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RESEARCH ARTICLE **OPEN ACCESS**

Gender Differences in Anaerobic and Aerobic Responses to a Full Season of NCAA Division 1 Ice Hockey

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Abstract:

Introduction: Ice hockey is a physiologically demanding sport that requires aerobic and anaerobic fitness. Very little research exists comparing male and female athletes who compete in this sport. This comparative study examined the impact of a full season on aerobic fitness, anaerobic power, and fatigue in highly trained male and female hockey players.

Methods: A total of 29 (15 men, 14 women) NCAA Division 1 hockey players were included in the study. Differences and seasonal changes in aerobic fitness, anaerobic power, and fatigue as determined by preseason and postseason testing were assessed using a standardized graded exercise test and Wingate Anaerobic Tests (WAnT).

Results: Maximal oxygen uptake did not differ between the pre- and post-season in either gender ($p > 0.05$). However, men had significantly higher maximal oxygen uptake (VO2 max) at both time points ($p < 0.05$). WAnT-derived relative mean power (W/kg), relative peak power (W/kg), and fatigue index (%) were not significantly different between pre- and post-season for either gender ($p > 0.05$). Men demonstrated a significantly higher RMP than women ($p < 0.05$) in both pre- and post-season data, but no differences were observed between genders in Relative Peak Power (RPP) ($p = 0.791$) or FI ($p = 0.250$).

Discussion: Despite data supporting changes over a season in other sports, a season of ice hockey did not elicit changes in aerobic or anaerobic fitness in both groups. However, data does support that when athletes are exposed to similar environments, gender differences are minimal.

Conclusion: Coaches may employ similar strategies when approaching different genders participating in the same sport.

Keywords: Performance, Strength and conditioning, Aerobic capacity, Anaerobic capacity, Hockey players, Athletes.

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1. INTRODUCTION

Ice hockey is a high intensity physiologically demanding sport that is characterized by rapid accelerating and decelerating and non-conventional movements of the body, arms, hips, and legs, changes of direction, with the possibility of high-impact body contact [1-7]. At the elite level, the ice hockey season traditionally consists of 5-6 days per week of practicing and competing for up to 8 months. The typical ice hockey contest consists of three 20-minute periods, and each period is separated by a 15-minute intermission. The average hockey shift for a skating forward or defensive player (excluding goalies) ranges from 30 to 80 seconds; this is followed by a recovery period of 4-7 minutes [3, 8]. Of the total 60 minutes, it is estimated that the effective playing time for the skating athlete ranges from 18 to 24 minutes [3]. Given the identified physical demands of ice hockey, it has therefore been suggested that success at the elite level requires athletes to maximize their fitness levels, including anaerobic power and strength, as well as aerobic endurance [3, 9-11].

To date, research on the contributions of both anaerobic and aerobic fitness to the hockey athlete is somewhat limited and contradictory in its findings. Several studies have shown players exhibit gains in different variables associated with anaerobic fitness, but little to no change in aerobic endurance over the course of the season [1, 3, 12]. However, a number of studies have suggested that aerobic fitness plays a vital role in on-ice performance as it relates to repeated sprint performance [13, 14]. Overall, women are underrepresented in athlete research, and there is a lack of data comparing male and female athletes in any sport, especially those who compete at the elite level [15]. Studies have been conducted on highly trained *versus* amateur female athletes in relation to body composition (by position), bone density, anaerobic capacity, and anaerobic power [16, 17]. In those that have compared elite athletes, the majority have focused on primarily aerobic sports, and the anthropometric and cardio-respiratory performance differences; in addition to being traditionally taller, and possessing greater muscle mass, muscle strength, and bone mass in loaded areas, data does show male athletes tend to have higher aerobic capacity [7, 15, 18, 19]. In the limited ice hockey research, Durocher *et al*. did report that male hockey players achieved a higher maximal oxygen uptake (VO2 max) and a higher lactate threshold than their female counterparts despite reaching similar maximum heart rates [20]. However, despite men having a greater aerobic capacity, recent data have indicated that females may exhibit faster recovery times and less muscle fatigue (*e.g.*, greater lactate threshold) during aerobic exercise [19, 21].

The purpose of this observational and comparative study was to examine the impact of a full season on aerobic fitness and anaerobic power and fatigue in highly trained male and female hockey players; in addition, it sought to compare anaerobic and aerobic performance variables in highly trained adult female and male athletes who compete in the same sport. Given the physical demands (anaerobic and aerobic) placed on men and women during the season, it was hypothesized that changes would occur in both aerobic and anaerobic fitness; in addition, since the demands on both athlete groups are similar, once adjusted for relevant variables, gender differences in athletes who participate in the same sport would be minimal. Gender comparison studies in team sports can be highly beneficial, as much of the existing literature is focused on male athletes; a better understanding of gender differences may lead to changes in how training is approached.

2. METHODS

2.1. Design

A total of 57 highly trained National Collegiate Athletic Association (NCAA) Division I male and female ice hockey players (28 male, 29 female) from the same institution were originally included in the study. The inclusion criteria included athletes who were members of the men's or women's team roster at the start of the season and were able to complete both pre-season and post-season testing. Participants were excluded if they became injured and/or were rehabilitating from a season injury. Additionally, all athletes were given the option to exclude their data from the study. Data were collected in both pre-season and post-season in the University of St. Thomas Sports Science Institute Lab. Pre-season data were collected within 10 days of the first practice of the season. All postseason data were collected two weeks after the final game of the season to comply with NCAA regulations. All participants played a full season of ice hockey, which lasted approximately eight months and included regular sport-specific practice and NCAA competition, along with regular in-season strength training. The strength training protocols were not a controlled part of the study, but both programs were created by the same strength coach and incorporated hockey-specific exercises. All study procedures were approved by the Institutional Review Board, and each participant provided written informed consent prior to participation in the study. The Sex and Gender Equity in Research (SAGER) guidelines were followed by the authors.

2.2. Participants

Separate group characteristics for males and females are shown in Table **1**. A total of 57 athletes were initially included in the study. However, due to exclusions including injuries and athletes who had graduated, data from 29 athletes were used for the final analysis (15 men and 14 women). Groups were well-matched in terms of age, training sessions, and sport-specific training hours per week. Males and females ranged from 18-25 years of age (mean age, males = 22.1 yrs; mean age, females = 20.2 yrs) and were of normal body mass, height, and Body Mass Index (BMI; mean BMI, males = 25.96 kg•m^{-2}; mean BMI, females = 23.54 kg•m^{-2}) [22, 23]. Total body mass in kilograms was obtained (to the nearest 0.1 kg) using an electronic scale accurate to 200 kg (Tanita BWB 800: Tokyo, Japan). Standing height was measured using a standard wall stadiometer (AccustatTM Genentech: San Francisco, CA) to the nearest 0.1 cm. Body mass index was then determined. As expected, males were heavier (+12.5 kg) and taller (+17 cm).

2.3. Instruments and Procedure

Changes in aerobic and anaerobic fitness pre- and post-season were assessed using a standardized graded maximal oxygen uptake (VO2max) and Wingate Anaerobic Test (WAnT) tests on separate days during both pre- and post-seasons (a total of 4 tests were performed; 2 VO2max, 2 WAnT). Prior to testing, participants were fitted with a heart rate monitor (Polar®). VO2max tests were conducted on a calibrated treadmill; Gas was collected using the Hans Rudolf Oro-Nasal Mask (7450 Series Silicone V2™) and analyzed with a ParvoMedics® TrueOne 2400. The VO2max protocol consisted of a 2-minute warm-up at 7.0 miles per hour (mph) at zero percent. Following the warmup, the speed was increased to 7.5 mph, and the percent grade of the treadmill was increased by 2% every two minutes (beginning at 0%). The test termination criteria were determined by: (1) participant voluntary termination; (2) Respiratory Exchange Ratio (RER) reached 1.10, and/or (3) heart rate (HR) reached age-predicted maximum (220–age). The highest VO2max level (ml/kg/min) reached during each of the tests was used in the final analysis.

Anaerobic capacity (*e.g.*, Fatigue) and power output were assessed *via* the Wingate Anaerobic Test (WAnT), which employed a computer-controlled LODE Excalibur Sport Cycle Ergometer® and a standardized 30-second testing protocol. Prior to testing, participants were required to warm up for 5 minutes at 100 watts. To ensure proper engagement of fast-twitch muscles during the warm-up, participants performed a series of 5-second submaximal sprints every 90 seconds. Following the warm-up, participants were then instructed to pedal as fast as possible (with minimal resistance) within three seconds of their maximal speed. A fixed resistance (7% of body mass for male participants and 6.7% of body mass for female participants) was then applied to the flywheel. Participants were encouraged to cycle at a maximal effort for the duration of the test. Relative Mean Power (RMP; w/kg), Relative Peak Power (RPP; w/kg), and fatigue index (FI; %) were recorded for all participants.

While in-season workouts were not controlled for by this study, all athletes participated in team practices, team strength training 2-3 days per week, and NCAA games throughout the season. Strength training sessions included a variety of full-body workouts, with a main focus on injury prevention and building strength. As this study was observational, we did not have input on strength and conditioning sessions.

2.4. Statistical Analysis

The SPSS (v.25) statistical software was used for all analyses. Means and Standard Deviations (SD) are presented as descriptive statistics. A two-way Analysis of Variance (ANOVA) with a 2 (gender) by 2 (time point) model was used to compare VO2 max and multiple Wingate parameters. WAnT parameters analyzed included RPP, RMP, and FI. The percentage change between the pre- and post-season was compared between genders using an independent t-test. Statistical significance was set at $p < 0.05$.

3. RESULTS

Table 1 shows demographics of all participants who completed both testing sessions. Men were significantly taller and heavier, but no statistically significant changes were observed in age or BMI.

Table 1. Demographics.

-	Age (yrs)	Height (m)	Weight (kg)	BMI
Male	22.11 ± 1.28	1.85 ± 0.07	88.55 ± 9.12	25.96 ± 2.17
Female	20.16 ± 1.37	*1.67 ± 0.06	*66.02 ± 6.98	23.55 ± 2.12

Note: *$p < 0.05$ compared to males.

Values for VO2 max are presented in Table 2. As hypothesized, men demonstrated statistically significantly higher VO2 max values than women ($p < 0.05$). However, there were no statistically significant differences between pre-season and post-season for either gender ($p = 0.578$). In addition, the percentage change in VO2 max between pre- and post-season was analyzed for both genders, and no significant differences were found ($p = 0.632$). Wingate results are presented in Table 3. No statistically significant differences were observed in RPP between genders or time points (gender: $p = 0.791$; time point: $p = 0.788$). Additionally, there were no statistically significant differences in RMP between time points; however, there was a significant difference in RMP between genders, with men having significantly higher RMP (gender: $p < 0.01$; time point: $p = 0.140$). Lastly, there was no significant difference in the fatigue index either between genders or time points (gender: $p = 0.250$; time point: $p = 0.830$).

Table 2 displays results from preseason and postseason VO2 max testing along with percent changes from preseason to postseason. Men had a significantly higher VO2max both pre and postseason, but no statistically significant changes were observed between pre and postseason for either gender.

Table 3 displays preseason and postseason wingate performance data along with percent changes from preseason to postseason. Men had significantly higher relative mean power both pre and postseason compared to women, but no statistically significant changes were observed between pre and postseason for either gender.

Table 2. VO2 max results.

-	Preseason (ml/kg/min)	Postseason (ml/kg/min)	Difference Pre to Post (%)
Male	55.16 ± 4.18	52.65 ± 4.25	4.77 ± 5.6
Female	*45.40 ± 5.08	*46.47 ± 5.88	2.36 ± 1.15

Note: *$p < 0.05$ compared to males.

Table 3. Wingate results.

-	Preseason	Postseason	Difference Pre to Post (%)
Relative Peak Power (w/kg)			
Male	15.27 ± 5.26	12.98 ± 3.78	17.64 ± 14.30
Female	12.97 ± 10.25	16.40 ± 11.27	26.44 ± 10.25
Relative Mean Power (w/kg)			
Male	8.76 ± 0.95	8.21 ± 0.83	6.7 ± 5.8
Female	*6.75 ± 1.09	*7.10 ± 0.91	5.19 ± 4.67
Fatigue Index (%)			
Male	66.16 ± 22.71	68.06 ± 22.93	2.87 ± 5.98
Female	56.63 ± 25.79	60.73 ± 25.79	7.24 ± 3.08

Note: *$p < 0.05$ compared to males.

4. DISCUSSION

Based on the physical demands of ice hockey, it can be inferred that highly trained hockey athletes need to possess both aerobic and anaerobic fitness to be successful. However, to date, there is a paucity of data available, and findings are somewhat contradictory. Moreover, there is also a lack of data comparing male and female athletes in sport, especially those who compete at the elite level. The primary goal of this study was to assess any changes in aerobic and anaerobic fitness that may occur over the course of a season. In addition, it examined whether significant differences exist in anaerobic and aerobic capacities between highly trained male and female athletes who compete in the same sport. It was hypothesized that there would be significant changes in fitness after 8 months of practice and competition, and after adjusting for critical variables, differences would be minimal between males and females, given that the athletes experience similar environments. Our data were consistent with previous research showing men did exhibit a higher relative aerobic capacity compared to women [24, 25]. Our data were inconsistent with other research in other sports, which has shown significant changes in aerobic performance from pre- to post-season [26]. In addition, results do not indicate any statistically significant differences between the genders in most of the anaerobic variables, including fatigue index and peak power. The lack of difference suggests that, regardless of gender, the sport and training environments may be the most influential factors.

To our knowledge, this is the first study to directly compare both aerobic and anaerobic fitness between genders and to examine how those variables respond to a full season of Division I ice hockey. Aerobic capacity has consistently been shown to be significantly higher in men than in women in a variety of sports [8, 27-30]. While the majority of data regarding VO2 max differences between genders comes from studies in endurance athletes, it has been accepted that men traditionally have a higher relative VO2 max [19]. The majority of these differences can be attributed to anatomical differences, including men having larger hearts and a lower body fat percentage on average [23]. Our data support previous findings showing that men exhibit higher overall VO2 values. The current study also examined the effects of a full season on VO2 max response in collegiate male and female hockey players. Interestingly, pre- and post-season data indicate that neither male nor female participants showed any significant changes in VO2 max as a result of the full season. Previous studies examining junior ice hockey players and collegiate ice hockey players have shown increases in aerobic capacity, but these studies used significantly younger participants, did not show increases when VO2 max was adjusted for body mass, and used submaximal tests to predict aerobic capacity [6, 30]. The lack of a significant increase in VO2 max in the current study potentially indicates that either athletes began the season with excellent aerobic capacity or that a season of ice hockey does not provide an adequate stimulus to significantly improve aerobic fitness.

Results from the WAnT showed that men had a significantly higher mean power per body mass than their female counterparts. However, once adjusted for body mass, fatigue index and peak power per body mass were not significantly different between genders. Neither men nor women showed any significant change in any WAnT variable between pre- and post-season. While specific data regarding the effect of a season on Wingate outcomes are limited, previous research has shown an improvement in a variety of other variables over the course of an ice hockey season in a variety of participants [24, 31]. Relative Mean Power (RMP) was higher in men compared to women; this may be due to larger muscle mass and a related ability to sustain power over the course of a 30-second WAnT. Previous research has shown increases in RMP over the course of multiple seasons in male adolescent hockey players [5, 32, 33]. The current study only measured one full season; therefore, more longitudinal research is needed to examine the potential for improvements in RMP in both men and women.

The lack of significance in gender differences in other Wingate variables and VO2 max is also an important finding, as it suggests that there are minimal differences between genders when athletes are exposed to similar competition and sport-specific training environments. There may be several reasons why a lack of significance was found in this area. Most notably, athletes may have entered the season in peak aerobic and anaerobic shape and therefore possessed less potential for improvement. In addition, the current study was observational, and both teams used the same strength coach and were exposed to similar training regimens.

5. LIMITATIONS

There are several limitations to the current study. First, because data collection spanned the NCAA regular season and playoffs, we could not standardize either season length or in-season training protocols, which were managed independently by the University of St. Thomas strength and conditioning staff. Second, athletes who missed one of the testing sessions—whether due to injury or graduation—were excluded from analysis, potentially introducing selection bias. Additionally, as this was an observational study, no control group was utilized, making causal inferences difficult to draw. Body composition was not assessed for either group. While all data were standardized by body mass, using total muscle mass may have provided a clearer picture. Finally, motivation was an uncontrollable variable. Anecdotally, players tend to perform better in preseason as their results are perceived to be more important. Postseason testing may have been seen by some players as less important, considering the season had ended. In future studies, subjective survey data regarding motivation may be useful.

CONCLUSION

This study provides a better understanding of how anaerobic and aerobic capacity of both male and female athletes respond to a full season of ice hockey. Based on the current data, a season of ice hockey did not appear to be an effective stimulus to increase either VO2 or Wingate variables. Additionally, the higher VO2 max observed in men was in line with the majority of previous data. Furthermore, research is needed to determine the impacts of team sport participation and in-season play on lab-based variables. Data from the current study suggest that there is no viable scientific reason to create significantly different training protocols for men and women of the same sport. While men traditionally have a higher VO2 max and, in the current study, demonstrated a higher RMP, these higher values were not significantly different from those of women in their response to a full season. Hence, the data suggest that strength coaches may approach different genders participating in the same sport with similar strategies.

AUTHORS' CONTRIBUTIONS

The authors confirm their contribution to the paper as follows: P.M.: Study conception and design; D.M.: Data collection; N.V., B.B.: Draft manuscript. All authors reviewed the results and approved the final version of the manuscript.

LIST OF ABBREVIATIONS

VO2	=	Maximal Oxygen Consumption
WAnT	=	Wingate Anaerobic Test
RMP	=	Relative Mean Power
RPP	=	Relative Peak Power
FI	=	Fatigue Index
BMI	=	Body Mass Index

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the University of St. Thomas Institutional Review Board, USA. The reference number is 2316772-1.

HUMAN AND ANIMAL RIGHTS

All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or research committee and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

All participants provided written informed consent to participate in this study.

STANDARDS OF REPORTING

STROBE guidelines were followed

AVAILABILITY OF DATA AND MATERIALS

All data generated or analyzed during this study are included in this published article.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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