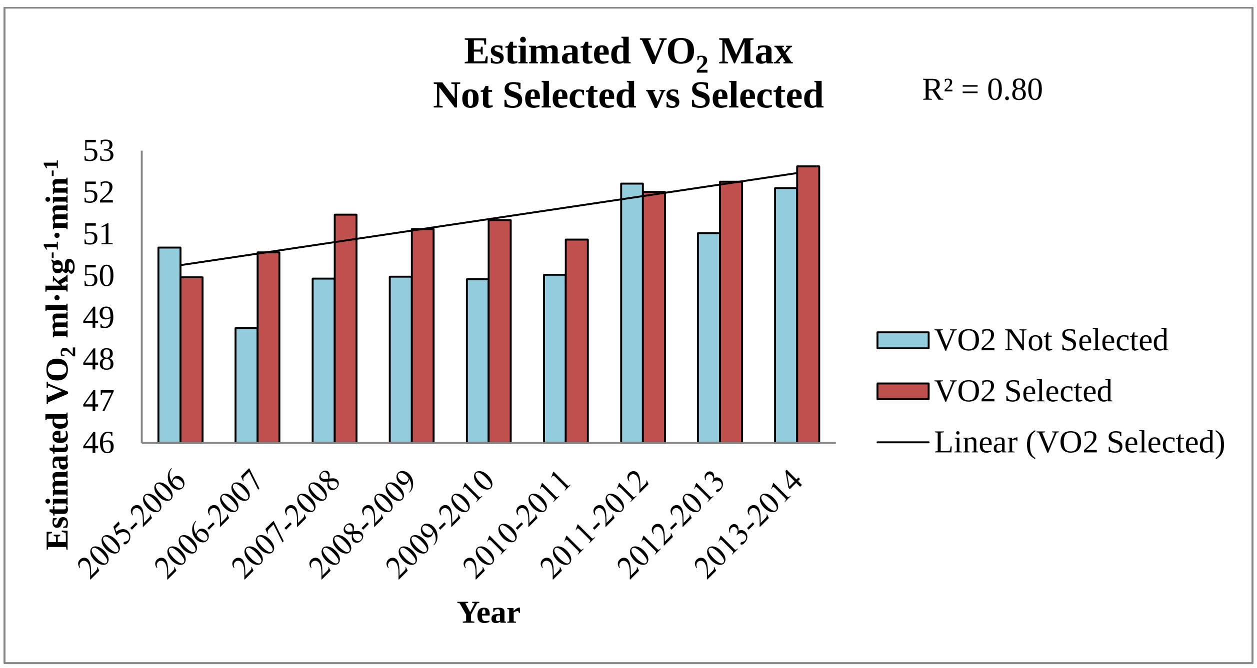

Figure 5. Mean bench press 4 repetition maximum of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.

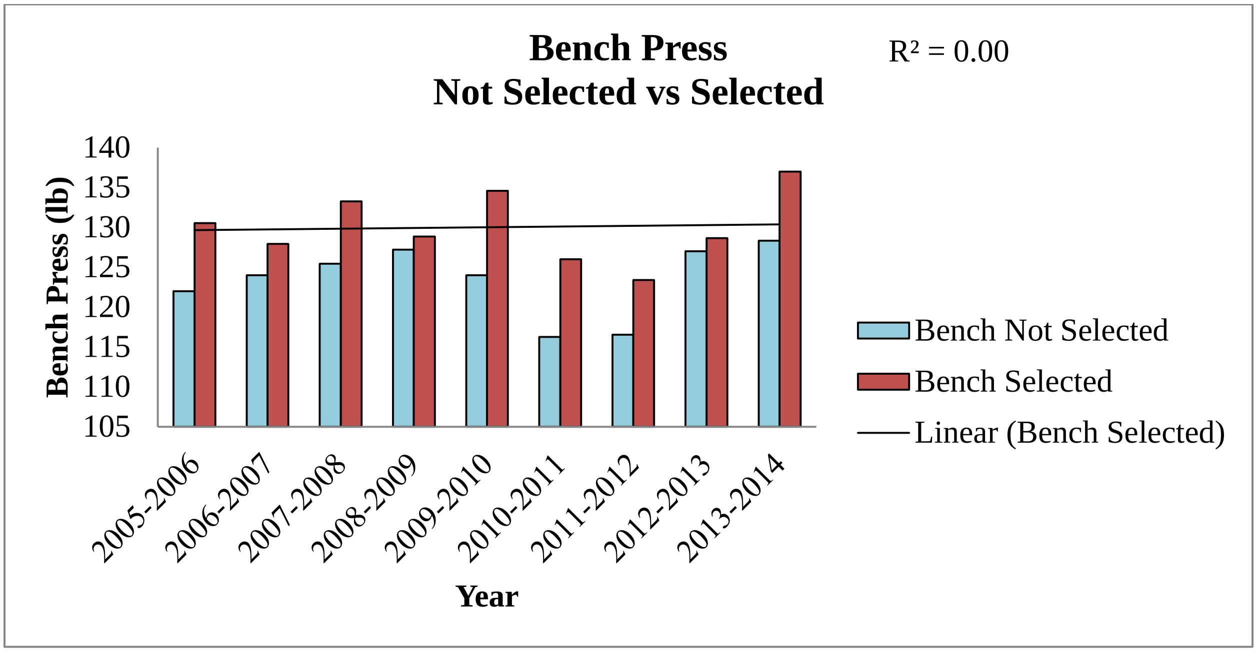

Figure 6. Mean maximum number of chin-ups of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.

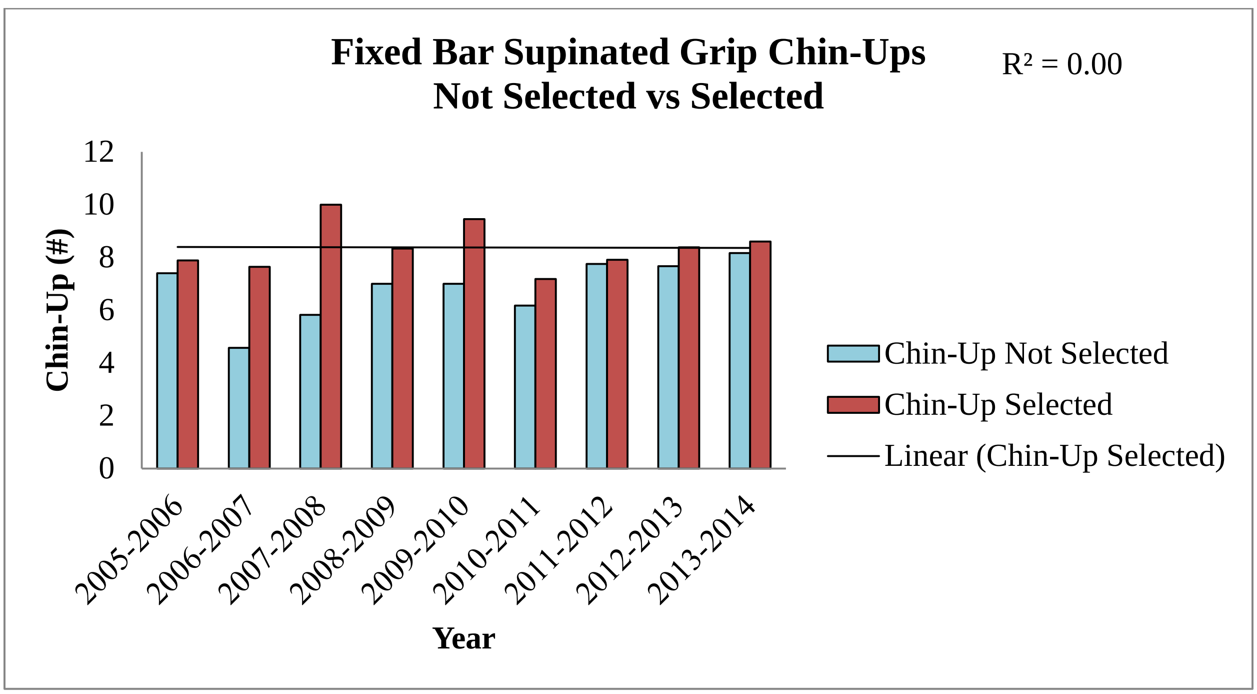

Figure 7. Mean squat vertical jump results of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.

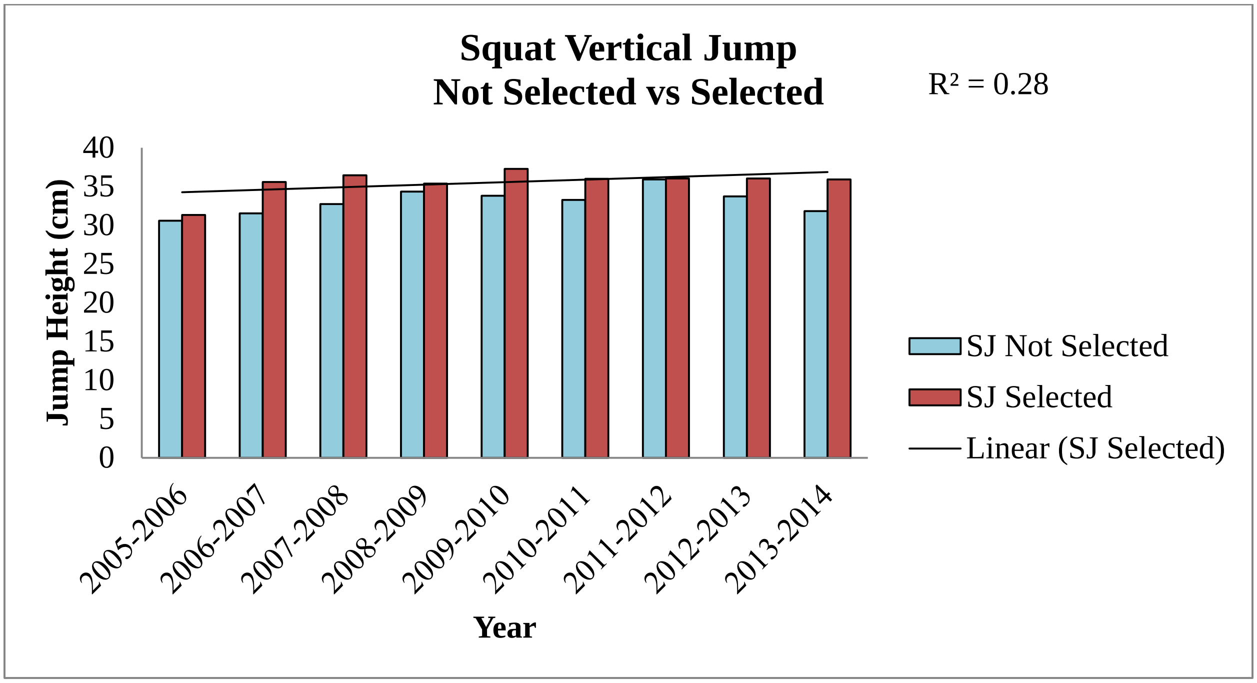

Figure 8. Mean counter-movement vertical jump results of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.

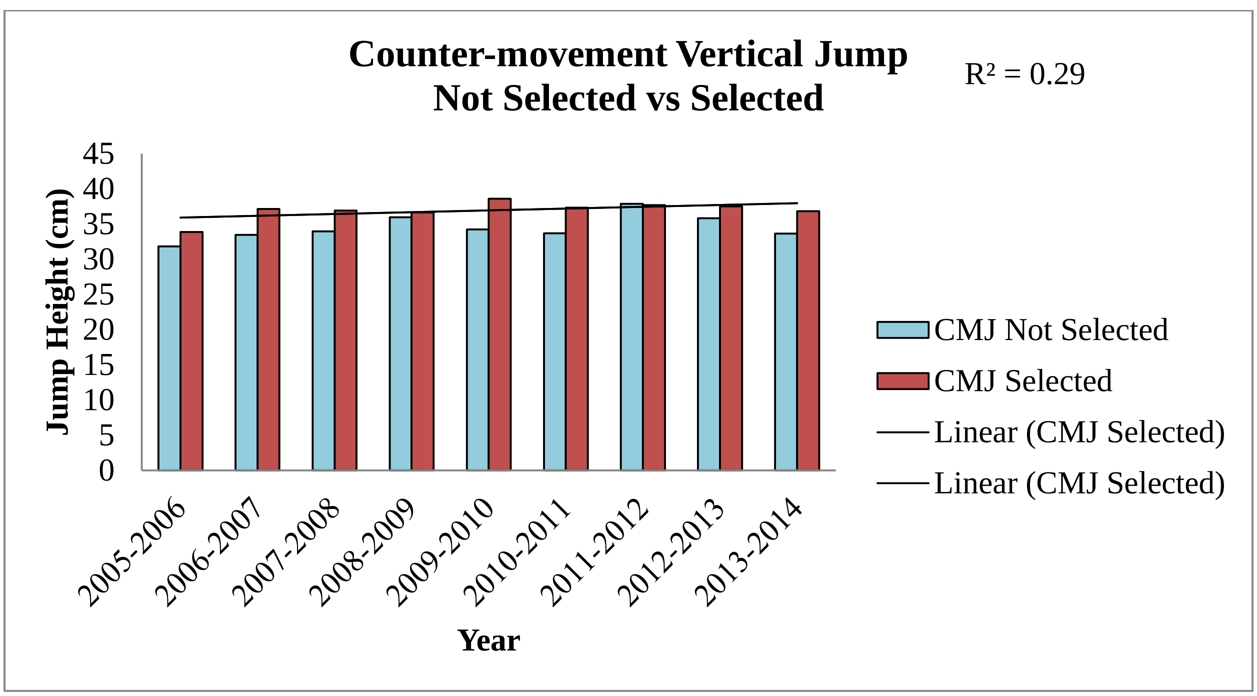

Figure 9. Mean drop jump results of athletes selected and not selected to the team from the seasons 2005-2006 through 2013-2014.