Seasonal Changes of Physical Fitness Attributes in Collegiate Ice Hockey Players

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Table of Contents

List of Figures

List of Tables

List of Equation

List of Common Terms and Abbreviations

BL – Blood lactate

DXA – Dual Energy X-Ray Absorptiometry (Body Composition Methodology)

HR – Heart rate

MS – Mid-season time-point [December]

NCAA – National Collegiate Athletics Association (Collegiate Hockey League in USA)

NHL – National Hockey League (Professional)

ES – End-season time-point [March]

PS – Pre-Season time-point [September]

RPE – Rate of perceived exertion

U-sports – Canadian Interuniversity Sport (Collegiate Hockey League in Canada)

*Manuscripts were formatted for particular journals; therefore, abbreviations may not have been used in these two chapters.

Acknowledgments

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Abstract

Ice hockey continually overloads the athletes with limited time for recovery, which may induce fatigue and affect the physical condition. The monitoring over time of collegiate hockey player's physiological responses to submaximal stress and body composition can reflect physical fitness fluctuations. In-season physical fitness assessments can help players, team coaches or strength and conditioning professional better tailor their training program to optimize performance and well-being among their players. Two separate studies took place in this investigation. The first study's purpose was to identify changes in physiological responses and body composition profiles over the competitive season in male and female collegiate ice hockey players and to identify between-sex differences. The second study's purpose was to determine the changes in internal load perception during a short 4-minute submaximal physiological assessment over a competitive season in collegiate ice hockey players.

In the first study, forty-four players, twenty-four males, and twenty females participated in 4-minutes submaximal exercise tests and body composition assessment at pre-season, mid-season and end-season. Changes in physiological parameters and body composition were analyzed using repeated measures ANCOVA controlling for age and between-sex mean changes were analyzed using one-way ANOVA. Men's post-exercise blood lactate concentration decreased ($p \leq 0.05$) from pre- to mid-season and both sexes increased ($p \leq 0.05$) the concentration from mid- to end-season. Heart rate increased ($p \leq 0.05$) after the 3^{rd} and 4^{th} minutes of the test in both sexes from pre- to end-season and from mid- to end-season. Males' body fat percentage decreased ($p \leq 0.05$) from pre- to mid-season, while increases were observed ($p \leq 0.05$) in both sexes from mid- to end-

season. This study produced evidence that male and female collegiate hockey athletes' physiological responses and body composition profiles change over the season. Detraining was observed in both sexes in the second half of the season.

In the second study, from the previous study, internal load ratios were created from the 4-minutes submaximal exercise and participants completed a subjective fatigue questionnaire before physical testing at pre-season, mid-season, and end-season. Changes in the internal load ratios and subjective fatigue scores at the three time-points were analyzed using repeated measures ANCOVA controlling for age and sex. HR-RPE ratio after the 1st and 2nd minute were lower at end-season compared to pre-season (F (1,41) =2.855, $p \leq 0.05$). BL-RPE ratio was higher at mid-season compared to pre-season (F (1,41) =2.855, $p \leq 0.05$), was lower at end-season compared to mid-season. A subjective rating (RPE) of effort in relation to physiological responses (HR, BL) might be an efficient way of assessing internal loading and fatigue in collegiate hockey players.

The findings of each study can have important implications for the performance and well-being of collegiate athletes and help team coaches better tailor training programs. Maintaining an ideal level of physical fitness throughout the competitive university season would help the collegiate player maintain or improve both athletic and academic performance, increase their health, well-being, and reduce fatigue.

Résumé

Le hockey sur glace impose un stress physiologique continu aux athlètes et laisse peu de temps pour la récupération ce qui peut causer de la fatigue et affecter la condition physique. Le suivi de la réponse physiologique à un effort sous-maximal et de la composition corporelle chez les joueurs de hockey universitaire peux refléter les changements de la condition physique. L'évaluation de la condition physique durant la saison peut aider les joueurs, les entraîneurs et les préparateurs physiques à mieux adapter le programme d'entraînement pour optimiser la performance et le bien-être des joueurs. Deux différentes études ont pris place durant cette investigation. Le but de la première étude était d'identifier les changements de la réponse physiologique à l'effort et du profil de la composition corporelle durant la saison parmi des joueurs de hockey universitaire masculin et féminin. Aussi, le but était d'identifier les différences entre les sexes. Le but de la deuxième étude était de déterminer les changements de la perception de la charge interne durant un test d'effort sous-maximale de 4 minutes au cours de la saison.

Lors de la première étude, quarante-quatre joueurs, vingt-quatre hommes et vingt femmes, ont participé au test sous-maximal de 4 minutes ainsi qu'à l'évaluation de la composition corporelle à chacune des trois sessions (pré-saison, mi-saison et fin de la saison). Les changements des paramètres physiologiques et de la composition corporelle ont été analysés à l'aide du test statistique ANCOVA à mesures répétés en contrôlant pour l'âge. Les hommes ont diminué leur taux de lactate dans le sang ($p \leq 0.05$) à la mi-saison en comparaison avec la présaison, alors que les deux sexes l'ont augmenté ($p \leq 0.05$) à la fin de la saison en comparaison avec la mi-saison. La fréquence cardiaque a augmenté ($p \leq 0.05$) après la 3^{ième} et la 4^{ième} minute du test chez les hommes et les

femmes. Le pourcentage de gras a diminué ($p \leq 0.05$) chez les hommes à la mi-saison, alors que les deux sexes ont augmenté ($p \leq 0.05$) à la fin de la saison en comparaison avec la mi-saison. L'étude démontre que la réponse physiologique à l'effort ainsi que la composition corporelle des joueurs de hockey universitaire changent durant la saison de compétition. Une diminution de la condition physique a été observée chez les deux sexes lors de la 2^{ième} moitié de la saison.

Lors de la deuxième étude, des ratios de la charge interne était calculés à partir du test d'effort de la première étude. Aussi, les participants ont complété un questionnaire sur leur fatigue subjective au repos. Les changements des ratios de la charge interne et du questionnaire ont été analysés à l'aide du test statistique ANCOVA à mesures répétés en contrôlant pour l'âge et le sexe. Les ratios HR-RPE après la 1^{ière} et la 2^{ième} minute et le ratio BL-RPE étaient plus bas à la fin de la saison en comparant avec la pré-saison ($p \leq 0.05$). Mettre une évaluation de l'effort subjective (RPE) en relation avec un paramètre physiologique (HR, BL) peut être une manière efficace d'évaluer la charge interne et la fatigue des joueurs de hockey universitaire.

Les résultats de chacune de ces études peuvent avoir des utilités pour la performance des joueurs de hockey universitaire et peuvent aider à mieux adapter les programmes d'entraînement. Maintenir un niveau optimal de condition physique durant la saison de compétition pourrait aider les performances sportives des joueurs.

Preface and Contribution of Authors

Patrick Delisle-Houde was the primary author with roles in subject recruitment, data collection, analysis and interpretation, and thesis preparation.

Dr. Ross E. Andersen, Professor, Department of Kinesiology and Physical Education, McGill University, the candidate's supervisor, was actively involved in every step and decision made regarding the research study and the completion of this thesis.

Ryan E.R. Reid assisted in the management of data collection and statistical analysis.

Jessica A. Insogna assisted in participants testing and editing.

Nathan A. Chiarlitti assisted in participant recruitment and participant testing.

Chapter 1 – Introduction

1.1 Scope of the Problem

Approximately 11,000 student-athletes represent their university in Canada's Interuniversity Sport (U-Sports) and over 460,000 in United States' National Collegiate Association (NCAA). There are around 1,700 student-athletes participating in hockey within Canada; among them roughly 900 are males and 800 are females (Canadian Interuniversity Sport; National Collegiate Athletics Association, 2015). In Canada, male hockey student-athletes age range in average from 20 to 25, meanwhile female hockey student-athletes range from 18 to 24 years old. Varsity student-athletes are committed to their sports and their studies (Curry, Snyder, Cook, Ruby, & Rehm, 1997). Accomplishing both the student-athlete's athletic and academic goals requires much effort and busy, long days balancing their sport participation and school responsibilities (i.e. studying, attending lectures; (Curry et al., 1997; Etzel, 2006)). Varsity student-athletes are often associated with physical health benefits; however, it is known that the physiological and psychological stress imposed on them may affect their physical and mental state (Dubuc-Charbonneau, Durand-Bush, & Forneris, 2014; Etzel, 2006; Kavazis & Wadsworth, 2014; Stanforth, Crim, Stanforth, & Stults-Kolehmainen, 2014). Nevertheless, stresses due to sport and academic responsibilities can shift their physical and psychological state from acute fatigue to an overtraining status (Coutts & Cormack, 2014; Etzel, 2006; Saw, Main, & Gastin, 2015). Overtraining is defined as a long-term decrement in performance capacity resulting from an accumulation of training and non-training stressors that affect one's body and one's mind (Kreider, Fry, & O'Toole, 1998).

Ice hockey players constantly stress their body with high volume and high-intensity exercise (Green et al., 2010). While there is some importance placed on on-ice tactics and techniques, off-ice training remains a priority because high levels of physical fitness are linked to on-ice success (Ransdell, Murray, & Gao, 2013) and winning percentage in hockey (Cox, Miles, Verde, & Rhodes, 1995). Nowadays, most athletes perform physical training in addition to their regular practices and their competitions/games. Sport scientists and strength and conditioning specialists are employed by teams to maintain the athlete's maximal performance capacity and general health (Taylor, Chapman, Cronin, Newton, & Gill, 2012). Unlike professional athletes, collegiate athletes may not be followed on a regular basis to determine the effect of the competitive season on their well-being, health and performance status. Due to their high workload (i.e. athletics, academics), collegiate hockey players are at risk of overtraining which underlies physiological and psychological factors (Kreider et al., 1998; Saw et al., 2015; Soligard et al., 2016). Identifying potential trends of overwork that could affect male and female varsity hockey players' health and performance, represents a public health priority.

Former students in the Health and Fitness Promotion Laboratory have studied body composition changes over time during the hockey off-season and the first half the competitive season. Prokop et al. (2016) found that lean and fat tissues changed over this period of time, which suggests that university hockey student-athletes' fitness may change during the playing season. Little is currently known about collegiate players' physiological responses over the competitive university season. Understanding the seasonal changes of physical fitness in a student-athlete's journey is important given its potential to inform intervention and policy to help improve the performance, health, and well-being of student-athletes (Miller & Kerr, 2002).

Fatigue affects several physiological responses to training and non-training variables that can be either modified or controlled using an tailored training program. However, a further understanding of the student-athlete's changes in physical fitness parameters over the course of the hockey season must be monitored in order to tailor programs to best meet their needs. Maintaining an ideal level of physical fitness throughout the university competitive season would help collegiate ice hockey players maintain or improve both athletic and academic performance, increase their health, well-being, and reduce fatigue (Prokop, Reid, & Andersen, 2016).

1.2 Purpose

The primary purpose of the study was to identify changes in physical fitness attributes over the competitive season. Physical fitness was defined as a set of attributes that a person has or can achieve (Caspersen, Powell, & Christenson, 1985). In this study, physiological responses (i.e. heart rate [HR], blood lactate [BL] concentration) during a cycle ergometer test and body composition evaluation were used to assess physical fitness. A second objective of the investigation was to explore between-sex differences regarding changes of physical fitness attributes. The third objective of this study was to identity changes in internal loading perception.

1.3 Rationale

Varsity student-athletes have many responsibilities related to their academics and athletics (Curry et al., 1997). The athletes in the U-Sports need to maintain a cumulative GPA of 2.7 and they need to be full-time students to be eligible to play, in addition to performing at a high level in their sport. Ice hockey is arguably one of the most demanding sports at the university level in Canada. In the U-Sports, hockey has the longest season with the most regular season games divided into two half seasons corresponding to the fall and winter academic semesters. U-Sports teams average 2 games per week and are required to travel for half of their regular season games. Ice hockey has some features that make the sport unique: it is a high-intensity sport with many changes in velocity and direction where on-ice presences average 45 seconds, although presences can range from 30 to 80 seconds (Montgomery, 1988). Furthermore, hockey is an intermittent sport with bursts of effort followed by short recovery periods, which required the athletes to be trained aerobically and anaerobically to respond to the physiologic demands (Montgomery, 1988; Twist & Rhodes, 1993b). In addition to their academic obligations, games, and practices, most U-Sports hockey teams require their players to perform off-ice training 1 to 3 times per week to maintain and improve physical fitness attributes. To date, no evidence exists showing that collegiate hockey players were monitored over the course of the season in terms of physiological response to exercise and body composition (important physical fitness attributes) compared to professional athletes where load monitoring is becoming a trend (Soligard et al., 2016; Taylor et al., 2012). Therefore, there is a paucity of research examining how physical fitness attributes change over the competitive university season. Physical fitness changes may affect sport performance, health, and well-being of student-athletes.

A study done by Cox et al. (1995) assessed physical fitness during a submaximal test using physiological parameters (i.e. HR, BL) over time among professional National Hockey League (NHL) players at 4 different time points during the regular season (Cox et al., 1995). Physiological parameters such as HR and BL concentration can quantify workload in sports (Halson, 2014; Soligard et al., 2016; Thorpe, Atkinson, Drust, & Gregson, 2017). These two physiological parameters are useful to determine how the body's energy systems react to stress imposed by exercise and in relation to physical fitness levels (Cox et al., 1995). Figure 1 shows a continuum of physical fitness using HR and BL as markers. For example, when HR and BL concentration increase under the same physiological stress, physical fitness is decreasing (Cox et al., 1995).

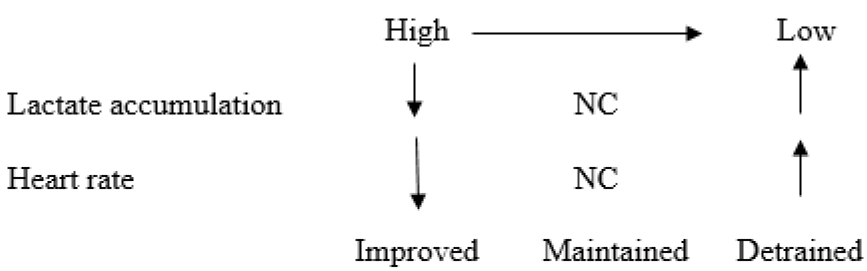

Figure 1 HR and BL under long-term physiological stress (Cox et al., 1995)

In addition, HR and BL concentration can be used to create a ratio with the rate of perceived exertion (RPE) to evaluate the perception of internal load in athletes under fixed submaximal load (Halson, 2014; Martin & Andersen, 2000; Snyder, Jeukendrup, Hesselink, Kuipers, & Foster, 1993). This study was important for assessing and monitoring the physical condition collegiate ice hockey players over the course of a competitive season, which may enhance sport performance. The project provided valuable information to improve periodization of training programs, as well as, general levels of physical fitness and sport performance using pre- mid- and end-season (PS, MS, ES) reports on the evolution of the physiological profile of the varsity hockey student-athlete. Also, many studies have investigated the sex differences effect on concussion symptoms, lifestyle and sport participation motivation, but to the best of our knowledge, no study has looked at the sex differences in physical fitness attributes in collegiate ice hockey players. Past studies have proposed physiological sex differences (Maldonado-Martin, Mujika, & Padilla, 2004). The findings of our study may help exercise scientists and coaches better tailor training programs to promote sport performance, health and well-being in collegiate ice hockey players.

1.4 Hypothesis

Objective #1: Identity changes in physical fitness attributes over the competitive season in varsity hockey student-athletes.

A competitive varsity hockey season is very demanding because of the academic and athletic obligations imposed on student-athletes. Stress imposed on players can influence physical fitness attributes. Therefore, it was hypothesized that a player's physical fitness attributes would deteriorate as the season progressed because student-athletes would accumulate fatigue from training and non-training stressors, which was associated with a decrease in performance capacity. At submaximal exercise, HR was expected to increase as well as the RPE at the same moment in the test compared to PS submaximal test. The HR recovery, as well as the BL concentration three minutes after the submaximal test, were expected to be higher during the second and third assessment than the first. A HR monitor and a BL analyzer were used during and after the submaximal exercise test to evaluate the physiological changes in the player. Body composition profiles were expected to change negatively, which means an increase in fat tissue mass and a decrease in lean tissue mass over the course of the season.

Objective #2: Explore sex-differences in changes of physical fitness attributes

Male and female bodies react differently to stress imposed by exercise (Billaut & Bishop, 2009; Maldonado-Martin et al., 2004). Since possible changes in physical fitness could be observed in collegiate ice hockey players during the competitive season, it was hypothesized that male and females would have a different decrease in physical fitness level over the competitive season, where the males would detrain more than the females.

Objective #3: Identity changes in internal load perception over the competitive season

Regarding our third objective and hypothesis, it was hypothesized that internal load perception would increase from PS to MS and ES. Physical fitness was previously tracked, and with the addition of a subjective fatigue questionnaire, internal load perception would have objective and subjective measures. Questionnaire administered before the submaximal test was used to gain insight on subjective mental and physical fatigue. The questionnaire was used to corroborate the physiological information and to gain a better understanding on their fatigue status.

1.5 Delimitations

For the purpose of this study, the following delimitations have been identified:

1. Participants were student-athletes at McGill University.
2. Participants were currently active hockey players.
3. Participants were aged between 18 and 25 years old.

1.6 Limitations

These delimitations may lead to the following limitations:

1. Due to the unique sample of this study, results might not be generalizable to the larger population but provides important information regarding physical fitness, internal loading perception and subjective fatigue of elite Canadian university hockey players.
2. Results may be affected by participant's nutrition, sleep habits, school work load, and daily stressors.

1.7 Strengths

Both sexes were represented, one team for each sex, in this project. The two teams were playing at the same elite level of their sport, were both national ranked in the top ten and came from a top-ranked school, which suggested strong academic and athletics ambitions. Both teams have had success in the past, which suggests a winning culture and attention to detail to strive their goal. The level of the players that participated in the study makes the findings of interest to elite hockey teams.

Chapter 2- Review of Literature

Performance and health are valued in collegiate sports. These aspects can be influenced by physiological and psychological factors. This literature review gives an overview of the sport of ice hockey and examines physical fitness attributes (i.e. physiological response and body composition) in ice hockey players. Although many variables are not within the control of health care professionals, coaches, or student-athletes, managing academic and athletic training schedules are two variables that are manageable and can affect performance and physical fitness of the collegiate ice hockey players over the course of a season. This literature review also includes sections on sex-differences in sport performance, internal load perception and an overview of collegiate athletes in North America and especially collegiate hockey players in Canada. Figure 2.1 illustrates different life components/variables that can affect the health and performance of a hockey student-athlete.

Figure 1 Potential variables affecting health and performance

2.1. Physiological Demands and Injuries in Ice Hockey

Ice hockey is a sport that requires elite players to perform 30 to 80 second high-intensity shifts followed by inactive rest periods of two to five minutes (Montgomery, 1988). It is characterized by rapid directional changes involving stopping, backward skating, and lateral movements (Twist & Rhodes, 1993a). Twenty skaters will wear the official game uniform (i.e. 12 forwards, 6 defenseman, 2 goalies) and play between 15 to 20 minutes per game (Skahan, 2016). To achieve peak performance, players need to develop their aerobic and anaerobic capacities (Cox et al., 1995; Montgomery, 1988). The energy used by the player during the on-ice presence will primarily come from anaerobic metabolism and regeneration between shifts will primarily rely on the aerobic system (Green & Houston, 1974; Montgomery, 1988; Skahan, 2016; Twist & Rhodes, 1993b). Other sport-specific fitness components are required, including; power, strength agility, muscular endurance, and flexibility (Twist & Rhodes, 1993a).

In ice hockey, high-speed collisions are occurring throughout the entire game (Montgomery, 1988). As a result, players are often subjected to various forms of injury. Concussions are the most common followed by knee injuries, shoulder injuries, and ankle injuries (Flik, 2005). Preliminary findings show that injuries tend to occur towards the end of the game in the second or third period, suggesting that fatigue may play an important role (Agel & Harvey, 2010).

2.2 Physical Fitness Attributes

Specific physical fitness attributes are associated with high performance in hockey players (Green, Pivarnik, Carrier, & Womack, 2006; Montgomery, 1988; Ransdell & Murray, 2011). The physical characteristics that are needed to perform at the elite level can vary dependent on the position played and style of play (Green & Houston, 1974; Montgomery, 1988; Twist & Rhodes, 1993a). Some characteristics are uncontrollable (i.e. genetics), but most of these attributes are controllable (i.e. trainable) and can be evaluated precisely using advanced technology. Fitness level and metabolic profiles of an ice hockey player have a tendency to fluctuate over the competitive season, which may result in a change in performance (Green et al., 2010; Stanula et al., 2016; Twist & Rhodes, 1993a). Physical fitness is considered to be a set of attributes that a person has or can achieve (Caspersen et al., 1985). Physical fitness components often evaluated in ice hockey players include cardiorespiratory endurance, muscular endurance, muscular strength, body composition, and flexibility (Nightingale, Miller, & Turner, 2013; Vescovi, Murray, Fiala, & VanHeest, 2006).

There are two common ways that elite sport organizations use to evaluate physical fitness. Most often, physical evaluation is completed prior to a competitive season in collegiate sports, such as ice hockey. The primary purpose of a pre-season fitness evaluation is to determine if the players have made progress during the off-season (Prokop, Duncan, & Andersen, 2015) and to aid in the selection of athletes that will be on the team roster (Nightingale et al., 2013). Tests are conducted to evaluate attributes such as muscular strength, body composition, anaerobic capacity, muscular power, cardiovascular endurance, flexibility, and muscular endurance because those physical fitness attributes were linked to team success (Ransdell et al., 2013) and players' performance (Roczniok et al., 2016). On the other hand, the new trend is to monitor different attributes of physical fitness to ensure fatigue management and optimal performance in- and off-season training (Halson, 2014; Taylor et al., 2012; Thorpe et al., 2017; Thorpe et al., 2015). Two types of training loads can be monitored: internal and external load. The external load would be the result obtained by the work accomplished by the athletes, while internal load would be the physiological response to the external load (Halson, 2014). An increased number of organizations started to work with monitoring assessments during the playing season which are designed to evaluate progress and maintenance of physical abilities (Ebben, Carroll, & Simenz, 2004; Halson, 2014; Taylor et al., 2012). Taylor, Chapman, et al. (2012), surveyed exercise scientists and coaches of high-performance programs to identify their best athlete monitoring practices. Different performance tests have been used to track hockey players, including; submaximal running/cycling tests, jump tests, strength assessments, sprint tests, and sport-specific monitoring. Information gained through these fitness tests help maintain and improve athlete's health, well-being and performance.

2.2.1 Physiological Response

Multiple physiological characteristics such as aerobic and anaerobic power, cardiorespiratory fitness, body composition, and muscle tissue have been investigated in hockey research evaluating the relation of off-ice tests with on-ice performance (Montgomery, 1988; Nightingale et al., 2013; Quinney et al., 2008; Roczniok et al., 2016). Specific physiological parameters can indicate the internal response to a specialized training program for elite hockey players (Cox et al., 1995). These physiological responses can be measured by maximal and submaximal assessments (Halson, 2014). Past studies have evaluated seasonal either changes of HR, BL, cellular activity, pulmonary function and rate of perceived exertion (Cox, 1993; Durocher, Leetun, & Carter, 2008; Green et al., 2010; Green & Houston, 1974; Halson, 2014; Koutedakis, 1995). Physiological response fluctuated depending on the parameters used and the level of play, which suggest that the stress imposed by the season would affect physical fitness level.

Cox, Miles, et al. (1995) evaluated the HR and the BL level during a submaximal exercise test to determine if the hockey players were detraining over the season. The work rate was based on their lactate threshold during a 5-min steady-rate cycle ergometer protocol, and the observations were made 4 times on 16 NHL players. They found a constant rise in lactate for a given work rate over the season; however, an only statistically significant difference was observed during session 4 (Figure 2). The investigators suggested that the physiological stress imposed on the NHL players may not be high enough to maintain their level of physiological fitness achieved in the off-season.

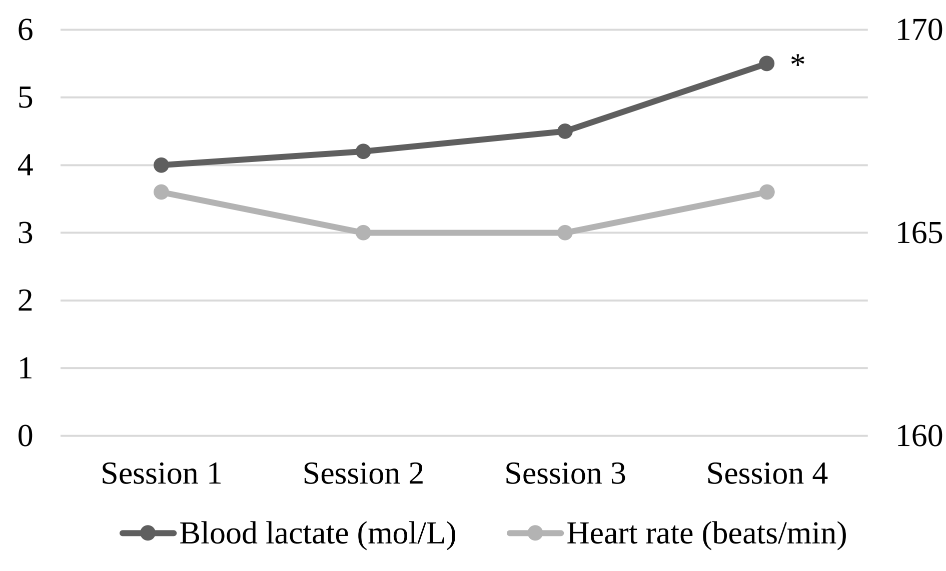

Figure 2 Evolution of the HR and the BL during an NHL season (Cox et al., 1995)

Green et al. (2012) studied cellular responses in skeletal muscle during a season of ice hockey among elite male Canadian university players. They showed that hockey player's muscles were atrophying during their season and suggested that the short time of recovery between games and practices that the players have may lead to fatigue and lack of physiological adaptations (Green et al., 2010; Green et al., 2012). In opposition to the aforementioned study, they investigator proposed that the negative adaptations were produced by an overload of stress imposed during the season.

Durocher, Leetun, et al. (2008) examined the evolution of lactate threshold and maximal aerobic capacity with a sport-specific skating protocol among NCAA Division I collegiate athletes. They found that lactate threshold increased from PS to MS when it was considered with the skating velocity, but not when evaluated as a percentage of HR max. Also, they showed that $\dot{V}O_2max$ decreased from PS to ES and that RPE may be associated with the physical workload in hockey players.

Technology has allowed strength and conditioning coaches to perform simple laboratory assessment on the field. Cycling and running are two methods of assessment that are not sport specific to ice hockey, but are easier to administer because of the cost and often unavailability of the ice. The type of training should be taken into account when deciding the modality of testing to account for different training during the off-season, pre-season and in-season.

The following subsections are reviewing physiological parameters to assess physical fitness. HR and BL were selected because they recurred in the hockey literature and they can be used for field testing by team strength and conditioning specialists. RPE was added to gain more information on the internal load experienced by the athletes during physical effort.

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2.2.1.1 Heart Rate

HR is the measure of beats per minute of the heart. There is a linear relationship between HR and the rate of oxygen consumption during steady-state exercise. The rise in HR during exercise is the result of increased sympathetic activity in combination with a reduction of parasympathetic activity. Also, the opposing activity of the autonomic nervous system is responsible for the HR recovery at the cessation of exercise (Halson, 2014). All these measures are physiological responses that assess cardiac function. The ability to reach high HR under maximal intensity is known to be an important characteristic of cardiorespiratory fitness. Nevertheless, HR can indicate fitness level at the submaximal effort and rest. Increase in HR at fixed submaximal effort would indicate a decrease in fitness level, such as efficiency of blood to get to the muscle and efficiency of the heart to pump blood (Cox et al., 1995; Schmitt et al., 2013). An athlete's HR has often been used to assess training status, however HR can be affected by other factors such as hydration status or caffeine consumption (Powers, 2014). In addition, HR can be measured during recovery enabling it to monitor changes in endurance, performance, and to determine if the training load is adequate for the athlete (Lamberts, Rietjens, Tijdink, Noakes, & Lambert, 2010; Lamberts, Swart, Capostagno, Noakes, & Lambert, 2010).

The game of ice hockey requires short bursts of effort with a player's peak HR exceeding 90% of HR maximum and with an average on-ice value of 85% of HR maximum (Montgomery, 1988; Twist & Rhodes, 1993b). A recent study looking at the HR found that there was a difference between forwards and defensemen in intensity during the game. In contradiction with Montgomery (1988), they are both spending most of the game at low intensity, which is considered approximately 75-80% of HR maximum and under the ventilatory threshold. However, players spend more time in higher intensity zones as the game advance, which could be caused by the accumulation of fatigue (Stanula et al., 2016). Another study examining the work and HR evolution during university women's ice hockey game found that a majority of the time the game is played at low to moderate-intensity, but with a high HR response. This is indicating substantial cardiovascular demand at submaximal and maximal levels in ice hockey (Jackson, Snydmiller, Game, Gervais, & Bell, 2016). The ability to maintain a low HR during submaximal effort indicate high level of physical fitness and may be important to ensure consistency of performance over the game and the season in ice hockey players.

2.2.1.2 Blood Lactate

Anaerobic metabolism is a central component of the bioenergetic function of a hockey player (Green & Houston, 1974; Montgomery, 1988). BL concentration is known as being an important marker of anaerobic metabolism (McArdle, Katch, & Katch, 2010; Powers, 2014) lactate being the terminal substrate of this energy pathway. Under high-intensity, skeletal muscles will produce pyruvate which will be reduced to lactate in the absence of oxygen (McArdle et al., 2010; Powers, 2014). Lactate accumulates in the blood when the rate of production is faster than the removal. The ability to produce a high quantity of lactate at maximal effort is a good indicator high anaerobic power.

However, the increase in lactate threshold might be more beneficial to on-ice performance (Durocher et al., 2008). Lactate threshold is the highest level that lactate can accumulate before a sudden substantial raise, seen from the result of the shift from aerobic energy supply to anaerobic energy supply. The second threshold is approximately 4 mmol/L of BL where a major increase happens, and this is termed onset of blood lactate accumulation (McArdle et al., 2010; Powers, 2014). While the ability to produce high quantity of BL is associated with high anaerobic power during maximal effort, limited production of BL during submaximal effort is associated with reliance on the oxidative energy pathway. BL is often associated with objective and subjective fatigue when muscle contraction is repeated and muscle force declines (Cairns, 2006). H^+ (the by-product of lactate) might be responsible for the decline in muscle force production. Nevertheless, BL remains an excellent physiological marker of physical fitness and fatigue due to the role played in energy systems (La Monica et al., 2015). Figure 3 shows how BL reacts to a different work rate.

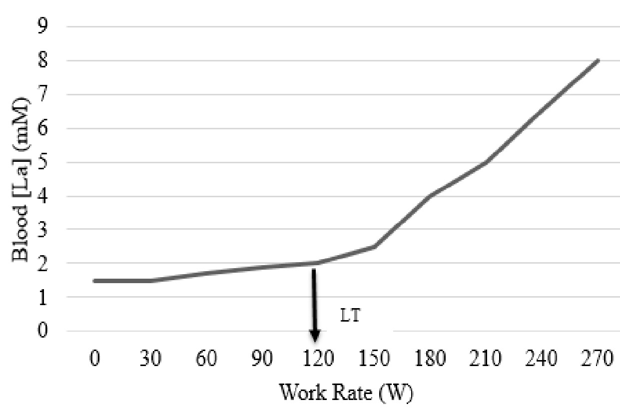

Figure 3 Reaction of BL to workload (Smith, Skelton, Kremer, Pascoe, & Gladden, 1997)

Ice hockey requires many muscles to be coordinated under a high level of effort and it has been suggested that lactate accumulation may be associated with a decline in performance (Green et al., 1976; Montgomery, 1988; Noonan, 2010). Also, it has been shown that during a hockey game there is a high variability of BL production due to the variation in intensity levels because highly variable high-intensity with values ranging from 4.4 to 13.7 mmol/L (Noonan, 2010). The ability to maintain a low BL concentration during submaximal effort indicate a high level of physical fitness and may be important to ensure consistency of performance over the game and the season in ice hockey players.

2.2.1.3 Rate of Perceived Exertion

RPE is an indicator of individual's degree of physical strain (Borg, Hassmén, & Lagerström, 1987) based on the comprehension that athletes can have on the physiological stress imposed on their bodies by exercise (Borresen & Lambert, 2009). RPE is reported verbally during exercise by the athlete using a scale system. A variety of scaling systems exist; however, the "Borg 6-20 RPE scale" is the most commonly used in the general population (Borresen & Lambert, 2009). It has been previously demonstrated that RPE correlates with HR during steady-state and short sprints executed on a cycle ergometer (Borg et al., 1987; Borresen & Lambert, 2009; Halson, 2014). The ratio of HR-RPE may be a useful tool providing insight on internal load imposed to the athlete (Halson, 2014). Afterward, RPE has been shown to be a valid indicator of BL concentration (Halson, 2014). An investigation looking at the difference between RPE in upper versus lower body exercises demonstrated that the relationship between RPE and BL has a negative acceleration (Borresen & Lambert, 2009). Same as with the HR, BL-

RPE ratio is useful in identifying internal load and fatigue (Halson, 2014; Snyder et al., 1993). HR-RPE and BL-RPE ratios will be termed internal load perception ratios in this thesis.

In recent years, periodization and monitoring athletes have become popular in the strength and conditioning field. RPE has become more frequently used to assess the stress imposed on the athlete. This method is often used to monitor the perception of effort under submaximal and maximal effort during individual exercise testing session (Lamberts, Rietjens, et al., 2010). A study monitoring fitness, fatigue, and running performance during pre-season training camp in Australian football players used RPE to monitor total training load, which is a valid method of estimating this parameter in team sports (Buchheit et al., 2013). In summary, RPE may be of importance to quantify perception of the athlete's physiological stress imposed by exercise, especially in relation to other physiological parameters, such as HR and BL.

2.2.2 Body Composition

Body composition is another physical fitness attributes that can influence physical fitness. Body composition can impact the performance of elite athletes (Ackland et al., 2012) and is useful in evaluating a variety of health attributes (Montague & O'rahilly, 2000; Moore, Durstine, & Painter, 2016). In the past, skinfold measurements were used to estimate body fat percentage in ice hockey players (Montgomery, 2006; Vescovi et al., 2006). A current gold standard for body composition assessment is the dual energy X-ray absorptiometry ((DXA; (Bray & Bouchard, 2014)) a laboratory method used in the hockey research (Henriksson, Vescovi, Fjellman-Wiklund, & Gilenstam, 2016; Prokop et al., 2016). DXA accurately measures body composition (i.e. fat mass, fat-free mass, lean mass) and bone density (Ackland et al., 2012; Bilsborough et al., 2014). Body fat percentage was used to establish player norms (Montgomery, 2006) and to help form teams (Roczniok et al., 2016).

Recently, body composition profiles of elite male collegiate hockey players in Canada have been tracked over time during the off- and in-season time periods to observe possible fluctuations. Significant increases were found in fat tissue from ES to PS; however, the opposite was observed from PS to MS (Prokop et al., 2016). Stress imposed by the sport of hockey showed positive adaptations in body composition during the first half of the competitive season. Further investigation is needed to observe if these adaptations will be maintained over the second half.

Due to the limited information on seasonal changes in body composition in ice hockey players, investigations on other sports were included in the literature review. A study assessing in-season body composition of NCAA Division I soccer players with a DXA scanner showed positive changes in total mass and lean mass (Silvestre et al., 2006). This study suggested that improvement in body composition profile were observed after the stress imposed by a competitive soccer season.

A longitudinal study (3 years) was conducted among female NCAA Division I athletes of different sports (i.e. volleyball, soccer, basketball, swimming, track). They revealed an increase in fat mass in basketball players and an increase in lean mass in volleyball players after the three-year study, suggesting that body composition can change over the years and therefore may lead to health consequences in student-athletes (Stanforth et al., 2014). Trainers, coaches, players, nutritionists, and strength and conditioning specialists may work together to maintain optimal playing body composition of their student-athletes throughout the year to sustain high-performance level, reduce injury risk and enhance their general health and well-being.

The body composition of athletes seems to be different between sports (Baechle & Earle, 2008; Jeukendrup & Gleeson, 2010) and fluctuations were reported to be dissimilar (Stanforth et al., 2014). Ice hockey is a high-intensity sport that requires athletes to be fast and strong due to the speed of the game, the high physiological demands and the physicality of the sport (Montgomery, 1988). Both male and female ice hockey players with relative lean body mass values were associated with an increase in skating speed (Gilenstam, Thorsen, & Henriksson-Larsén, 2011) while an increase in body fat was moderately correlated with diminished speed (Potteiger, Smith, Maier, & Foster, 2010). These are important correlations that can have an impact in the hockey community, however, the findings mentioned above are only representative of pre-season performance as there is few information on how body composition profiles are changing throughout the season. This information is crucial and could help maintain optimal sport-specific performance and reduce injury risk of ice hockey players.

2.3 Between-Sex Differences in Sport Performance

Recently, female ice hockey is growing in popularity (Auster, 2008), however, there is minimal information on the evolution of their physiological response and body composition profiles in comparison to their male counterparts. In general, Male subjects have been found to have a higher $\dot{V}O_{2max}$, ventilatory threshold, and onset of BL accumulation for similar relative performance level, which could be explained by the larger muscle mass and greater cardiac dimensions (Shephard, 2000). However, the physiological parameters mentioned above seem to be significantly higher for females when exercise is done at a submaximal level. Maximal pulse rate has been found to be similar in both men and women, however, females tend to have a higher HR during exercise at submaximal work (Maldonado-Martin et al., 2004). Maximal pulse rate has been found to be similar in both men and women, however, females tend to have a higher HR during exercise at submaximal work. Moreover, research demonstrates that males and females have sex-specific body composition profiles, aerobic and anaerobic properties, where males are usually taller, heavier, with larger muscle mass and cross-sectional area, lower body fat content, greater adrenergic stimulation and muscle BL accumulation (Esbjörnsson-Liljedahl, Bodin, & Jansson, 2002; Jacobs, Tesch, Bar-Or, Karlsson, & Dotan, 1983; McArdle et al., 2010; Robbins et al., 2009).

In ice hockey, Gilenstam et al. (2011) investigated the relationship between physiological off-ice tests and on-ice performances in male and females. They showed that off-ice fitness predicted skating performance in females, but not for males. All the background variables such as anthropometric measures, body composition, muscle strength, agility, sprinting ability and aerobic performance were significantly different between sexes. Between-sex differences in off-ice variables were reduced when values were related to lean body mass. Physiological sex differences justify an investigation on a similar population to gain a better understanding and implement sex-specific training and academic program.

2.4 Internal Load Perception

Internal load is considered the relative physiological and psychological stress imposed on the athlete which may be important in monitoring fatigue and in determining future adaptations. Fatigue is a complex phenomenon that can be associated with by multiple mechanisms. Fatigue can have different definitions, and it is known to be affected by a variety of factors (Halson, 2014). Monitoring elite athletes' response to stress and wellness is of interest to coaches and practitioners to gather valuable information in their applied environment (Gastin, Meyer, & Robinson, 2013; Thorpe et al., 2017).

Internal load perception represents how an athlete can perceive the physiological stress imposed on the body, which is important for fatigue monitoring. HR-RPE and BL-RPE ratios can provide insight on internal load imposed to the athlete (Halson, 2014). Few studies investigated these ratios even though RPE is related to HR and BL concentration (Borresen & Lambert, 2009; Martin & Andersen, 2000; Snyder et al., 1993). Martin and Andersen (2000) investigated the relationship between HR and RPE in cyclists and found that RPE was greater at any given HR after periods of high intensity. These results suggested that under fatigue cyclists rated their effort higher for the same objective measure of physiological stress. Also, Snyder, Jeukendrup, et al. (1993) showed that the HR-BL ratio declined during overtraining among competitive cyclists. Internal load perception ratios may be of interest for strength and conditioning specialists because it regroups physiological and psychological aspects under the same measure and has proven relationships with well-known physiological parameters.

Another method to measure load or fatigue can the use of questionnaires. Different questionnaires (i.e. POMS, DALDA, TQR, and REST-Q) have been used to assess elite athletes by researchers in order to determine self-reported measures of training load and fatigue (Thorpe et al., 2017). These measures are valued because they determine athletes' perception. Often, sport scientists and strength coaches have limited time with athletes and questionnaires are habitually extensive and time-consuming. This prevents their use on a regular (e.g. daily, weekly) basis (Thorpe et al., 2017) and has the potential to decrease the athlete's commitment level (Beckmann & Kellmann, 2003). Due to the aforementioned constraints, customized questionnaires have been adopted by multiple teams that target desired aspects and are shorter in duration (Taylor et al., 2012). Saw et al. (2015) showed that self-reported measures had greater sensitivity compared to objective measures for acute and chronic training loads (Saw et al., 2015). With inadequate recovery after excessive constant loading, the athletes' condition can decline on the well-being continuum ((Figure 4;(Schwellnus et al., 2016)). Exercise scientists, strength and conditioning specialists and coaches should implement strategies of physical training to promote physiological adaptations and avoid fatigue in collegiate athletes.

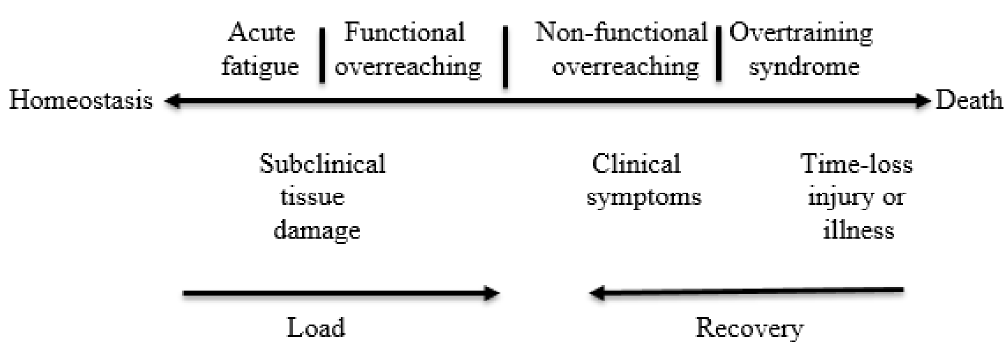

Figure 4 Well-being Continuum (Schwellnus et al., 2016)

2.4 Brief Overview of Collegiate Athletes in North America

Collegiate athletes are registered under two governing bodies in North America: U-Sports and NCAA. U-Sports governs inter-university sports in Canada, whereas the NCAA is responsible for the United States. University hockey is a way for hockey players to complete their studies while competing at the highest non-professional hockey level. This level can be a stepping-stone for their future professional hockey careers in North America or Europe.

In comparison to major junior leagues in Canada, NCAA, or professional teams, U-Sports has a financial disadvantage. This league allows student-athletes to participate in competitive sports while completing their studies. Also, the U-Sports team budgets, as well as scholarships and facilities are significantly less than in the NCAA and professional ice hockey teams. The main goal of the U-Sports student-athletes may be different from the NCAA student-athletes.

A collegiate hockey team in Canada will practice regularly 3-4 times and play 2 games per week. Additionally, 1 to 3 off-ice sessions will be held depending on the program and the time of the year. PS begins early September and ends the beginning of October. Half of the regular season is played from October to early December, and the remaining half is played from January to mid-February. Thereafter, playoffs start and last approximately one month.

Two important aspects of the university student-athlete's life are sport performance and health. Sport performance is defined as maintaining high-level play, while health is defined as 'a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity' (World Health Organization, 2014).

Sport performance and health at the university level have been linked to athletic participation, academic success and improve social experiences (Etzel, 2006; Miller & Kerr, 2002). Most collegiate sport performance studies have been done among NCAA players, therefore there is a need for a growing body of research in Canadian collegiate athletes.

Chapter 3 – Methods

The primary objective of the study was to identity changes in physical fitness attributes (i.e. physiological response and body composition profiles) during the competitive season in male and female elite university student-athletes. The second objective of the investigation was to explore between-sex differences of physical fitness attribute changes. The third objective of this study was to identity changes in internal load and fatigue perception.

3.1 Participants

Fifty-two players enrolled in the study. Forty-four elite Canadian collegiate hockey players, twenty-seven males (age = 22.7 ± 1.3 years, height = 1.82 ± 0.6 m, weight = 86.87 ± 6.44 kg) and twenty-two females (age = 19.9 ± 1.8 years, height = 1.66 ± 0.7 m, weight = 68.76 ± 5.91 kg) completed this investigation. All participants were members of the men's and women's varsity hockey team from McGill University and were aged 18 years and over. The participants were eligible to participate in the study if they were free from a long-term injury keeping that would prevent them from participating in over 75% of the team's practices, training session, and games. Recruitment for the study was done in person, with the agreement of the coaches of both teams, following a McGill varsity hockey team practice during the pre-season. The McGill University, Department of Medicine Institutional Review board approved the research protocol. All the players gave written informed consent prior to participation in this investigation.

3.2 Timeline

Three assessments at different time-points (i.e. first week of September [PS], first week of December [MS], third week of March [ES]), corresponding to the beginning, the end of the first half of the season and the end of the season, evaluated the players' physical fitness attributes and internal load perception. PS, MS and ES time-points were chosen to divide the season into two portions and establish possible trends in the different parts of the season.

Testing sessions were scheduled at the convenience of the student-athletes during the morning (i.e. 8:00 A.M.-12:00 P.M.) and testing times were the same for all three sessions. The first time-point was scheduled during the pre-season (i.e. first week of September). The second time-point was scheduled for the first week of December, which was the end of the fall semester. The third and last time-point was scheduled the week following the last game of both teams (i.e. third week of March). During testing sessions, participants underwent anthropometric assessment, a whole-body DXA scan, filled out a questionnaire, and participated in a 4-minute submaximal cycling exercise test. During the pre-season and the season, the varsity hockey student-athletes participated in regular practices (45-90 minutes on-ice practice) five days per week, two weight training sessions (30-40 minutes) per week, and a regular physical testing session (not including $\dot{V}O_{2max}$ test). The weekly schedule of the men's team is as follows: Monday to Thursday practices, Friday and Saturday games, and Sunday is off. The weekly schedule of the women's team is as follows: Monday is a day off, Tuesday to Thursday are practice days, Friday and Sunday are game days, and Saturday can be either a practice day or a day off.

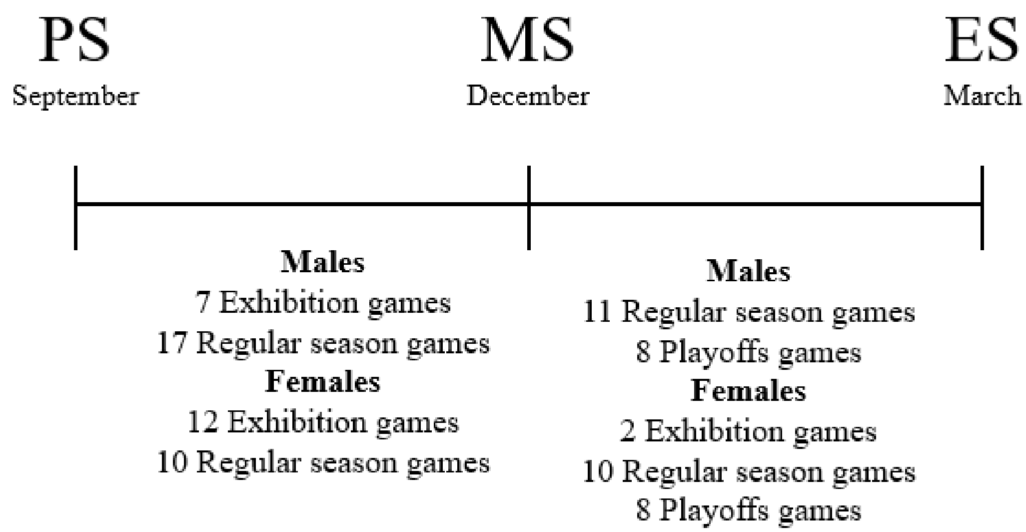

Figure 1 Season timeline

3.3 Anthropometric assessment

Player's height was measured to the nearest centimeter using a Seca 216 wall-mounted stadiometer, and weight was assessed to the nearest 10th of a kilogram using a Seca 635 platform (Seca, Birmingham, UK) following the American College of Sports Medicine's guidelines (ACSM, 2013).

3.4 Body composition

Body composition was assessed using a Lunar DXA^{TM} scanner (Dual Energy X-Ray Absorptiometry, General Electric Encore 11.20; Madison, Wis., USA), and matching software (GE's Lunar software enCORE^{TM} v13.60 was used to estimate whole body and regional body composition. This method is considered to be a gold standard, as well as one of the most accurate for evaluating body composition (Bray & Bouchard, 2014; Delisle-Houde et al., 2017). To ensure the precision of the DXA Scan, the machine was calibrated each day before the first scan of the day (Bray & Bouchard, 2014).

Participants wore standardized athletic shorts and t-shirts and removed all metal (i.e. necklaces, rings, watches). Participants placed themselves in the middle of the scanning bed's box in an anatomical, supine position. The technician ensured that their positioning was correct and centered with the scanning bed's longitudinal midline, and strapped the ankles with a Velcro strap, resulting in the player's feet being angled slightly inward. The subjects were asked to lay still during the entire assessment and to keep the initial distance between limb to avoid crossover during the analysis (Bilsborough et al., 2014; Delisle-Houde et al., 2017).

3.5 Player's Questionnaire

Subjective fatigue was the psychological variable evaluated, and the questionnaire has been included in the appendix. Subjective fatigue was assessed using the Chalder Fatigue Scale, which has two distinct parts: physical and mental fatigue (Chalder et al., 1993). This scale was validated using a sample of participants aged between 18-45 years old and demonstrating an internal consistency ranging from .88 to .90 and a validity of .85 (Chalder et al., 1993; Shahid, Wilkinson, Marcu, & Shapiro, 2011). The questionnaire was chosen because it fit the operational definition of subjective fatigue and has been found to be valid and reliable for healthy adults. Moreover, they are short and easy to complete and gave insight on the general perception of fatigue. These are important criteria when monitoring athletes due to the short amount of time they have available since the questionnaires used with athletes in the literature take a significant amount of time to complete (Thorpe et al., 2017). The questionnaire was also used to determine if the player's perception of their internal load corresponded to the subjective fatigue level throughout the season.

3.5.1 Chalder Fatigue Scale

The Chalder Fatigue Scale is made up of 14 questions divided into two parts. The first part addresses physical symptoms and is composed of eight questions. The second part addresses the mental symptoms of fatigue and is composed of six questions. The objective of this questionnaire was to determine how the players perceived their fatigue over the course of the first half of the competitive season. Additionally, it was possible to observe the evolution of the perception of fatigue and make a link with physical fitness attributes and well-being scores. The players' subjective fatigue on the Chalder Fatigue Scale was measured on a four-point scale. The participants will indicate how they feel for 14-item questions: (a) = Better than usual, (b) = No more than usual, (c) = Worse than usual, and (d) = Much worse than usual. Players' Chalder Fatigue Scale score were given a total, which was compared to the following assessments.

3.6 4-minute Submaximal Exercise Test

The physiological response was evaluated using a submaximal cycling exercise test because it was an easy and non-fatiguing test to observe physiological parameters evolution throughout the season. This test was easy to administer and might be of further use for testing athletes. Submaximal effort was assessed using a 4-minute submaximal cycling exercise test at an approximation of 75% of the established $\dot{V}O_2max$ value for male and female elite ice hockey players (i.e. male: 54 ml/min/kg, female: 46 ml/min/kg;

(Cox et al., 1995; Montgomery, 1988; Ransdell et al., 2013)). The power output (resistance) applied during the submaximal cycling exercise test was determined using Equation 3.1, considering the body mass (kg) of the individual at pre-season. Maximal effort was avoided in this study that was trying to observe changes in physical fitness attributes and internal load in hockey players to limit additional workload from non-hockey related physiological stress. The four minutes duration was based on the time used to reach steady-state in other maximal or submaximal tests (Baechle & Earle, 2008). 75% of the players' estimated average capacity was based on the statistics that hockey players spend their ice-time at, on average, 85% of their maximal heart rate (Montgomery, 1988), which in theory represents 75% of their maximal oxygen consumption (Baechle & Earle, 2008).

$$\dot{V}O_2 \text{ (ml/kg/min)} = [(10.8 \text{ x } (\text{power output} \div \text{body mass})] + 7$$

Equation 1 Estimate average steady state VO_2 cost of cycling (Balady, 2013)

The participants were asked to sit on a cycle ergometer and adjust their seat so that their bottom leg was straight when their heel was strapped into the pedal (Baechle & Earle, 2008). Then the participant pedaled for 2 minutes at a power output of 50 watts to warm-up. After that, the resistance was set at 75% of their estimated maximal oxygen consumption capacity for four minutes, while heart rate and rate of perceived exertion were recorded every minute during the test. After the four minutes, a recovery session was performed. The recovery session consisted of sitting on a chair beside the cycle ergometer, for two minutes while heart rate was recorded every minute. Blood lactate was measured 3 minutes after the cycle ergometer test was completed. Participants were instructed to maintain a cadence of 70 rpm throughout the test.

3.6.1 Heart Rate Assessment

Heart rate was assessed using a Heart Rate Polar Monitor (Polar Electro Oy, Kempele, Finland). The device was placed at the level of the sternum and just below the nipple for the males and under the breast for females. A matching watch was synchronized with the device and it was kept in close distance to the participant. The heart rate was recorded at rest, at time zero after the two-minute warm-up, at each minute of the test, and at every minute of the recovery period.

3.6.2 Blood Lactate Assessment

Blood lactate was assessed using a Portable "Lactate Scout" (Vacumetrics Inc., Ventura, CA, USA). After the 4-minute submaximal cycling exercise test, the participants were asked to sit quietly in a chair for three minutes. At the three-minute mark, an auto-lancet punctured the index finger to obtain several drops of whole blood. Subsequently, a small quantity (~0.2 μl) of blood using a strip was then inserted into the lactate analyzer. Within fifteen seconds, results appeared on the Lactate Scout Portable Lactate Analyzer (Waller, Robinson, Holman, & Gersick, 2016).

3.6.3 Rate of Perceived Exertion

RPE was evaluated using a 6-20 Borg Scale (Borg et al., 1987). The chart was colored and used images to help the participant identify their status. The scale was situated at a comfortable place for the participant so that they could easily see and either point at a number or say it aloud. The rate of perceived exertion was asked and recorded at rest, at time zero, after the two-minute warm-up, and after each minute of the test.

3.7 Training log

The training log assessed intensity, type, and duration of physical activity through a seven-day log. Athletes were given the log on the days they came to the lab for assessment, and their coaches collected it at a practice one week later. The training log was used to control sex-differences in training regimen.

3.8 Analysis

Data were collected by the research assistant using a heart rate monitor, a blood lactate analyzer, the Borg scale, and a DXA scanner and were analyzed using proprietary software (GE's Lunar software enCORE™ v13.60). The statistical software SPSS V.20 (IBM Corporation) was used for all analyses. Changes in the physiological parameters and body composition measures over the course of a university season at three different time-points (i.e. PS vs. MS vs. ES), were analyzed using two separate repeated measures ANCOVA for controlling for age. Least significant difference (LSD) post-hoc analyses were performed to evaluate the differences between specific time-points. Between-sex seasonal mean changes were analyzed using one-way ANOVA with sex as the independent variable. Also, internal load ratios were created by dividing heart rate and blood lactate by the corresponding RPE. HR-RPE ratios were calculated at each stage of the physiological test by dividing the respective physiological measure by the associated RPE. BL-RPE ratio was computed by dividing the post-exercise BL concentration by the 4^{th} minute (highest) RPE. Additionally, Chalder Fatigue Scale scores and fatigue ratios were compared over time. Changes in the fatigue ratio and subjective fatigue scores at the three time-points were analyzed using repeated measures ANCOVA controlling for age and sex. LSD post-hoc analyses were performed to evaluate the differences between specific time-points. Questionnaire scores were further used to determine if the player's perception of their subjective fatigue correspond to the evolution of their internal load ratios. Pearson correlations were used to investigate relationships among changes in subjective fatigue and the internal load ratios. We set α at $p \leq 0.05$.

Chapter 4

Manuscript 1

Seasonal changes in physiological responses and body composition during a competitive season in male and female elite collegiate ice hockey players

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Running Head: Physiological and body composition seasonal changes

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ABSTRACT

Ice hockey continually overloads athletes with limited time for recovery, which may affect several physiological responses and alter body composition. The purpose of this study was to identify changes in physiological parameters and body composition profiles over the competitive season in elite collegiate ice hockey players. Forty-four players, twenty-four males (age = 22.7 ± 1.3 years, height = 1.82 ± 0.6 m, weight = 86.87 ± 6.44 kg) and twenty females (age = 19.9 ± 1.8 years, height = 1.66 ± 0.7 m, weight = 68.76 ± 5.91 kg) participated in 4-minute submaximal exercise tests and body composition assessments at pre-season, mid-season, and end-season. Changes in physiological parameters and body composition were analyzed using repeated-measures ANCOVA controlling for age. Males' post-exercise blood lactate concentration decreased ($p \leq 0.05$) from pre- to mid-season (9.3 vs. 6.2 mmol/L) and increased ($p \leq 0.05$) from mid- to end-season (6.2 vs. 8.0 mmol/L). Heart rate increased ($p \leq 0.05$) after the 3rd and 4th minute of the submaximal test in both sexes from pre- to end-season and from mid- to end-season. Males' body fat percentage decreased ($p \leq 0.05$) from mid-season (17.4 vs. 16.1%), while increases were observed ($p \leq 0.05$) in both sexes from mid- to end-season. This study produced evidence that male and female collegiate hockey athletes' physiological responses and body composition profiles change over the season. Sport scientists working with collegiate hockey teams, may need to revise annual training programs to attenuate reductions in fitness and hopefully prevent injuries.

Key words: Heart rate, Blood lactate, Body fat, Physical fitness, Submaximal test

INTRODUCTION

Physiological stresses imposed by the energy demands of an ice hockey season affect body composition and physical performance response (Cox et al., 1995; Green et al., 1976; Green & Houston, 1974; Montgomery, 1988; Prokop et al., 2016). The ice hockey season has been shown to induce changes in the energetic capacities and associated functions of the body (Cox et al., 1995; Green et al., 2010; Green & Houston, 1974). In theory, the physiological stress imposed by the sprint nature of the sport should improve the anaerobic energy system (Green, 1987; Twist & Rhodes, 1993b) with a concomitant increase lean tissue mass (Green et al., 2010). Recent studies on cellular activity in hockey players demonstrate that chronic training imposes a continuous stress on athletes, and shifts their training status from acute fatigue to overreaching, and later overtraining (Coutts & Cormack, 2014; Green et al., 2010; Green et al., 2012). However, a relatively modest upregulation of oxidative and glycolytic pathways was observed. Also, an investigation on body composition assessments shows a decrease in fat mass and total body weight with no change in lean mass (Prokop et al., 2016) suggesting fluctuations over the season.

To prevent reductions in maximal performance and maintain general health, sport scientists and strength and conditioning specialists closely monitor their athletes (Taylor et al., 2012). Unlike professional athletes, collegiate athletes are typically not followed on a regular basis to determine the effect of a competitive season on their health and fitness. Elite collegiate hockey programs typically have similar demands for both sexes; however, student-athletes also struggle to balance academic obligations with their athletic duties and rigorous training regimes (Curry et al., 1997; Schellenberg, Gaudreau, & Crocker, 2013).

To date, no evidence suggests that collegiate hockey players have been monitored over the course of the season regarding physiological responses to exercise and body composition, in opposition to professional athletes where load monitoring is becoming a trend (Soligard et al., 2016; Taylor et al., 2012). Also, sex differences of the seasonal effects on ice hockey players are still unknown. Currently, traditional physical fitness assessments measure external loads, which quantify the work accomplished by the athletes without taking into consideration the internal physiological stress imposed on the body (Halson, 2014).

Ice hockey seems to continually overload athletes, with limited time for recovery (Green et al., 2010; Green et al., 2012), which may induce fatigue and affect several physiological parameters and body composition (Durocher et al., 2008; Green et al., 2010; Green & Houston, 1974; Kavazis & Wadsworth, 2014). Submaximal cycling exercise testing and dual energy X-ray absorptiometry (DXA) can respectively evaluate physiological stress imposed (i.e. heart rate, blood lactate concentration) and body composition profile fluctuations (Lamberts, Rietjens, et al., 2010; Lamberts, Swart, Noakes, & Lambert, 2011; Prokop et al., 2016; Taylor et al., 2012) without inducing additional maximal physiological stress to the body (Thorpe et al., 2017). Consequently, the primary aim of this study was to identify changes in the physiological parameters and body composition profiles of male and female collegiate ice hockey players over the competitive season. It was hypothesized that a player's physical fitness would decrease as the season progressed because student-athletes will accumulate fatigue from training and non-training stressors, which is associated with a decrease in performance capacity. The secondary aim of this study was to identify between-sex differences. It hypothesized that males would detrain more than the females.

METHODS

Experimental Approach to the Problem

During the season, players reported to the on-campus laboratory at three time points (i.e. pre-season, mid-season, and end-season) where they completed a whole-body DXA scan followed by a 4-minute submaximal cycling exercise test. All testing sessions were performed in the morning (i.e. 8:00 A.M.-12:00 P.M.) before team practice to accommodate players' academic and athletic schedules, in addition, providing approximately a full day of rest from previous practice before the assessments. Also, the timing of the session allowed players to avoid food consumption for 2-3 hours prior to tests. Training logs were used to gain insight into players' in-season training regimen. All participants included in the study participated in at least 75% of the mandatory on-ice practices of their respective teams.

Subjects

Fifty-two players enrolled in the study. Forty-four elite Canadian collegiate hockey players, twenty-four males (age = 22.7 ± 1.3 years, height = 1.82 ± 0.6 m, weight = 86.87 ± 6.44 kg) and twenty females (age = 19.9 ± 1.8 years, height = 1.66 ± 0.7 m, weight = 68.76 ± 5.91 kg) completed this study. The Medical Ethics Institutional Review Board of the university approved this study, and all players gave written, informed consent to participate in this study.

Procedures

Body composition assessment. Height was measured to the nearest centimeter using a Seca 216 wall-mounted stadiometer and weight was assessed to the nearest 10^{th} of a kilogram using a Seca 635 platform (Seca, Birmingham, UK) following the American College of Sports Medicine's guidelines (ACSM, 2013). DXA scan (General Electric Encore 11.20; Madison, Wis., USA) and corresponding software (GE's Lunar software enCORE v13.60) was used to assess body composition (i.e., fat mass (kg), lean mass (kg), visceral adipose tissue (kg)). Participants wore standardize athletic shorts and t-shirt and they were not allowed to wear metal (i.e. necklaces, rings, watches). They were instructed to lay in the middle of the scanning bed box in an anatomical supine position. The technician ensured that the position was adequate, centered with the scanning bed's longitudinal midline and strapped the ankles with a Velcro strap resulting in the player's feet turned slightly inward. The subjects were asked to stay still during the entire procedure and to keep the initial distance between limbs to avoid crossover during the analysis (Bilsborough et al., 2014).

4-minute submaximal exercise test. The 4-minute submaximal exercise test was performed at approximately 75% of the individual's maximal capacity on a cycle ergometer. The power output was determined using Equation 1 considering the body mass (kg) of the individual, as well as an approximation of their maximal oxygen capacity. Average $\dot{V}O_2max$ for males was previously established at 54 ml/min/kg, from unpublished data on this same hockey team in the past year and past studies (Cox et al., 1995; Montgomery, 1988) while average $\dot{V}O_2max$ for females has been set at 46 ml/min/kg using the literature (Ransdell et al., 2013). Maximal effort exercise testing was avoided in this study seeing as the aim was to observe changes in physiological responses and body composition profiles in hockey players, and not induce them through maximal testing. The goal was to limit additional workload and at the same time, limit non-hockey related stress. The duration of 4 minutes was based on the time used to reach steady-state in maximal or submaximal tests (Baechle & Earle, 2008). The 75% of the player's estimated average capacity was based on the statistics that hockey players spend the majority of their ice-time at on average 85% of their maximal heart rate (Montgomery, 1988), which in theory represent 75% of their maximal oxygen consumption (Baechle & Earle, 2008).

Equation 1. $\dot{V}O_2$ (ml/kg/min) = [(10.8 x (power output ÷ body mass)] + 7 (Balady, 2013)

Subject's body mass was previously measured before the DXA scan. The ergometer seat was adjusted so that the leg was straight when the heel was on the pedal and the pedal was closest to the ground (Baechle & Earle, 2008).A Polar Heart Rate Monitor was placed on their chest (Polar Electro Oy, Kempele, Finland) to measure heart rate. The participants pedaled for 2 minutes set at 50 watts at 70 revolutions per minute (rpm) to warm-up. The test started by increasing the resistance to 75% of their estimated $\dot{V}$

O_2max for 4 minutes. Participants' heart rate was recorded at each minute of the test. A cadence of 70 rpm was maintained for the duration of the test. After the 4-minute test, the participant sat quietly on a chair beside the cycle ergometer to recover and heart rate was recorded every minute. Post-exercise blood lactate was measured 3 minutes after the completion of the test. Blood was sampled by venipuncture of the fingertip to collect a small quantity (0.2 μl) of blood that was analyzed using the Lactate Scout Portable Lactate Analyzer (Vacumetrics Inc., Ventura, CA, USA), as previously described (Waller et al., 2016).

Statistical Analysis

Changes in physiological parameters and body composition measures over the course of a university season at three different time-points (i.e. pre-season, mid-season, and end-season) were analyzed using repeated measures ANCOVA controlling for age. Least significant difference (LSD) post-hoc analyses were performed to evaluate the differences between specific time-points. Between-sex seasonal mean changes were analyzed using one-way ANOVA. The statistical software SPSS V.22 (IBM Corporation) was used for all analyses and α was set at $p \leq 0.05$.

RESULTS

Participants' baseline and training characteristics are presented in Table 1. No between-sex differences were found between the number of strength training sessions, number of cardio sessions, and number of years played at university. Also, on average males played 3.65 ± 1.60 years in the Major Junior hockey league and 92% had Major Junior Experience, which is the highest level of hockey in Canada for players below the age of 20. This information was not available for female players because there is no equivalent league in Canada, however, 5 of the players participated in international competitions on the Canadian National hockey team.

Physiological responses. During the 4-minute submaximal exercise cycling test, after the 1st minutes of the test, heart rate increased ($p \leq 0.05$) increased by 5.8 bpm from mid- to end-season (131.4 vs. 137.1) in males. After the 2nd minute of the test, heart rate increased ($p \leq 0.05$) by 6.4 bpm from mid-season to end-season (142.6 vs. 149.0) in males and by 5.8 bpm from pre-season to end-season (155.4 vs. 161.1) in females. After the 3rd minute, heart rate increased ($p \leq 0.05$) by 6.0 bpm from pre- to end-season (149.6 vs. 155.6) and by 8.1 bpm from mid- to end-season (147.5 vs.155.6) in males, while in females it increased by 6.0 bpm from pre- to end-season (161.1 vs. 167.1) and by 4.6 bpm from mid- to end-season (162.5 vs. 167.1). After the 4th minute of the test, heart rate increased ($p \leq 0.05$) by 7.2 bpm from pre- to end-season (152.4 vs. 159.6) and by 8.9 bpm from mid- to end-season (150.7 vs.159.6) in males, while in females it increased by 3.2 bpm from pre- to mid-season (164.1 vs. 167.3) and by 6.5 bpm from pre- to end-season (164.1 vs. 170.6). After the 1st minute of recovery, heart rate increased ($p \leq 0.05$) by 10.2 bpm from pre- to end-season (106.5 vs. 116.7) and by 13.9 bpm from mid- to end-season (102.8 vs.116.7) in males, while in females it increased by 12.9 from pre- to end-season (114.9 vs. 127.7). After the 2nd minute of recovery, heart rate increased ($p \leq 0.05$) by 11.1 bpm from pre- to end-season (87.3 vs. 98.4) and by 15.3 bpm from mid- to end-season (83.1 vs. 98.4) in males, while in females it increased by 12.0 bpm from pre- to end-season (94.8 vs. 106.8) and by 9.0 from mid-season to end-season (97.8 vs. 106.8).

Males' post-exercise blood lactate concentration decreased ($p \leq 0.05$) from pre- to mid-season by 3.1 mmol/L (9.3 vs. 6.2) and increased ($p \leq 0.05$) by 1.8 mmol/L from mid- to end-season (6.2 vs. 8.0). Females' post-exercise blood lactate concentration increased by 1.9 mmol/L from pre- to end-season (7.6 vs. 9.4) and by 2.7 mmol/L from mid- to end-season (6.7 vs. 9.4). Also, there was an interaction between time and sex for post-exercise blood lactate concentration ($F(2, 82) = 5.298$, $p \leq 0.05$). Figures 1 and 2 illustrate the heart rate and blood lactate seasonal fluctuations, respectively. Seasonal mean difference variations for heart rate after the 4th minute of the test in-between pre- to mid-season ($F(1, 43) = 4.168$, $p \leq 0.05$) and mid- to end-season ($F(1, 43) = 4.898$, $p \leq 0.05$) were significantly different between sexes. Post-exercise blood lactate concentration mean differences were significantly different between males and females from pre- to mid-season ($F(1, 43) =5.309$, $p \leq 0.05$) and pre- to end-season ($F(1, 43) = 8.294$, $p \leq 0.05$).

Body composition profiles. Males' body fat percentage decreased ($p \leq 0.05$) by 1.2% from pre- to mid-season (17.4 vs. 16.1) and increased ($p \leq 0.05$) by 1.2% from mid- to end-season (16.1 vs. 17.3). Among females, body fat percentage increased ($p \leq 0.05$) by 1.3% from pre- to end-season (25.5 vs. 26.8) and by 1.2% from mid- to end-season (25.6 vs. 26.8). Visceral fat mass decreased ($p \leq 0.05$) by 0.027 kg among females at mid-season in comparison with pre-season (0.077 vs. 0.050). Males' fat mass increased ($p \leq 0.05$) by 1.190 kg from mid- to end-season (1.348 vs. 1.467), while females increased (p

≤ 0.05) their fat mass by 1.1 kg from mid- to end-season (15.9 vs.17.0). Body fat percentage, visceral fat mass, lean mass, and fat mass changes are displayed in Figure 3, 4, 5, and 6 respectively. Body fat percentage changes were significantly different between males and females from pre- to mid-season ($F(1, 43) = 6.843$, $p \leq 0.05$) and pre- to end-season ($F(1, 43) = 4.077$, $p \leq 0.05$).

DISCUSSION

The present investigation aimed to identify changes in physiological parameters and body composition profiles over the competitive season in male and female collegiate ice hockey players and to identify between-sex differences. The main findings of this study were that 1) from pre- to mid-season, elite male collegiate ice hockey players decreased their post-exercise blood lactate concentration assessed with a submaximal cycling exercise test and their percentage of body fat, 2) from mid- to end-season, both sexes increased their heart rate at different times of the test, post-exercise blood lactate concentration and percentage of body fat and 3) mean changes were different between sexes for post-exercise blood production concentration, the heart rate after the 4^{th} minute of the cycling test and percentage body fat. To our knowledge, this was the first study comparing the impact of a competitive season, between sexes, using physiological responses to a submaximal exercise test and body composition assessment.

Another important finding of this study was the increase in heart rate during the submaximal cycling exercise test and post-exercise blood lactate concentration from mid- to end-season in both sexes. Heart rate response during the assessment was similar from pre- to mid-season and post-exercise blood lactate concentration decreased over the first half of the season in males. The results of the current study suggest that the athletes were able to maintain or improve their pre-season fitness levels over the first half of the season. However, during the second half, players showed significant detraining. The effects of an ice hockey season have been previously studied (Daub et al., 1982; Durocher et al., 2008; Green et al., 2010; Green & Houston, 1974) and suggested detraining from the start in comparison to the end of the season (Cox et al., 1995; Durocher et al., 2008; Green & Houston, 1974). One study investigated physical fitness with a similar design and found that blood lactate concentration increased continuously during the season, but demonstrated significant differences only at the end of the season (Cox et al., 1995). Green et al. (2010) observed the cellular response in skeletal muscle during a season and suggested that the sport placed extreme demands on the players, which may cause negative adaptations. Furthermore, it was suggested that due to the high demands of the season in ice hockey, players may suffer overtraining (Green et al., 2012). These physiological responses during submaximal effort (heart rate and blood lactate concentration increase) showed that players' physical fitness decreased over the season, especially over the second half of the season may be the results of an inadequate physiological stress imposed (too high vs. too low).

Another important physical fitness attribute in ice hockey is body composition. Fluctuation profile analysis was in accordance with the previously discussed physiological responses and showed a decrease in fat percentage over the first half of the season in males. However, a significant increase in body fat percentage from mid- to end-season was observed in both sexes. A recent study by Prokop et al. (2016) explored body composition fluctuations during the first half of the season in male collegiate ice hockey players and reported similar findings. Comparable investigations have been done among male and female National Collegiate Athletic Association (NCAA) athletes of other sports (Silvestre et al., 2006; Stanforth et al., 2014). Male collegiate NCAA soccer players performed a body composition assessment at different time points of the season. An increase in lean tissue mass (less than 1 kg), total mass, and no change in fat tissue mass were observed (Silvestre et al., 2006). In women collegiate NCAA athletes of different sports (swimming, basketball, and track) fat mass decreased and volleyball players' lean mass increased (Stanforth et al., 2014). The increase in fat mass showed in our study during the second half of the season is of importance because high levels of muscle mass and low levels of fat mass were associated with faster skating speed in male and female ice hockey players (Gilenstam et al., 2011; Peyer, Pivarnik, Eisenmann, & Vorkapich, 2011; Potteiger et al., 2010). Also, we showed a significant decrease in visceral fat mass from pre- to mid-season among female players, which was interesting due to the importance of central adipose tissue on disease risk (Kuk et al., 2006). More longitudinal and seasonal research in this sport will be important to get a better understanding of body composition and overall health variations.

Mean changes were different between sexes for post-exercise blood lactate production, the heart rate after the 4th minute of the cycling test, and percentage body fat. Post-exercise blood lactate concentration and percentage body fat between-sex variation differences could be explained by pre-season fitness level. Our data suggest that males may not have been in optimal physical condition at pre-season in comparison with the females. Off-season training habits can affect pre-season fitness levels and explain the improvement in these two variables from pre- to mid-season, but a study showed that male athletes report exercising more than females during this period (Brumitt, Heiderscheit, Manske, Niemuth, & Rauh, 2014). However, time spent exercising does not provide any insight on the total quantity and quality of the training. As off-season training habits are hard to monitor, it might still be possible that females arrived at pre-season camp with a higher fitness level than males, who just maintained their physical fitness, and therefore males had potential to improve their physical condition. Mean changes of the heart rate after the 4th minute from pre- to mid-season and mid- to end-season may be explained by the improvement in physical fitness in males over the first half of the season. The decrease in heart rate response at this moment of the test from pre- to mid-season gave a larger window for increase in heart rate from mid- to end-season. More work is needed to better understand cardio-metabolic sex difference variations, which could help sport scientists better tailor sex-specific training programs for elite athletes.

A strength of this study was the use of DXA technology, which allows analysis of whole-body composition profiles with a coefficient of variation of 0.22% at the time of testing (Carver, Christou, Reid, & Andersen, 2014). Also, both teams were playing at an elite level of sport and came from the same school and varsity program. This strengthens the sex-comparison on the assumption that the athletes undergo similar athletic and academic obligations, however, it may also reduce the generalizability of these findings.

Furthermore, to our knowledge, this was the first study comparing the longitudinal impact of a competitive season in both sexes using physiological responses to a submaximal exercise test and body composition assessment. A limitation of this study was the unknown fitness levels of players at pre-season in comparison with their optimal physical condition; however, it is difficult to quantify the work accomplished by each athlete during their off-season. Also, physical fitness can be further impacted by nutrition and lifestyle, but these behaviors are hard to monitor in collegiate-athletes due to the challenging schedules (e.g. exam periods, sport road trips).

PRACTICAL APPLICATIONS

The study produced evidence that male and female collegiate hockey athletes' physiological responses and body composition profiles change over the course of the competitive season. The second half of the season was a time period where most of the physical deconditioning was observed. Strength and conditioning coaches must be aware that off-ice physical fitness is of importance for players in this sport because it was shown to increase the number of scoring chances (Green et al., 2006) and to be linked to team success (Ransdell et al., 2013). Hockey organizations should implement in-season physical fitness assessments, which may help all team coaches better tailor their on- and off-ice training programs to optimize performance, health, and well-being of their players. Moreover, physiological testing and body composition assessments should be implemented to assess the training regimen or implementation of sport nutrition programs. Team strength coaches often have limited time with their players and should choose fitness tests that can thoroughly monitor their athletes and represent important aspects in the sport while not adding additional physiological stress.

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Table 1. Baseline players' characteristics

Characteristics	Males	Females
Age (years)	22.7 ± 1.3	19.9 ± 1.8*
Height (m)	1.82 ± 0.6	1.66 ± 0.7*
Body mass (kg)	86.87 ± 6.44	66.76 ± 5.91*
Years of varsity competition	2.5 ± 1.4	2.1 ± 1.4
Lean body mass (kg)	68.58 ± 4.72	45.85 ± 7.74*
Tissue percent fat (%)	17.4 ± 4.4	25.6 ± 4.5*
Average tension (Watts)	268.5 ± 20.0	170.3 ± 14.8*
# of strength sessions /wk	2.1 ± 1.2	1.9 ± 0.7
# of cardio sessions /wk	0.5 ± 1.0	0.9 ± 0.7

*$p \leq 0.05$, significantly different between sexes

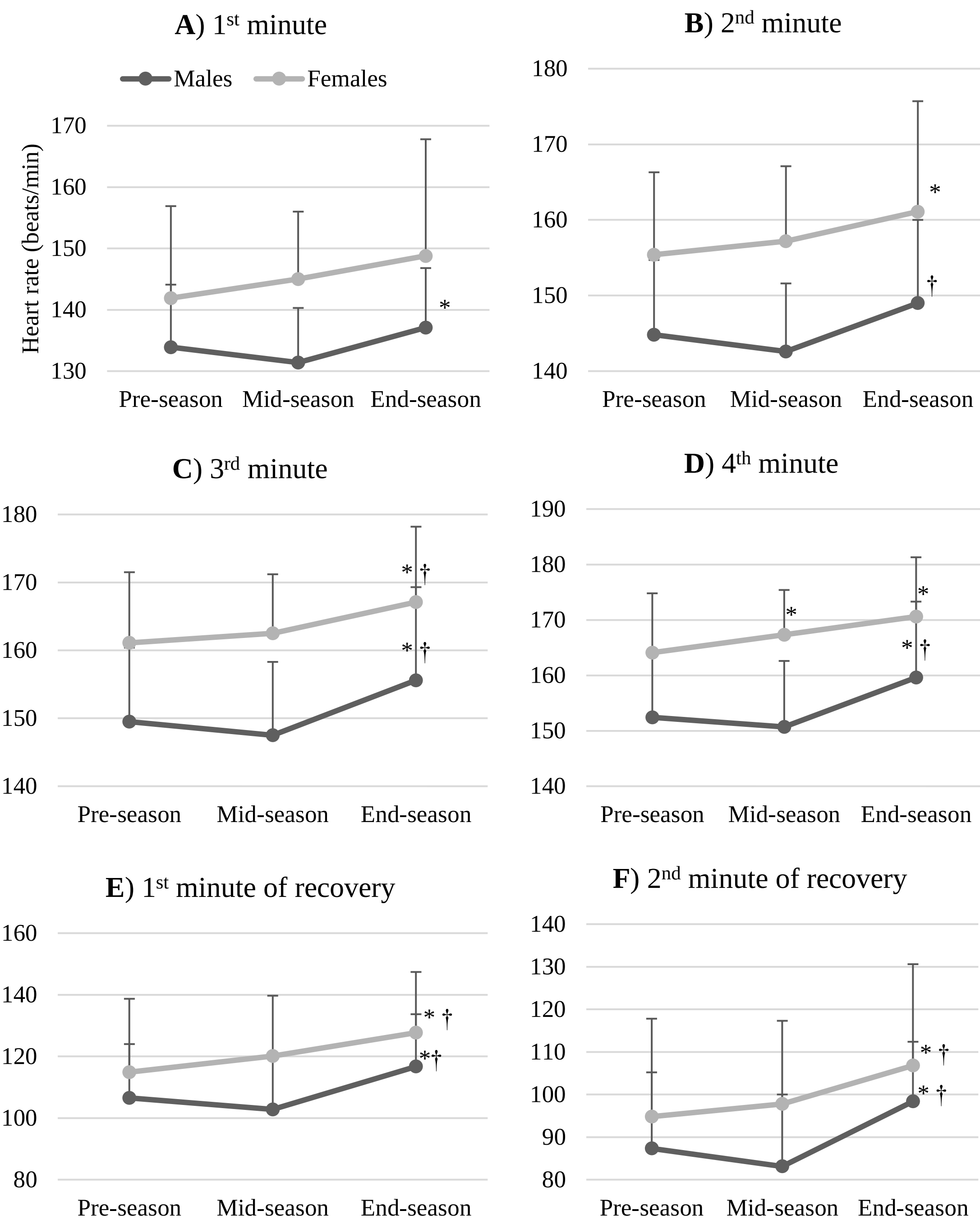

Figure 1. In-season heart rate fluctuations (means ± SD) A) after the 1st minute B) 2nd minute, C) 3rd minute, D) 4th minute, E) 1st minute of recovery, and F) 2nd minute of recovery

* $p \leq 0.05$, significantly different from Pre-season

† $p \leq 0.05$, significantly different from Mid-season

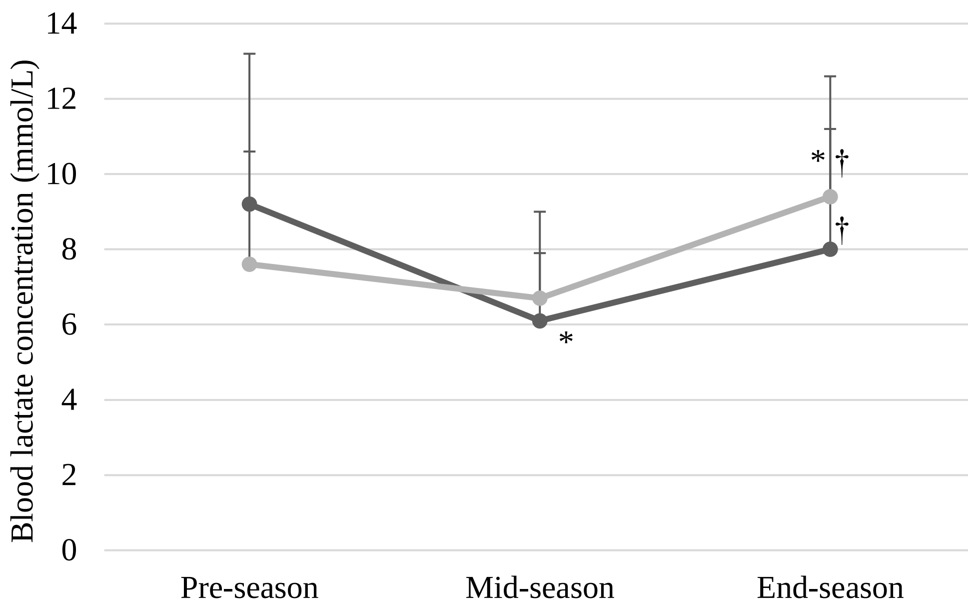

Figure 2. In-season post-exercise blood lactate concentration fluctuations (means ±SD)
* $p \leq 0.05$, significantly different from Pre-season
† $p \leq 0.05$, significantly different from Mid-season

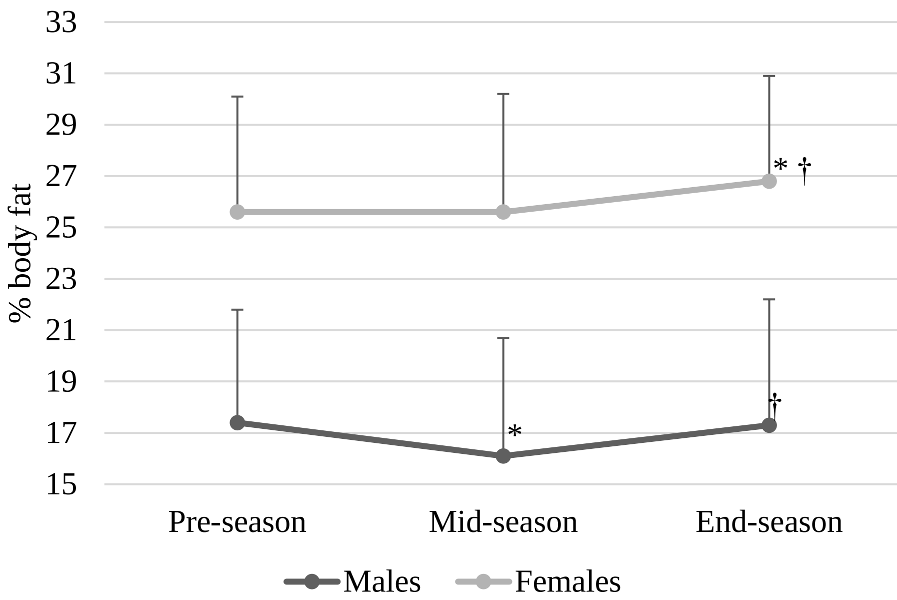

Figure 3. In-season percent body fat fluctuations (means ± SD)
* $p \leq 0.05$, significantly different from Pre-season
† $p \leq 0.05$, significantly different from Mid-season

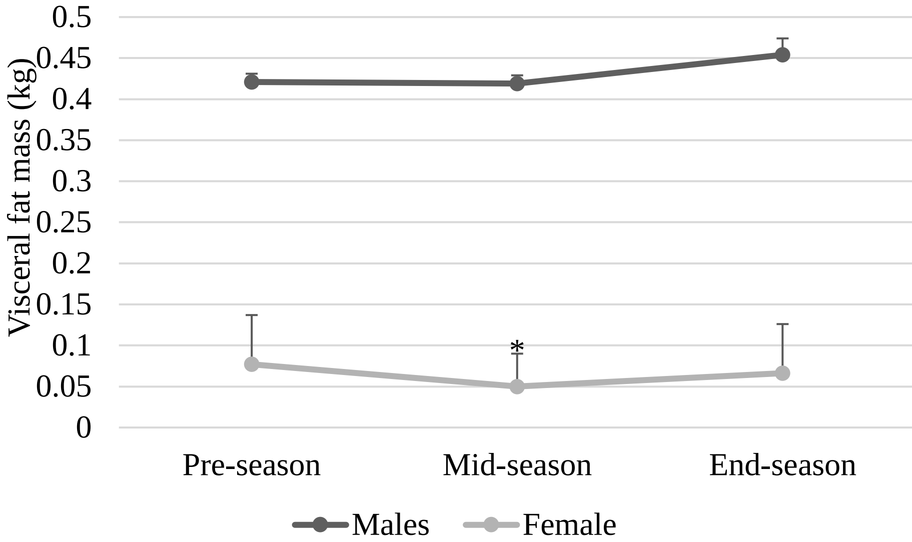

Figure 4. In-season visceral fat mass fluctuations (means ± SD)
* $p \leq 0.05$, significantly different from Pre-season

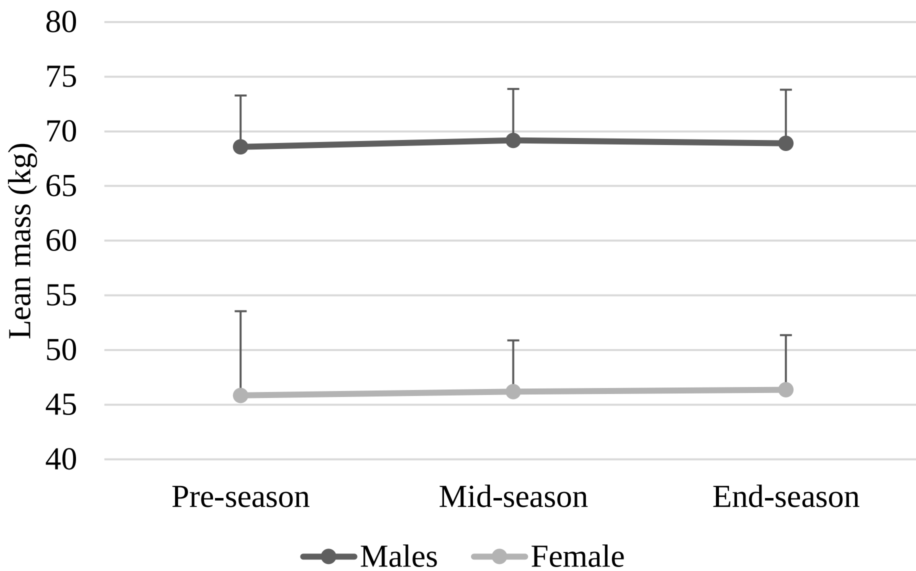

Figure 5. In-season lean mass fluctuations (means ± SD)

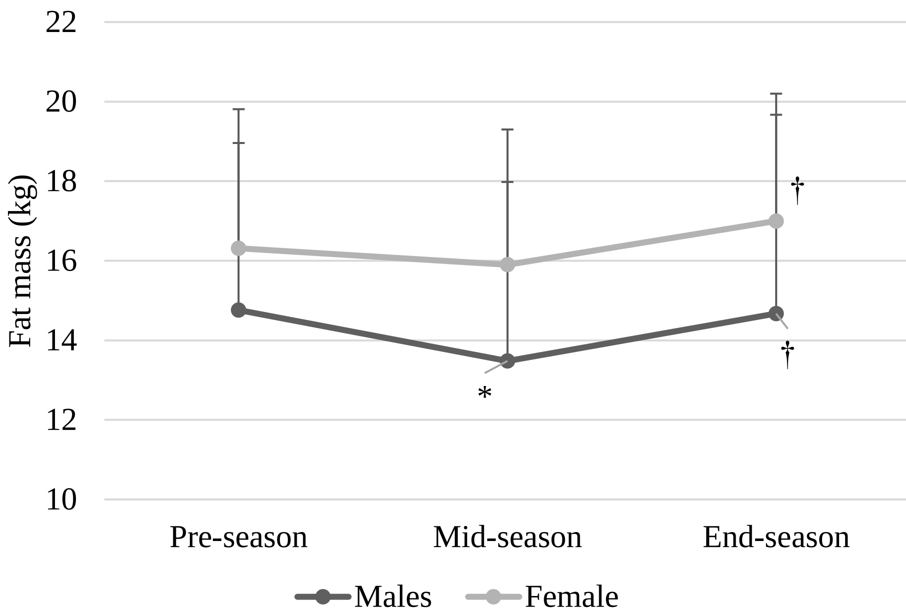

Figure 6. In-season fat mass fluctuations (means ± SD)
* $p \leq 0.05$, significantly different from Pre-season
† $p \leq 0.05$, significantly different from Mid-season

Chapter 5

Manuscript 2

Seasonal Changes of Perception of Internal Load in Collegiate Ice Hockey Players

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Running Head: Perception of Internal Load in Ice Hockey Players

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Abstract

Rate of perceived exertion (RPE) during exercise is a self-reported indicator of an individual's degree of physical strain based on the athlete's understanding of the physiological stress imposed on their bodies by exercise. RPE can be used in ratios with physiological parameters, such as heart rate (HR) and post-exercise blood lactate concentration (BL) to provide insight on internal loads. The purpose of this study was to determine the changes in internal load perception during a short 4-minute submaximal physiological assessment over a competitive season in ice hockey players. Forty-four (n = 44) collegiate hockey players (age = 21.4 ± 2.1 years, height = 1.75± 0.1 m, weight = 77.87 ± 11.83 kg) completed the exercise test at three time-points (pre-season [September], mid-season [November] and end-season [March]). RPE, HR and BL were measured during and after each test. The HR-RPE ratio after the 1st and 2nd minute were lower at end-season compared to pre-season (F (1,41) = 2.855, $p \leq 0.05$). The BL-RPE ratio was higher at mid-season compared to pre-season (F (1,41) = 2.855, $p \leq 0.05$), and was lower at end-season compared to mid-season. A subjective rating of effort (RPE) in relation to physiological responses (HR, BL) might be an efficient way of assessing internal loading and fatigue in collegiate hockey players.

Key words: *Performance, Team Sport, Fatigue*, *Fitness*

Introduction

Athletic fatigue management has been a rising topic in elite team sports. Fatigue monitoring tools are being widely developed and used to help optimize performance in high-performance sports (Taylor et al., 2012). Maximal performance assessments provide rates of work and external loading information; however, they require time and are often very exhaustive, making it difficult to administer in a team sport (Thorpe et al., 2015; Twist & Highton, 2013). Two types of training loads can be monitored: internal and external load. External load is the work accomplished by the athlete, while the internal load is the physiological response to the external load (Halson, 2014). Alternative methods to fatigue assessment are physiological responses associated with self-reported measures during submaximal exercise to gain insight on internal load perceptions (Halson, 2014; Thorpe et al., 2017). These are used by strength and conditioning coaches and generally assess an individual's training status (Taylor et al., 2012). Player's status is affected by stress imposed by training, showing a negative relationship with chronic training and an improvement with proper exercise prescription or reduced training load (Meeusen et al., 2006; Saw et al., 2015; Urhausen & Kindermann, 2002). The athlete's perception of their physiological state may be of importance for performance.

Rate of perceived exertion (RPE) during exercise is a self-reported indicator of an individual's degree of physical strain (Borg et al., 1987; Pageaux, 2016) based on the athlete's understanding of the physiological stress imposed on their bodies by exercise (Borresen & Lambert, 2009). RPE is reported verbally by the athlete during exercise using a scale system, and although a variety of scaling systems exist (Pageaux, 2016), the Borg 6-20 RPE scale is generally the most used (Borg et al., 1987; Borresen & Lambert, 2009). RPE is frequently used to monitor the physiological stress imposed on athletes (Bompa & Haff, 2009; Halson, 2014), most commonly, the perception of effort under submaximal and maximal intensities during individual exercise sessions (Lamberts, Rietjens, et al., 2010). A study monitoring fitness, fatigue, and running performance in Australian football players used RPE to monitor the total training load, which was established as a valid method of estimating training response in team sport (Buchheit et al., 2013). It has been previously demonstrated that RPE correlates with heart rate (HR) and oxygen consumption during steady-state and short sprints executed on cycle ergometers (Borg et al., 1987; Borresen & Lambert, 2009; Halson, 2014; Pageaux, 2016). Additionally, RPE has been shown to be a predictive indicator of blood lactate (BL) concentration. Both HR-RPE and BL-RPE (internal load ratios) can be useful tools in order to provide insight on the perception of internal physiological loads imposed on the athlete (Halson, 2014). Despite a large amount of literature on hockey fitness testing, there is limited agreement on which tests should be administered and what physiological parameters should be observed during the season to monitor internal loading.

Often, sport scientists and strength coaches have limited time with athletes and most assessments are extensive and time-consuming. This prevents their use on a regular (e.g. daily, weekly) basis (Thorpe et al., 2017) and has the potential to decrease the athlete's commitment level (Beckmann & Kellmann, 2003). Monitoring training loads can be helpful in reducing illness and risk of injuries (Schwellnus et al., 2016; Thornton et al., 2016). A recent study among Australian Rugby League players demonstrated that self-reported measures have a relationship with injury/illness and that macrocycle assessments could provide useful information on players' illness risk (Thornton et al., 2016).

Self-report measures, such as RPE during a short submaximal test in relation with physiological parameters (i.e. BL, HR) may be a quick, efficient, and non-loading way to gain information on the training state and fatigue status in a university team sport setting (Gastin et al., 2013; Halson, 2014). The primary aim of this study was to determine the changes in internal load perception during a short 4-minute submaximal physiological assessment over a competitive season in ice hockey players. It was hypothesized that the participants would rate their effort higher for the same imposed physiological stress across the season.

Materials and Methods

Participants

In total, forty-four (n = 44) collegiate hockey players (age = 21.4 ± 2.1 years, height = 1.75 ± 0.1 m, weight = 77.87 ± 11.83 kg) completed the study and were assessed at three time-points (pre-season [September], mid-season [November] and end-season [March]). The sample consisted of twenty-four males and twenty females. The Institutional Faculty of Medicine Review Board approved this study and all players gave consent to participate in this project. Players reported to the laboratory to participate in a 4-minute submaximal exercise test. Also, all participants filled out a 7-day training log to evaluate their training type, duration, volume, and intensity during a regular week of their season. All time-point assessments were performed within a week. To be included in the study, players had to take part in over 75% of the team's on-ice practices and not miss more than two weeks in a row of team activities (i.e. games and practices sessions).

Submaximal cycling exercise test

The power output applied during the submaximal cycling exercise test was determined using Equation 1 considering the body mass (kg) of the individual and an approximation of 75% of established $\dot{V}O_2$ max values for male and female elite ice hockey players (i.e. male: 54 ml/min/kg, female: 46 ml/min/kg; (Cox et al., 1995; Montgomery, 1988; Ransdell et al., 2013)).

Equation 1: $\dot{V}O_2$ (ml/kg/min) = [(10.8 x (power output ÷ body mass)] + 7 (Balady, 2013)

Each participant pedaled for 2 minutes at 50 watts as a warm-up and then 4 minutes at the pre-determined load maintaining 70 revolutions per minute. HR was measured using Polar Monitors (Polar Electro Oy, Kempele, Finland) and RPE was measured according to the 6-20 Borg Scale (Borg, 1970). HR and RPE were recorded at each minute of the test. After 4 minutes, the participant was instructed to sit on a chair beside the cycle ergometer for 2 minutes to recover, where HR was recorded after each minute and BL was measured at the end of the 3 minutes with a Portable Lactate Scout (Vacumetrics Inc., Ventura, CA, USA), as previously described (Waller et al., 2016).

Statistical analysis

HR-RPE ratios were calculated for each minute of the physiological test by dividing the respective physiological measure by the associated RPE. BL-RPE ratio was calculated by dividing the post-exercise BL concentration by the RPE at the 4^{th} minute (highest). Changes in RPE and the internal perception ratios at the three time-points were analyzed using repeated measures ANOVA. Least significant difference (LSD) post-hoc analyses were performed to evaluate the differences between specific time-points. Analyses were considered statistically significant at $p \leq 0.05$ and an effect size of 0.25

was fixed with a sample size of 44 using this statistical test. All analysis were performed on SPSS statistical software version 20.0.

Results

Baseline players' characteristics are presented in Table 1. RPE after one minute was lower at end-season compared to pre-season (F (2,86) = 4.978, $p \leq 0.05$). The seasonal changes in RPE are shown in Figure I. HR-RPE ratio after one minute was lower at end-season compared to pre-season (F (2,86) = 4.027, $p \leq 0.05$); however, no statistical differences were observed between pre- and mid-season, as well as mid- and end-season. The HR-RPE ratio after the second minute showed similar results (F (2,86) = 3.607, $p \leq 0.05$), while HR-RPE ratios of the 3rd and 4th minutes did not show an effect of time between any of the testing sessions. The seasonal changes in HR-RPE ratios are displayed in Figure 2.

BL-RPE ratio was higher at mid-season compared to pre-season (F (2,86) = 8.307, $p \leq 0.05$), and was lower at end-season compared to mid-season, but no differences were found between pre- and end-season. Figure 3 presents the evolution of the BL-RPE ratio over the testing session.

Discussion

The purpose of this study was to investigate possible changes in internal load perception using RPE and internal load ratios during submaximal exercise from pre- to mid- to end-season in collegiate ice hockey players. These methods may be innovative, simple and time-efficient for evaluating player's internal loading perception.

An important finding was the different BL-RPE ratios at mid-season in comparison with the end-season and the pre-season baseline tests. BL-RPE ratios increase at mid-season and are associated with an improvement in physical condition, while the decrease observed at end-season may be associated with detraining or overtraining. Changes in the post-exercise BL concentration at fixed RPE and changes of the RPE at fixed BL can affect the BL-RPE ratios. Previous research has shown that a decreased BL-RPE ratio with fixed work rate was related to short-term overtraining (Snyder et al., 1993). Ratings of physical stress have also been shown to reflect neural mechanisms, which suggest that this increase in BL-RPE ratio may be associated with neural fatigue at the end-season testing point (Ross, Leveritt, & Riek, 2001). In accordance with these results, HR-RPE ratios decreased from pre- to end-season after the 1st and 2nd minutes of the submaximal test. A decrease in the HR-RPE ratio suggested greater fatigue due to high internal loading and may be used to monitor apparition of overreaching (Martin & Andersen, 2000; Pyne & Martin, 2011). Previous research proposed that submaximal physiological responses were linked to performance in football, where managing training load and fatigue showed improvement in running performance (Buchheit et al., 2013). Players' perception of training load and fatigue seems to be related to internal physiological processes during exercise. Further, investigations that target health and performance monitoring are needed to gain a better understanding of BL/RPE and HR/RPE ratios.

The results from the study showed that solely relying on RPE may not provide enough insight on the perception of an individual stress imposed; however, the addition of physiological parameters, such as HR or BL to create a ratio may be a better way of understanding the perception of physiological loading. The BL-RPE ratio was the only variable demonstrating sensitivity of change over time, while RPE and HR-RPE showed an effect of time after the 1st, and 1st and 2nd minute of the submaximal exercise test respectively. This suggests that RPE, HR and BL could be used to allow strength and conditioning specialists monitor their athletes in a limited period of time with an objective physiological assessment. Past research shows a well-managed and administrated training program can help maintain or improve performance, fatigue and well-being ratings by including recovery strategies and training periodization (Gastin et al., 2013; Kenttä & Hassmén, 1998). Athletes' monitoring is essential to guide a sport program to a high-performance level and our study provide evidence that a 4-minute submaximal test assessing perception of internal load appears to be responding to physiological training stress.

This investigation was unique because it examined the perception of collegiate hockey players using RPE and internal load ratios during a submaximal physiological test. The study was strengthened by representation of both sexes and the uses of field-based physiological measures. This study was limited by the day-to-day variability of HR, but to account for this variability, players performed the test at a similar time of day before on-ice practice or off-ice training throughout the three sessions.

Conclusion

Detection of internal loading and fatigue is important to sport performance because of the constant stresses imposed on athletes. A subjective rating (RPE) of effort in relation to physiological responses (HR, BL) may be an efficient way of assessing internal loading and fatigue in collegiate hockey players; however, HR-RPE ratios may be more responsive during the early phase of a steady-state exercise. The high academic and athletic demands reduce the time allowed to strength and conditioning and impede their ability to monitor their collegiate athletes with long and exhaustive tests. A 4-minute submaximal cycling test with HR and post-exercise BL concentration may be of utility to observe internal load perception changes, providing additional knowledge concerning the performance, or training status of the athletes.

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Table I. Baseline players' characteristics

Characteristics	Mean ± Standard deviation
Age (years)	21.4 ± 2.1
Height (m)	1.75 ± 0.1
Body mass (kg)	77.73 ± 11.83
Years of competition (years)	2.3 ± 1.3
Tissue percent fat (%)	21.1 ± 6.0
Average tension (Watts)	223.9 ± 52.5
# of strength sessions / wk	2.0 ± 1.0
# of cardio sessions / wk	0.7 ± 0.9

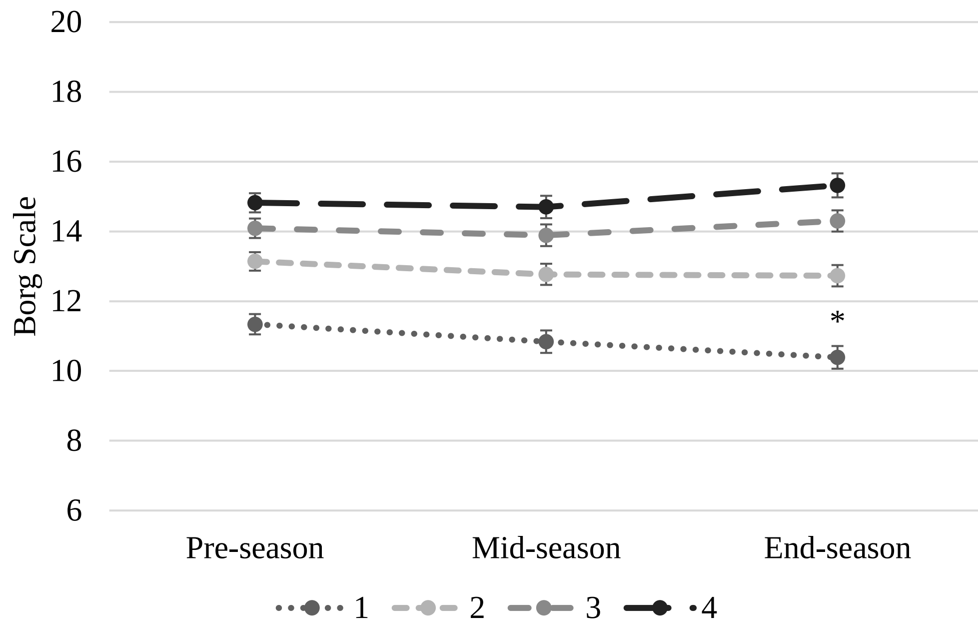

Figure 1. RPE at every minute of the test for each testing session (means ± SE)
*Significantly different from Pre-season ($p \leq 0.05$)

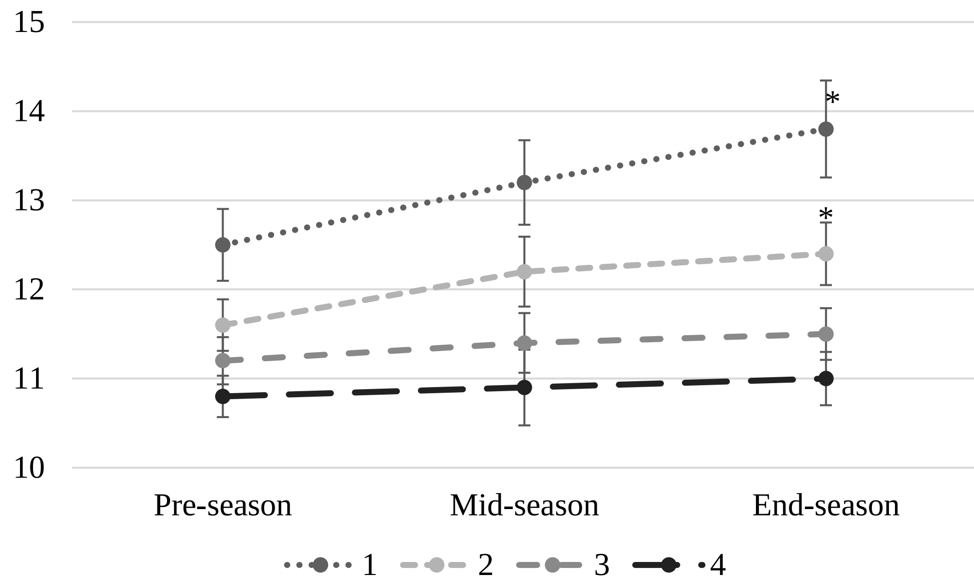

Figure 2. HR-RPE ratio at every minute of the test for each testing session (means ± SE)
*Significantly different from Pre-season

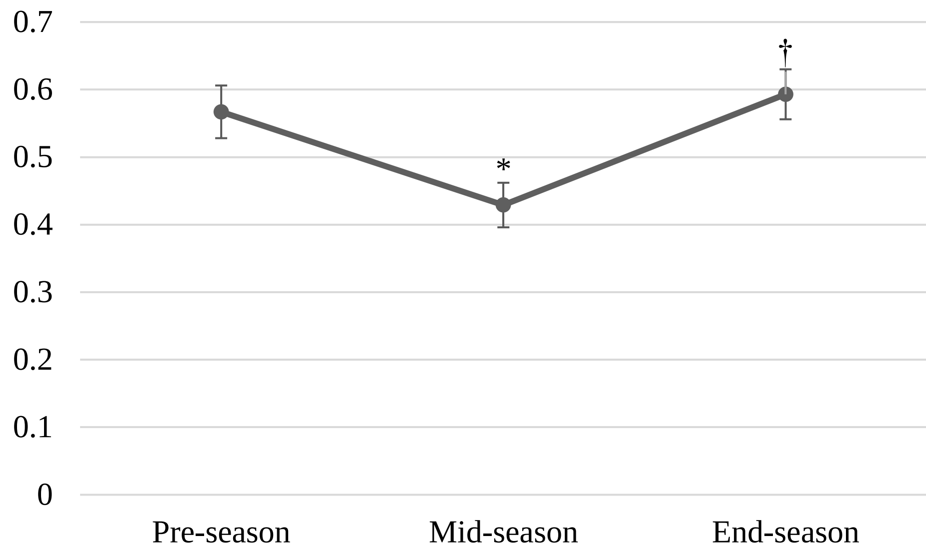

Figure 3. BL-RPE ratio for each testing session (means ± SE)
*Significantly different from Pre-season ($p \leq 0.05$)
†Significantly different from Mid-season ($p \leq 0.05$)

Chapter 6 – Summary, Conclusion, Recommendations and Practical Applications

6.1 Summary

The purpose of this project was to identify changes in physical fitness attributes (i.e. physiological response, body composition) over the competitive season, to explore between-sex differences of physical fitness attributes, and to identity changes in internal load and fatigue perception. Three assessments at different time-points corresponding to the PS, MS and ES, evaluated players' physical fitness attributes and internal load perception. During testing sessions, participants underwent anthropometric assessment, a DXA scan, filled out a questionnaire, and participated in a 4-minute submaximal cycling exercise test.

The participants in this study were forty-four players [n=48], twenty-four males and twenty females, all members of the men's and women's varsity hockey team from McGill University and were aged 18 years and over. All participants included in the study performed physical fitness testing, body composition evaluation and responded to the questionnaires in the Health and Fitness Promotion lab under proper supervision and participated in at least 75% of the mandatory ice-session of their respective teams.

The first hypothesis of this study was that a player's physical fitness attributes would deteriorate as the season progressed, where at submaximal exercise, heart rate was expected to increase as well as post-exercise blood lactate concentration. Body composition profiles were expected to change negatively, which means an increase in fat mass and a decrease in lean mass. At MS, males' post-exercise blood lactate concentration decreased by 3.096 mmol/L (9.263 vs. 6.167) in comparison to PS and increased by 1.846 mmol/L from MS to ES (6.167 vs. 8.01). Females' post-exercise blood lactate concentration increased by 1.880 mmol/L from PS to ES pre- to end-season (7.55 vs. 6.71) and by 2.725 mmol/L from MS to ES (6.705 vs. 9.430). The current study showed similar results in term of HR evolution over the season. As an example, after the 4th minute of the test, the heart rate increased by 7.2 bpm from PS to ES (152.4 vs. 159.6) and by 8.9 bpm from MS to ES (150.7 vs.159.6) in males, while in females it increased by 3.2 bpm from PS to MS (164.1 vs. 167.3) and by 6.5 bpm from PS to ES (164.1 vs. 170.6). Furthermore, males' body fat percentage decreased by 1.246% from PS to MS (17.379 vs. 16.133) and increased by 1.167% from MS to ES (16.133 vs. 17.300). Among females, body fat percentage increased by 1.2% from PS to ES (25.5 vs. 26.8) and by 1.3 % from MS to ES (25.6 vs. 26.8).

The second hypothesis predicted no sex differences in changes of physical fitness attributes. Our investigation showed that seasonal mean changes for heart rate after the 4th minute of the test in-between PS and MS and in-between MS and ES were different between sexes. Also, post-exercise BL concentration mean changes were different between males and females from PS to MS and from PS to ES. Body fat percentage mean variations were different between males and females from PS to MS and from PS to ES.

The Third hypothesis of this study projected that internal load perception would increase as the season would progress. This hypothesis was tested using internal load ratios (HR-RPE, BL-RPE). HR-RPE ratio after the 1st minute was lower at ES end-season compared to PS.HR-RPE ratio after the 2nd minute showed similar results, while HR-RPE ratios of the 3rd and 4th minutes did not show an effect of time between any of the testing sessions. BL-RPE ratio was higher at MS compared to PS pre-season and was lower at ES compared to MS. No HR/BL-RPE ratios X sex interactions were observed. Also, subjective fatigue was evaluated using a questionnaire at rest. No changes were observed between pre- to mid-season in the Chalder Fatigue Scale scores,

6.2 Conclusion

Within the delimitations and limitations of this project the following conclusions are:

1) The first half of the hockey season can have positive effects on male collegiate ice hockey players' physical fitness. This was shown by a decrease in post-exercise BL concentration after submaximal effort and in body fat percentage.
2) The second half of the season can have a detrimental effect on both male and female collegiate ice hockey players' physical fitness. This was shown by an increase in HR and post-exercise BL concentration under submaximal effort. In addition, they both increased their body fat percentage and total fat mass.
3) Physiological stress imposed by a hockey season can have a sex-specific effect on physical fitness attributes. Although most trends were similar some physiological responses and body composition mean changes were different between the sexes. This was reflected by sex-specific seasonal mean changes for heart rate after the 4^{th} minute, post-exercise BL concentration and body fat percentage.
4) Internal load perception is changing over the season. Players perceived their internal load to be higher at the end of the season, which was reflected by higher HR-RPE and BL-RPE ratio. The decrease in internal load ratios is associated with detraining, which is in accordance with the aforementioned conclusion.

6.3 Recommendations

Based on the findings of this study of the present study the following recommendations are:

1) Further studies should be conducted trying to identify relation between in-season physical fitness changes and injury rates, on-ice performance, and quality of life.
2) Follow-up studies on the 4-minute submaximal exercise test should attempt to be more repeated weekly/monthly in a field-based situation to get a better understanding of the physiological response and help coaches and athletic program tailor their team's training.
3) Future studies should attempt to demystify the sex differences observe in physiological profiles of elite athletes.
4) A new way to better understand training load could involve tri-axial accelerometry and physiological testing, such as the 4-minute submaximal test to gain better insight on external and internal loading.

6.4 Practical Applications

Physical fitness has multiples attributes and can be affected by many factors such as sport-specific training, recovery, nutrition, and lifestyle. Physiological responses and body composition profiles are recognized to be important physical fitness attributes and changes over the season can influence sport performance. This study provides important insight regarding changes in physiological responses, body composition profiles, and internal loading perception of male and female collegiate ice hockey players during a competitive season. This project may provide valuable information to improve periodization of training program, as well as, general levels of physical fitness and sport performance using PS, MS and ES reports on the evolution of the physiological profile of the collegiate ice hockey players.

Physiological testing and body composition assessments should be considered to assess training regimen or implementation of sport nutrition programs. Individualization and specialization are becoming trend in sport performance allowing the athlete to implement specific training and nutrition program that will propel them toward the highest achievement.

Recognition of internal load perception is important to sport performance because of the constant stresses imposed on athletes. Athletes monitoring is typically used to ensures performance optimization. The athlete’s perception of their physiological and psychological state may be way to gain valuable information on athletes. The high academic and athletic demands reduce and impede strength and conditioning to monitor their athletes with long and exhaustive tests. A 4-minutes submaximal cycling test with HR and post-exercise BL concentration may be of utility to observe physiological perception changes, providing additional knowledge concerning the playing or training status of the athletes.

Investigation of sex-difference of changes in physiological and body composition profiles are important to coaches better tailor their sex-specific training program to optimize performance and health among their players. This study gives insight on sex-specific adaptations to physiological stress imposed by the season. Differentiation must be made between the sexes to adapt training program to the targeted goal because the athletes have specific physiological reaction.

APPENDIX

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Participant ID

QUESTIONNAIRE-Chalder Fatigue Scale

Chalder Fatigue Scale

14-Item fatigue scale

Physical symptoms

1. Do you have problems with tiredness?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

2. Do you need to rest more?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

3. Do you feel sleepy or drowsy?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

4. Do you have problems starting things?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

5. Do you start things without difficulty but get weak as you go on?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

6. Are you lacking in energy?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

7. Do you have less strength in your muscles?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

8. Do you feel weak?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

Mental symptoms

9. Do you have difficulty concentrating?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

10. Do you have problems thinking clearly?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

11. D you make slips of the tongue when speaking?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

12. Do you find it more difficult to find the correct word?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

13. How is your memory?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

14. Have you lost interest in the things you used to do?
(a) Better than usual (b) No more than usual (c) Worse than usual
(d) Much worse than usual

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