Relationship Among Heart Rate Variability, Body Composition and Perceived Wellness in Collegiate Varsity Ice Hockey Players

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List of Common Terms and Abbreviations

ANS – Autonomic Nervous System

ASRM – Athlete Self-Report Measure

DXA – Dual Energy X-ray Absorptiometry

HR – Heart Rate

HRV – Heart Rate Variability

LnRMSSD – log-transformed root mean square of successive R-R intervals

RHR – Resting Heart Rate

RMSSD – root mean square of successive differences

RPE – rating of perceived exertion scale

SDNN – standard deviation of normal-to-normal

USports – Canadian Interuniversity Sports

VOBLA - velocity at onset of blood lactate accumulation

VO_2 max - maximum oxygen uptake

vVO_2 max - minimum velocity required to reach VO_2 max

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Abstract

Participating in varsity ice hockey offers substantial health and fitness benefits but also presents various risks. Athletes face unique physical and mental challenges, including musculoskeletal injuries, depression, anxiety, and struggle to balance demanding schedules. The intense, prolonged nature of the sport can lead to chronic fatigue and overtraining, impacting both performance and well-being. Psychological stressors such as mood, fatigue, and reduced sleep quality are common. One suggested method to monitor these conditions is heart rate variability (HRV), a non-invasive measure that reflects autonomic nervous system balance and can offer insights into an athlete's training status and overall health.

Despite the growing interest in HRV for athlete monitoring, research is lacking on how HRV relates to body composition and subjective wellness, and how these factors differ by sex throughout a competitive season. This study aims to address this gap by comparing changes in HRV, body composition, and subjective wellness between male and female collegiate hockey players over an academic semester. Participants underwent a dual-energy X-ray absorptiometry (DXA) scans for body composition and used Polar H10 chest straps for biweekly HRV recordings over 12 weeks. Subjective wellness was assessed via a questionnaire addressing sleep quality, fatigue, muscle soreness, stress levels, and mood. HRV and subjective wellness were collected daily, every second week.

Statistical analysis, including repeated measures ANOVA and mixed linear regression modelling, revealed significant sex-by-time interactions in HRV metrics. Males consistently showed higher HRV compared to female players, though females demonstrated an increase in

HRV from week 1 to week 12, while males exhibited a decrease. Both sexes improved in body composition, with decreases in body fat percentage and increases in lean mass over the semester. Additionally, subjective wellness scores were higher in males. These findings suggest that sex-specific training and recovery protocols, informed by HRV and subjective wellness data, could enhance both performance and well-being in athletes. Understanding these physiological and psychological differences is essential for optimizing training and support strategies for varsity hockey players.

Résumé

Participer au hockey sur glace universitaire offre des avantages considérables pour la santé et la condition physique, mais présente également divers risques. Les athlètes sont confrontés à des défis physiques et psychologiques uniques, notamment des blessures musculo-squelettiques, la dépression, l'anxiété et la difficulté à maintenir un équilibre dans les horaires exigeants. La nature intense et prolongée du sport peut entraîner une fatigue chronique et un surentraînement, impactant à la fois la performance et le bien-être. Les facteurs de stress psychologique, tels que l’humeur, la fatigue et la qualité du sommeil réduite, sont courants. Une méthode suggérée pour surveiller ces conditions est la variabilité de la fréquence cardiaque (VFC), une mesure non invasive qui reflète l'équilibre du système nerveux autonome et peut fournir des informations sur l’état d’entraînement et la santé globale d’un athlète.

Malgré l’intérêt croissant pour la VFC dans le suivi des athlètes, il manque de recherches sur la façon dont la VFC est liée à la composition corporelle et au bien-être subjectif, et comment ces facteurs diffèrent selon le sexe, tout au long d’une saison compétitive. Cette étude vise à combler cette lacune en comparant les changements dans la VFC, la composition corporelle et le bien-être subjectif entre les joueurs de hockey universitaire masculins et féminins au cours d'un semestre académique. Les participants ont subi des scans de composition corporelle par absorptiométrie à rayons X à double énergie (DXA) et ont utilisé des ceintures Polar H10 pour des enregistrements bihebdomadaires de VFC sur une période de 12 semaines. Le bien-être subjectif a été évalué à l'aide d'un questionnaire portant sur la qualité du sommeil, la fatigue, les douleurs musculaires, les niveaux de stress et l'humeur. La VFC et le bien-être subjectif ont été collectés chaque matin, de manière bihebdomadaire.

L’analyse statistique, comprenant une ANOVA à mesures répétées et des modèles de régression linéaire mixte, a révélé des interactions significatives entre le sexe et le temps dans les indicateurs de VFC. Les hommes ont montré des niveaux de VFC systématiquement plus élevés que les joueuses, bien que ces dernières aient démontré une augmentation de la VFC de la semaine 1 à la semaine 12, tandis que les hommes ont montré une diminution. Les deux sexes ont amélioré leur composition corporelle, avec des réductions du pourcentage de graisse corporelle et des augmentations de la masse maigre au cours du semestre. De plus, les scores de bien-être subjectif étaient plus élevés chez les hommes. Ces résultats suggèrent que des protocoles d’entraînement et de récupération spécifiques au sexe, basés sur les données de VFC et de bien-être subjectif, pourraient améliorer à la fois la performance et le bien-être des athlètes. Comprendre ces différences physiologiques et psychologiques est essentiel pour optimiser les stratégies d'entraînement et de soutien pour les joueurs de hockey universitaire.

Preface and Authors Contributions

Tricia Deguire 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.

Dr. Gordon Bloom assisted in the design of the study.

Patrick Delisle-Houde assisted in the design of the study.

Maximilian Daigle assisted in participants' recruitment and participant assessments.

Pierre P.W. Registe assisted with the statistical analysis.

Chapter 1 - Introduction

1.1 Scope of the study

Participating in varsity sports is often associated with health and fitness benefits, in addition to an increase in some health risks. The World Health Organization [WHO] (2022) defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity.” Student-athletes are at risk for multiple health-related issues, including both physical and mental health problems (Etzel, 2006). Physical health issues may include musculoskeletal injuries, while mental health problems may involve both depression and anxiety (Etzel, 2006). Varsity student-athletes, such as those participating in ice hockey, have a full-year season that includes multiple academic and athletic obligations (Curry et al., 1997). Achieving life balance is often challenging for student-athletes (Schellenberg et al., 2013). Psychological issues such as poor mood states, fatigue and lessened sleep quality (subjective wellness) have been linked to the stress imposed by chronic training in athletes (Ortigosa-Márquez et al., 2017). Additionally, chronic training imposes continual stresses on athletes while contributing to a shift in their well-being along a continuum from acute fatigue to an overtrained state (Saw et al., 2016). Physiologic stresses imposed on the student-athletes during the competitive season may shift an athlete’s status from acute fatigue to an overreaching or even an overtraining state (Halson, 2014; Thorpe et al., 2017).

Previous literature has reported that heart rate variability (HRV) has been found to detect autonomic imbalances in overtrained athletes. A recent meta-analysis found HRV to be a reliable marker of autonomic balance in short-term fatigue (Bosquet et al., 2008). Fatigue and well-being can also be influenced by several quality-of-life factors (e.i., sleep quality) (Doerr et al., 2015; Hills & Argyle, 2002; Samuels, 2008). These factors are commonly reported in student-athletes' lives and may be associated with future mental health problems such as depression and anxiety (Etzel, 2006) and may also influence student-athletes' performance (Kavazis & Wadsworth, 2014). Student-athletes are not routinely monitored for levels of fatigue or well-being throughout their varsity season. However, a physical evaluation is typically performed before the playing season begins (Peyer et al., 2011). The cardiac autonomic nervous system (ANS), as measured non-invasively by HRV, may provide quick, useful information on functional changes to a given training stimulus (Buchheit et al., 2007). For example, it can provide a signal of imbalance in the ANS which may be important in preventing heart complications.

To be useful in assessing physiological adaptations to training, a marker must be easily administered, allowing for regular monitoring with minimal burden to the athlete (Borresen & Lambert, 2008). Understanding the role of HRV in student-athletes is important given its potential to track training and recovery status, in addition to the well-being of student-athletes (Flatt et al., 2017). Currently, there is a void in the scientific literature comparing sex differences in training status among student-athletes. Researchers have shown major differences in the psychological, social and physiological determinants of health between male and female athletes (Verbrugge, 1985) (Maldonado-Martin et al., 2004; Verbrugge, 1985). There are reports that women seem to be more resistant to acute fatigue and may recover faster than their male counterparts. These variances are hypothesized to be related to sex-specific differences in body composition or substrate utilization (Billaut & Bishop, 2009).

1.2 Rationale

In Canadian universities, athletes must participate in all team activities (practices, training, meetings, travel and games) and be full-time students while maintaining a cumulative GPA of at least 2.7/4 to remain eligible to compete. Performing as a student athlete in university comes with challenges, sacrifices and choices. Varsity ice hockey is one of the longest seasons in U Sports, divided across both fall and winter academic semesters. Varsity ice hockey players' play, on average, two games per week, practice four to five times per week, and participate in off-ice training one to three times weekly. In addition, they typically attend team meetings and travel to half of their regular season games.

Hockey is one of the fastest and most vigorous sports in U Sports, involving frequent changes in speed and direction (Montgomery, 1988). The game consists of short high-intensity peaks and brief pauses for recovery (Montgomery, 1988). If the recovery period between games and practices is too short, the athlete may not fully recover, leading to an overtrained state (Budgett, 1998). Therefore, maintaining both physiological and psychological health is critical for the well-being of varsity athletes.

There is currently a dearth of research on collegiate hockey players' body composition and physiological responses to participation, as tracked throughout the course of the season. In fact, Makivić et al. (2013) examined performance levels and recovery capabilities by tracking aerobic fitness using a variety of metrics; including the maximum oxygen uptake (VO_2 max), the minimum velocity required to reach VO_2 max (vVO_2 max), the velocity at the onset of blood lactate accumulation (VOBLA), and the ability to repeat sprints. However, these assessments are expensive and complex for regular use (Makivić et al., 2013). These measures also require that exercise physiologists be part of multidisciplinary teams to carry out the tests and interpret the results (Makivić et al., 2013). As a result, coaches and trainers require practical, non-invasive ways to monitor important information related to physiological and emotional changes in their athletes (Makivić et al., 2013). HRV has recently been used as a non-invasive tool to assess and track training states in athletes. There are reports of significant relationships among HRV, measures of perceived training load, fatigue, and well-being in athletes (Fields et al., 2021). However, recent research suggests that an objective measure of ANS function, like HRV, should still be used in addition to subjective measures to validate athletes' reports of their training status (Fields et al., 2021). Past research has examined the relationship between HRV and subjective assessments, but investigations have failed to assess players' physical attributes using objective measurements like body composition. Thus, there is little research available when examining changes in relationship among HRV, body composition and subjective wellness across the hockey season of varsity ice hockey athletes.

Moreover, little has been done exploring sex differences in physiologic parameters in elite ice hockey players. On-ice testing in elite and non-elite female hockey players have explored physical and performance differences across positions and skill levels (Ransdell & Murray, 2011). Additionally, others included seasonal changes in physiological and physical parameters in male and female ice hockey players (Delisle-Houde et al., 2019; Dengel et al., 2021). In order to optimize both individual and team performance, exercise physiologists require quick, non-invasive ways to track training status.

1.3 Purpose

The purpose of this study was to investigate the relationship between changing HRV and body composition, as well as male and female student-athletes' subjective wellness over the course of an academic semester. The investigators aimed to understand the interactions among physiological and psychological changes that may occur in student-athletes during the academic semester when athletes must perform both academically and athletically. These changes were assessed in relation to markers of overtraining, and between-sex comparisons in each factor will also be explored. Documenting between-sex differences in these variables may help better tailor academic and training program approaches to promote health and well-being in varsity student-athletes.

The potential role that HRV has in tracking hockey players is unique for several reasons. While HRV has been extensively studied in the context of endurance athletes such as long-distance runners, cyclists, and triathletes, there is limited research involving hockey players (Lundstrom et al., 2022). Therefore, a study on HRV in hockey players would be novel and contribute to the understanding of how HRV could be used to track the physical and emotional condition of athletes in team sports. By tracking HRV, coaches and trainers could make informed decisions about player training and rest periods, which could improve overall player performance and reduce the risk of overtraining or injury (Saw et al., 2016). Hockey is a high-intensity sport with unique physical demands such as rapid changes in direction, collisions and physical contact (Burr et al., 2008). These demands could impact HRV measurements and the subjective wellness questionnaire in unique ways, making it important to study HRV and subjective wellness in hockey players specifically.

1.4 Hypothesis

Objective #1: Track changes in physiologic parameters over the first semester of play in male and female varsity ice hockey players.

Primary measure #1: Physiological parameters [HR, HRV] - Varsity student-athletes have high demands in terms of academic and athletic obligations. They must manage practices, games and schoolwork in their schedule while trying to maintain healthy habits to stay rested over a full semester. *We hypothesized that the physical strain of the season will affect body composition. Additionally, we hypothesized that the HRV would decline during the first academic semester of the season.*

Primary Measure #2: Subjective Wellness Questionnaire [McLean] – Varsity student-athletes, such as those participating in the sport of ice hockey, have full-year seasons with multiple academic and athletic obligations. As the season progresses, multiple academic tasks accumulate, while practices and games become very demanding and time-consuming. Student-athletes spend a portion of their day training for their sport and the other part taking care of their academic responsibilities (e.i., studying, attending lectures, resting, injury, travel), which may impact their energy levels and their perceived fatigue. Student-athletes can also start to feel overwhelmed and tired during this time (Schellenberg et al., 2013). *We hypothesized that varsity student-athletes would report elevated levels of subjective fatigue, soreness, and stress as the semester progresses. We also hypothesized that student-athletes would be at risk of diminished subjective sleep and mood over the semester.*

Primary Measure #3: Body Composition [Body Fat%, Fat Distribution, Bone Density] – The demands required of varsity student-athlete hockey players are elevated, and fitness and optimal body composition may decline. During the season, we believe less time is spent maintaining an optimal lifestyle because of school, on ice/field commitments, and game preparations. Therefore, we believe that a player's health measures are likely to fluctuate with the influence of increased subjective fatigue and physical fitness requirements. *We hypothesized that changes in body composition would be closely linked to variations in subjective wellness and physiological parameters throughout the season*.

Objective #2: Explore sex differences in the changing physiological and psychological measures over the fall semester in varsity athletes.

Secondary Measure: Between-Sex Differences [Monitoring Male and Female Athletes] – There are major differences in psychological, social and physiological determinants of health between males and females. Therefore, exploring sex differences in the changing physiological or psychological measures over the fall semester of the varsity athletes will be important. *We hypothesized that males would have greater reductions in physiological parameters over the fall semester of the competitive season.*

Pilot Measures: We recognize that a lack of statistical power may limit the accuracy of between-sex analyses. However, we planned to perform exploratory analyses to see whether trends in longitudinal interactions exist in changing fitness and psychological variables between male and female varsity hockey players.

1.5 Delimitations

The following delimitations have been identified for the purpose of this study:

1. Participants were student-athletes at McGill University
2. Participants were currently active varsity male and female hockey players
3. Participants age was to be between 18 and 25 years old

1.6 Limitations

The following limitations have been identified:

1. The results may not be generalizable to the larger population and will be limited by the unique sample of the study, which consisted of students who are ice hockey players. However, this study will provide insight into changing HRV, body composition and subjective wellness among Canadian university varsity ice hockey players.
2. The results may be influenced by the participants' sleeping habits, nutrition, school workload and daily stressors.

Chapter 2 - Review of Literature

Collegiate athletes strive to maintain both physical health and optimal performance levels. The main factors influencing these measures are the interaction among physical, physiological and psychological measures (Kentta & Hassmen, 1998). However, many variables, such as coaches' decisions, injuries, and assessments by healthcare professionals, are beyond student-athletes' control. Therefore, athletes need to focus on the controllable aspects of their daily lives. Through the literature review, this study provides an overview of the demands of collegiate ice hockey and the physical, physiological and psychological monitoring of student-athletes. Additionally, the last section reviews sex differences in sports.

2.1 Student-athletes demands

Student-athletes make sacrifices and impactful choices that will influence their future. They must find a delicate balance between their sport, academic achievement, social life and often a part-time job. Additionally, they train throughout the year, attend team meetings, and participate in all team activities. In the investigation by Stevens et al. (2013), over half of male collegiate athletes and slightly more than half of female athletes noted that the stresses of participating in sports had a major negative impact on their mental or emotional health. The stressors included pressure to win, excessive anxiety, frustration, conflict, irritation and fear (Stevens et al., 2013). At school, many male and female athletes indicated that stress was caused by things like quizzes and exams, writing papers for class, missing courses due to travel, and making up missed assignments (Stevens et al., 2013). Socially, relationships with professors, coaches, students, and other athletes were highly stressful and very difficult for athletes because they reported that unfavourable or unsatisfactory interactions happen frequently (Papanikolaou et al., 2003; Stevens et al., 2013). Many studies have observed that overstressed collegiate athletes are more prone to engage in unhealthy behaviours and have psychological issues such as bad eating habits and low self-esteem (Pritchard & Wilson, 2005).

Mental health problems are common among student-athletes, with issues such as sleep deprivation, continuous tension, fatigue, headaches, and digestive problems being commonplace (Stevens et al., 2013). Athletes also report higher levels of stress and insomnia compared to their non-athlete counterparts (Pritchard & Wilson, 2005). According to Stevens et al. (2013), student-athletes often describe having difficulties finding the right balance between academics and athletic demands.

2.2 Hockey demands

Ice hockey is a physically demanding sport requiring both physiological and biomechanical skills to optimize on-ice play. Quickness, agility, lean body mass, muscular strength, and endurance are all essential components of the sport (Burr et al., 2008; Cox et al., 1995). To meet these demands, a well-trained aerobic and anaerobic energy system is necessary (Cox et al., 1995). While the anaerobic system provides the majority of the energy consumed while on the ice, the aerobic system is primarily responsible for rapid recovery between shifts (Green & Houston, 1975; Montgomery, 1988; Skahan, 2016; Twist & Rhodes, 1993). A typical game of ice hockey is sixty minutes long and is divided into three, twenty-minute periods, with players typically playing between fifteen and twenty minutes per game (Skahan, 2016). During the game, playing time is divided among the twenty players, with the first six forwards on twelve, four first defense on six, and one goalie on two having higher playing time than other players. Each shift consists of high-intensity intervals of thirty to eighty seconds, followed by an inactive resting period of two to five minutes (Montgomery, 1988). During each shift, players must execute rapid directional changes involving hard stops, backward skating, and lateral skating movements (Twist & Rhodes, 1993).

At the beginning of each season, varsity athletes typically engage in physical testing and must maintain high standards to continue playing. Sport-specific athlete testing is particularly useful for identifying performance potential, physiological potential, specific injury types that can be avoided or minimized, and tailoring training programs (Cox et al., 1995).

2.3 Monitoring in team sports

Monitoring has become a significant aspect of the game. It aids in the development of an effective and balanced training program that allows athletes enough time to recover between sessions while minimizing the risk of injury or overtraining (Kuipers & Keizer, 1988). Recent studies have shown that dry land training can enhance on-ice performance (Delisle-Houde et al., 2018; Green et al., 2006). There are correlations between on-ice performance and upper- and lower-body strength, body fat percentage, lean tissue mass, and VO_2max (Gilenstam et al., 2011; Kniffin et al., 2017; Potteiger et al., 2010).

2.4 Heart Rate Variability

Monitoring physiological, anthropometric, and fitness changes through longitudinal tracking throughout a player's season or career can enable coaches to modify training schedules and ultimately maximize player performance (Chiarlitti et al., 2021). Chiarlitti et al. (2021) reported that longitudinal assessments can help coaches and sports scientists assess the rigour of a regular hockey season. According to a study by Makivić et al. (2013), long-term (more than 4 weeks) HRV variations over a sustained duration of exercise can be a potentially useful predictor of training status in athletes. Using HRV parameters may provide a potential substitute for more invasive and expensive assessments, such as lactate or ventilatory threshold testing, to monitor the body’s response to exercise (Makivić et al., 2013). It could become a recurrent measure used more extensively in athletic training to improve an athlete's level of fitness (Makivić et al., 2013). Recent technology has allowed for the use of different low-cost HRV recording methods. Traditionally, HRV recordings were done using specialized software and an electrocardiograph assessment (ECG) in research laboratories (Georgiou et al., 2018).

HRV is a measure of the variation in time between each heartbeat. HRV has been used to track changes in the overall health status of many different diseases. An important role that HRV can play is in detecting and predicting overtraining (Achten & Jeukendrup, 2003; Aubert et al., 2003; Mourot et al., 2004). Barron et al. (1985) reported significant psychophysiological issues among overtrained athletes. Overtraining can be characterized by a compromised autonomic balance (Achten & Jeukendrup, 2003; Aubert et al., 2003; Mourot et al., 2004). A variety of analyses exist to measure autonomic imbalance, but HRV analysis is based on the standard deviation of the RR interval (SDNN) time series, which is "the sequence of intervals between successive fiducial points of R peaks of QRS complexes in the electrocardiogram (ECG)" (Ferrario et al., 2012). In other words, the RR interval is discussed as an event series rather than an equally sampled continuous signal (Ferrario et al., 2012). It has been demonstrated that variations in RR intervals from beat to beat correctly represent the variability of the sinoatrial node (Ferrario et al., 2012). As the RR interval increases, the heart rate (HR) decreases and the HRV increases, indicating better health and well-being of the individual. Increased HRV is often a result in the decrease of sympathetic activity and an increase in the parasympathetic system, which may exist in a well-trained state. In contrast, when the variability in the RR interval decreases, the HR increases and the HRV decreases in reaction to stress stimuli (Ferrario et al., 2012). The decrease in HRV occurs because the brain sends a signal to the ANS (Fatisson et al., 2016). As there is a stress stimulus, the sympathetic nervous system activates, creating a flight or fight response, and therefore decreases the HRV (Fatisson et al., 2016). The decrease in HRV is related to fatigue and therefore a reduction in performance (Fatisson et al., 2016). When the ANS receives feedback signals of rest and recovery, the parasympathetic nervous system is activated, creating a growth and recovery action (Fatisson et al., 2016). This, in turn, increases the HRV to improve readiness and may be associated with increased performance (Fatisson et al., 2016). Understanding that each individual's HRV is highly variable is crucial because there is no typical HRV.

Overtraining syndrome is difficult to diagnose, and because there are no specific diagnostic standards, it frequently results in a diagnosis of exclusion (Meeusen et al., 2006).

Assessments of overtraining status have mostly been studied in endurance athletes (Lundstrom et al., 2022).

The majority of HRV-based overtraining monitoring techniques rely on comparing an athlete's HRV to their baseline readings (Lundstrom et al., 2022). This approach accounts for individual differences in HRV and helps identify changes that may indicate overtraining (Lundstrom et al., 2022). Typically, HRV is measured daily or weekly to track trends over time. For example, Mourot et al. (2004) observed reduced HRV in overtrained athletes. In contrast, a study of elite canoeists during a 6-day intensive training camp found that HRV remained stable even as VO_2max and peak lactate levels declined, suggesting short-term fatigue rather than overtraining (Hedelin et al., 2000). These findings highlight the potential of HRV to differentiate between short-term training exhaustion and overtraining. However, it remains unclear whether HRV monitoring can reliably detect the early stages of overtraining (Lundstrom et al., 2022). Tracking HRV changes over time and comparing them to baseline values could be a valuable tool for identifying an overtrained state. Early detection would enable coaches and trainers to adjust training volumes, preventing further performance decline and reducing the risk of injury (Saw et al., 2016).

Athletes typically have higher HRV scores than sedentary individuals due to their higher levels of physical fitness (Dong, 2016). Furthermore, physically fit adults and trained athletes often have lower resting heart rates (RHR) because their hearts are more efficient at pumping blood throughout the body (Smith, 2021). Regular physical activity has also been shown to increase HRV, likely to improve cardiovascular function and a more balanced ANS (Dong, 2016). Essentially, a higher HRV may indicate improved cardiovascular health and increased stress tolerance (Smith, 2021).

While an athlete's HRV scores are generally expected to be higher than those of a sedentary individual, the exact values can vary based on a variety of factors, such as the athlete's age, gender, and training status (Achten & Jeukendrup, 2003). There is no specific HRV range considered "normal" for athletes, as HRV can be influenced by numerous physiological and environmental factors (Aubert et al., 2003). However, most active people have an HRV range of 46-72 ms (Umetani et al., 1998), while athletes typically fall between 50-100 ms range (Khazan, 2019). The range is measured using the standard deviation of normal-to-normal intervals (SDNN). As a time domain recording, SDNN values in the literature align with studies by Melanson (2000) and Plews et al. (2014), who found that all HRV measurements in healthy subjects were within the normal range. With technology advancements, tools and apps such as Elite HRV have made recording HRV more accessible (Morgan & Mora, 2017). Even in healthy individuals, HRV typically decreases starting at the age of 30 years old (Umetani et al., 1998). Factors such as age, sex, gender, health and hormonal status can all influence HRV (Umetani et al., 1998).

HRV is typically assessed in athletes upon waking up to avoid external factors that could influence the result (Kiviniemi et al., 2007). With new technology, at-home assessments are now possible, which improves generalizability by establishing consistent circumstances. Several studies use wearable technology, such as HR monitors or smartwatches, to gather HRV data in realistic scenarios (Giles et al., 2016). However, HRV assessments are often conducted in controlled laboratory settings, where environmental and behavioural factors can be closely monitored and controlled (Lundstrom et al., 2022).

Athletes can now use various applications such as HRV4Training™ and Elite HRV™, which have been validated for measuring daily HRV to set baseline values and evaluate their daily recovery state (Stone et al., 2021). It is important to have the right tools for measurements as factors such as the time of day of the recording or the duration of data collection can affect the results (Lundstrom et al., 2022). The length of HRV recordings varies depending on the research question and the specific methods used to collect and analyze the data (Aubert et al., 2003). For athletes, resting-only measurements of 30 minutes (Voss, 2007) or as little as 5 minutes have been used (Camm et al., 1996).

Long-term HRV recordings that last 24 hours up to several days, weeks or months are often used for mindfulness-based interventions in individuals with anxiety (Shaffer & Ginsberg, 2017). These recordings assess the overall variability of heart rate over an extended period and evaluate the impact of chronic stressors or interventions on HRV (Shaffer & Ginsberg, 2017). For athletes, short-term HRV recordings lasting between a few minutes to several hours are used to evaluate the acute changes in HRV caused by various stimuli such as exercise, stress or medication (Shaffer & Ginsberg, 2017).

Longitudinal tracking of individual athletes allows for greater insight into how these measures can be utilized for the individuals (Plews et al., 2013; Voss, 2007). When using short-term HRV monitoring in a longitudinal study, a minimum of 3 randomly selected valid recordings per week are needed to obtain an accurate assessment (Plews et al., 2014). Additionally, to reduce the confounding effects related to the time of the day, HRV recordings should be taken during specific and standardized periods of the day, such as upon waking in the morning (Plews et al., 2013).

During physical activity, changes in exercise intensity can affect HRV, which is regulated by the autonomic nervous system responsible for the body's physiological responses to stress and exercise (Makivić et al., 2013). The sympathetic (fight or flight) branch of the autonomic nervous system is activated during exercise to increase heart rate, cardiac output, and blood flow to working muscles (Makivić et al., 2013). This leads to a decrease in HRV, which depends on the intensity of the exercise (Makivić et al., 2013). As exercise intensity increases, HRV decreases, reflecting an increase in sympathetic nervous system activity (Makivić et al., 2013). Conversely, as exercise intensity decreases, HRV increases, reflecting a decrease in sympathetic nervous system activity and an increase in parasympathetic nervous system activity (Makivić et al., 2013).

For example, an intense 75 km ski race resulted in decreased HRV one day after the race, and the time to return to baseline levels was influenced by the athlete's VO_2max (Hautala et al., 2001). However, studies assessing a single exercise bout have reported little to no disruption to HRV (Lundstrom et al., 2022). The time course of HRV adjustment during exercise also varies depending on exercise intensity (Makivić et al., 2013). During high-intensity interval training (HIIT), HRV decreases rapidly and only partially recovers during the rest interval, reflecting the repetitive stimulation of the sympathetic nervous system during work intervals, followed by brief periods of parasympathetic nervous system activation during the rest intervals (Makivić et al., 2013). In contrast, during low-intensity exercise, such as light jogging, HRV decreases gradually and reaches a steady state after several minutes of exercise, reflecting a balance between the sympathetic and parasympathetic nervous systems, which is maintained during low-intensity exercise (Makivić et al., 2013).

In general, as exercise intensity changes during physical activity, HRV adapts to reflect the altered activity of the sympathetic and parasympathetic neural systems. The magnitude and time course of HRV adjustment varies depending on the exercise intensity and duration. Additionally, it has been demonstrated that increasing the overall volume of exercise reduces HRV (Buchheit, 2014). The difficulties of matching intensity across various activities make it difficult to conclude from the few studies that have examined differences in HRV during exercise in various modalities (Plews et al., 2013). Hence, HRV is an independent measure that is distinct from the heart rate itself. Heart rate refers to the number of times the heart beats in a minute, while HRV refers to the variation in time between successive heartbeats (Shaffer & Ginsberg, 2017). The heart rate-regulating sympathetic and parasympathetic nervous systems work in harmony to regulate HRV. When HRV is high, the parasympathetic nervous system is in charge whereas when it is low, the sympathetic nervous system is in charge (Ferrario et al., 2012). As a result, HRV is a useful marker of autonomic nervous system health, stress levels, cardiovascular function, and general physiological health (Bosquet et al., 2008).

In clinical settings, HRV is also often used to assess the autonomic balance between the sympathetic and the parasympathetic branches of the nervous system and to evaluate a patient's overall cardiovascular health (Pignotti & Steinberg, 2001). Additionally, it can monitor the effectiveness of treatments for conditions that affect the ANS and assist in the diagnosis of certain conditions such as sleep apnea and atrial fibrillation (Pignotti & Steinberg, 2001). Studies have reported that HRV is a predictor of health outcomes, such as sudden cardiac arrest and all-cause mortality (Sandercock et al., 2005). Lower levels of HRV have been observed in patients with chronic diseases including heart disease, heart failure, hypertension, and diabetes, indicating an increased risk of health challenges (Sandercock et al., 2005). In contrast, high HRV is associated with a decreased risk (Pignotti & Steinberg, 2001). In clinical settings, specialized software is used to analyze HRV data and calculate various HRV parameters, such as SDNN and root mean square of successive differences (RMSSD) (Pignotti & Steinberg, 2001).

A study by Sztajzel et al. (2008) compared the HRV of endurance athletes and hockey players to a control group of healthy individuals. Both hockey players and endurance athletes had higher HRV compared to sedentary individuals, but endurance athletes, such as runners or cyclists, had greater HRV than hockey players (Sztajzel et al., 2008). The distinct roles and off-ice training practices of hockey players, which vary according to their position, may have a significant impact on HRV (Kaukonen, 2019). For example, Stanula et al. (2016) found that there was a difference in the HR response of ice hockey players between different positions (forwards and defenseman), with forwards experiencing higher intensity during the game. As the game progresses, players spend more time in zones of higher intensity, which may be due to an accumulation of fatigue (Stanula et al., 2016). Therefore, a steady decline in HRV is the most typical reaction to overtraining, as the sympathetic branch of the ANS is involved in the reaction to stressors (Stanley et al., 2013). In the presence of overtraining, HRV declines as the resting

HR increases, and the declining effect may not fully recover to baseline levels before the subsequent training stimulus, causing a cycle that is repeated (Stanley et al., 2013). If the cycle is prolonged, HRV will often respond first with a falling trend that tracks with performance declines (Stanley et al., 2013). However, lower HRV due to short-term fatigue does not always predict a decline in performance (Thiel et al., 2011).

2.5 Body Composition

Assessing body composition is one of the many types of physiological monitoring. Body composition has an impact on the performance of athletes (Ackland et al., 2012). Many recent studies have been using DXA to assess body composition since it accurately measures bone mass, as well as fat and lean mass (Ackland et al., 2012; Bilsborough et al., 2014). Before DXA was available, ice hockey players were often assessed using skinfold measurements to estimate body fat percentage (Montgomery, 2006). Body fat was assessed to characterize player norms (Montgomery, 2006) and facilitate roster formation (Roczniok et al., 2016). Body composition is one of the most often measured fitness factors in professional ice hockey players (Ebben et al., 2004) since changes in lean body mass can influence both power and speed (Quinney et al., 2008).

A recent study of hockey players by Stanzione et al. (2020) found that throughout a season, lean body mass did not change significantly. This study confirms previous work from Delisle-Houde et al. (2019) and Prokop et al. (2016), who have examined changes in body composition in elite ice hockey players over the course of a playing season. Delisle-Houde et al.

(2019) reported that for collegiate male ice hockey players, total body fat changed by 1.2% from pre- to mid-season and by 1.2% from mid- to end season. However, lean muscle mass remained constant throughout the entire season. For collegiate female ice hockey players, an increase in total body fat of 1.3% from the start to the conclusion of the season and 1.2% from the middle to the end was seen. The rise in female fat mass from mid- to end-of-season was the main cause of this change in total body fat. Delisle-Houde et al. (2019) also reported a significant decrease in visceral adipose tissue of 27 g in female ice hockey players at mid-season compared with pre-season, and no change in lean muscle mass was reported throughout the season. Prokop et al. (2016) reported significant increases in adipose tissue between the end of the season and preseason, with reductions being observed between preseason and mid-season. More precisely, Prokop et al. (2016) showed no change in total body weight in the preseason (August–September), mid-season (November–December), and end season (February–March) among male ice hockey athletes. Additionally, Prokop et al. (2016) reported that there was no change in lean muscle mass or visceral adipose tissue over the course of the competitive season. However, there was an increase in fat mass from the end of the season to the beginning of the next season and a decrease in fat mass from the beginning to the middle of the season. The results of this research indicate that lean body mass and fat-free mass are rather stable throughout the calendar year in varsity male hockey players (Delisle-Houde et al., 2019; Prokop et al., 2016; Stanzione et al., 2020).

In contrast, a study by Dengel et al. (2021) tracked body composition over a competitive season in NCAA Division 1 collegiate ice hockey athletes and found different results from the Delisle-Houde et al. (2019) study. Dengel et al. (2021) found that male body weight, fat mass, and lean muscle mass did not significantly change throughout the season, whereas female players demonstrated declines in both lean mass and fat mass. However, likely the differences between the Delisle-Houde et al. (2019) and Dengel et al. (2021) studies can be explained by the timing of the DXA scans over the course of the season.

Due to the high physiological demands and the physical nature of the sport, ice hockey is a high-intensity activity that requires participants to be quick and powerful (Montgomery, 1988). According to Gilenstam and Geithner (2019), the skating speed of male and female ice hockey players increases with their relative lean body mass values, whereas their speed decreases with an increase in body fat (Potteiger et al., 2010).

The relationship between HRV and body composition has been demonstrated frequently using measurements of body mass index (Koenig et al., 2014), waist-to-height ratio, or waist circumference (Windham et al., 2012). Additionally, there is a substantial connection between HRV and exercise (Rennie et al., 2003). Because lower lean mass and higher body fat, when measured with BMI, are associated with lower levels of exercise and parasympathetic depression, body composition may be a physiological mediator in the connection between exercise and enhanced HRV (Rennie et al., 2003).

2.6 Assessing Well-Being

Subjective monitoring of athletes involves self-reported data from athletes on their perceived mood, sleep, stress levels, and energy/fatigue levels (McLean et al., 2010). Support staff or coaches can confidently use these self-reported measures, as they reflect changes in the athlete's well-being and offer useful strategies for long-term athlete monitoring (Saw et al., 2016). Teams have used multiple questionnaires, such as the POMS, DALDA, RESTQ-S, to obtain athletes' self-reported measures of fatigue levels and training loads (Thorpe et al., 2017).

Athlete self-report measures (ASRM) are simple and inexpensive questionnaires used by multiple sports in research (Saw et al., 2015). There is growing support in the literature suggesting that ASRMs may be more sensitive and reliable than traditional performance measures(VO_2max, 1RM strength test, time-trial performance, and others) used for monitoring athletes (Buchheit et al., 2013).

The ASRMs typically include questions about key factors such as fatigue, sleep quality and quantity, muscle soreness, stress, and mood (Buchheit et al., 2013; Hogarth et al., 2015; Johnston et al., 2013). Some ASRMs also incorporate questions related to depression, confusion, emotional stress, social recovery, sleep quality and self-efficacy. However, these additional questions may have limited utility for monitoring athlete well-being in a context unrelated to training (Saw et al., 2016). To improve effectiveness, the focus should shift toward indicators more directly linked to athletic performance and recovery, such as non-training stress, fatigue, physical recovery, self-regulation, and low energy levels (Saw et al., 2016).

The subjective wellness questionnaire developed by McLean et al. (2010) was created to measure the athletes' subjective experience of fatigue. The questionnaire can be completed daily or once a week to monitor changes in fatigue over time (McLean et al., 2010). Athletes from various sports, including endurance, team, and power sports, have verified the questionnaire (Buchheit et al., 2013). The subjective wellness questionnaire is simple to use, affordable, and can evaluate several aspects of fatigue. Combining this questionnaire with additional physiological measurements like HRV can provide a thorough evaluation of athletes' tiredness.

Many studies have used the subjective wellness questionnaire developed by McLean et al. (2010) to examine various aspects of athlete performance. One study examined neuromuscular, endocrine and perceptual fatigue responses in athletes throughout a 26-week professional rugby league season (McLean et al., 2010). Another study also focused on professional rugby league, explored post-match neuromuscular, biochemical and perceptual fatigue and utilized the McLean et al. (2010) questionnaire (Twist et al., 2012). A third study, focusing on youth rugby, evaluated in-season neuromuscular and perceptual fatigue and found similar results using the same questionnaire (Oliver et al., 2015). In addition to youth sport, Sawczuk (2019) evaluated the true predictive capacity of an integrated athlete monitoring cycle model with regard to illness incidence and included the subjective wellness questionnaire from McLean et al. (2010) in their research. Finally, Carmichael et al. (2021), Buchheit et al. (2013) and Flatt et al. (2017) studied Australian football players, elite football players, and sprint swimmers, respectively, and used the McLean et al. (2010) questionnaire to assess subjective wellness.

Only a few studies (Buchheit et al., 2013; Flatt et al., 2017; Johnston et al., 2013) have assessed HRV and subjective wellness, and none have done it for hockey players. To date, REST-Q and POMS have been the more commonly used subjective wellness questionnaires, despite their length (Sawczuk, 2019). Unfortunately, in practice, it is not feasible to have athletes spend 10 to 15 minutes per day filling out these questionnaires (Sawczuk, 2019). Therefore, shorter questionnaires that takes 1 to 2 minutes to complete are more practical (Sawczuk, 2019).

Another type of subjective measure is the rating of perceived exertion scale (RPE), which provides insight into the exercise intensity perceived by the athlete. Both questionnaires and RPE scales are important as they reveal how athletes are feeling at any given time and help better manage their energy levels. However, some questionnaires may be time-consuming and extensive, which may be beyond what a typical coach needs. Therefore, multiple teams have customized questionnaires, making them shorter in duration and targeting specific information to quickly monitor the health and well-being of their athletes (Taylor et al., 2012). These adapted questionnaires have been designed to be relatively time-efficient (Beckmann & Kellmann, 2003). This is important since for acute and chronic training loads, self-reported measurements were more sensitive than objective measures such as HR, HR response, oxygen consumption and blood markers (Saw et al., 2016). Monitoring done subjectively is susceptible to change, both in terms of training loads and overtraining status (Saw et al., 2016). Consequently, some athletes may deteriorate on the well-being continuum with insufficient recovery following heavy continuous loading (Schwellnus et al., 2016).

Understanding the psychological stress an athlete is feeling, may be crucial for determining future training adaptations and for tracking and reducing fatigue. Different definitions of fatigue exist, and it is well-recognized that several factors can affect levels of fatigue (Halson, 2014). Strober and DeLuca (2013) defined fatigue as “the inability to function at the desired level due to incomplete recovery from demands of prior work and other waking activities." It is an important concept that coaches and practitioners must be aware of since ongoing fatigue leads to overtraining. Overtraining is defined as "an imbalance between training and recovery resulting in severe and prolonged fatigue" (Kuipers & Keizer, 1988), and overreaching is defined as "short-term overtraining" (Kuipers & Keizer, 1988). In competitive athletes, reduced performance, mood swings, and other changes in affective states are frequently recognized as reliable, perceptible, and early indicators of overtraining and overreaching (Meeusen et al., 2006; Urhausen & Kindermann, 2002).

Therefore, tracking how elite athletes respond to stress and well-being to gain useful data for their practical setting is valuable for coaches and practitioners (Thorpe et al., 2017). An important and easy method to assess levels of fatigue and overtraining can be with the use of questionnaires. These measures are valuable since they provide a subjective evaluation of the athlete's perception and help quantify the adaptive response to stress and overload.

Little research has been conducted, exploring the relationship between subjective well-being and HRV in ice hockey players. However, similar studies have been conducted on other athlete populations. Using a nine-item well-being questionnaire, Gastin et al. (2013) concluded that self-reported player ratings of wellness provide coaches and practitioners with a useful tool to monitor player responses to the high demands of training, competition, and life as an elite athlete. A study by Flatt et al. (2018) found that changes in HRV may be associated with subjective sleep quality, fatigue, stress, and mood in Division 1 sprint swimmers after four weeks of monitoring. These findings may have implications for designing targeted therapies when HRV declines are seen (Flatt et al., 2018). In addition, a decline in an athlete's HRV and subjective evaluation of well-being can signal to practitioners and coaches that the athlete may be at risk of chronic over-training (Flatt et al., 2018). Therefore, it is important to reduce the training volume to prevent this from happening (Flatt et al., 2018). This suggests that changes in perceived fatigue may occur before declines in physical performance (McLean et al., 2012). These findings are consistent with those of McGuinness et al. (2020), who studied elite female field hockey players and reported that changes in players' well-being were associated with declines in running performance. In fact, psychological monitoring is considered useful and important in determining how each person responds to training, as it is a non-invasive, low-cost, simple measure of tracking fitness and emotional health (McGuinness et al., 2020; McLean et al., 2012).

2.7 Between-sex differences in sports performance

Female hockey players have been understudied compared to their male counterparts (Auster, 2008). In a systematic review from Chiarlitti et al. (2021), on physiological and fitness evaluations in ice hockey players, it was reported that out of 23 studies, only 2 included female players in the trials. Women generally have lower variability in the time series of heartbeats, which may be explained by higher parasympathetic activation (Koenig & Thayer, 2016). Furthermore, studies show that male and female body composition differs in terms of aerobic and anaerobic properties, with males typically being taller, heavier, having larger muscle mass, and lower fat mass (Esbjornsson-Liljedahl et al., 2002; Jacobs et al., 1983). Gilenstam et al. (2011) examined the association between off-ice physiological tests and on-ice performances in male and female ice hockey players. They demonstrated that women's skating performance was predicted by off-ice fitness, but this was not true for men (Gilenstam et al., 2011). When lean body mass was considered, between-sex differences in off-ice variables were less pronounced (Gilenstam et al., 2011). Several variables such as anthropometric measurements, body composition, muscle strength, agility, and aerobic performance differ between male and female hockey players.

There are some differences in HRV between men and women, although the exact nature of these differences can vary depending on the specific HRV measure being used (such as time-domain measures) (Sookan & McKune, 2012). One study found that, on average, women have lower HRV than men, especially in measures of parasympathetic activity (Koenig & Thayer, 2016; Sookan & McKune, 2012). This may be due to differences in the anatomy and physiology of the ANS between men and women. In healthy people, females demonstrate greater parasympathetic regulation of cardiovascular activity than males (Du et al., 2006; Taylor et al., 2000). It has been reported that estrogen, oxytocin, and neural control may explain these differences (Du et al., 2006; Taylor et al., 2000). Other studies have found that women tend to have higher HRV scores during the follicular phase of the menstrual cycle (which corresponds to the time of ovulation), while men tend to have more stable HRV scores throughout the month (Kokts-Porietis et al., 2019; Tenan et al., 2014). The use of menstrual cycle assessment in HRV can help measure the changes that occur during a woman's cycle, such as variations in heart rate. Studying these variations helps researchers better understand how hormones affect a host of physiological responses in the body.

It is important to note that these differences are only general trends, and individual HRV scores can vary widely depending on a variety of factors, including age, physical fitness, and overall health. In addition, some studies have found that HRV differences between men and women may also be influenced by social and cultural factors, such as stress and lifestyle habits (Pickering, 1999; Valentini & Parati, 2009).

To reduce the knowledge gap in health research, sports scientists must invest time in studying female athletes. There is a need to include women in sports science research to provide coaches with insights to develop sex-specific training programs for their female athletes.

Chapter 3 – Methods

The primary aim of this study was to investigate the relationship between changing HRV and body composition, as well as the subjective wellness of male and female student-athletes, over an academic semester. These changes were assessed concerning markers of overtraining. The secondary aim was to explore sex differences in the changing physiologic or psychological measures over the fall semester in varsity athletes.

3.1 Participants

Members of the McGill Redbirds men's varsity hockey team and the McGill Martlets women's varsity hockey team aged between 18 years and older were invited to participate in the study. We anticipated that approximately ± 50 players would partake in the study during the 2023-2024 season.

To be eligible for participation, players must have met the following criteria:

1) be at least 18 years old.

2) be a member of the McGill Varsity Hockey Team (as listed on the roster).

3) not have a current season-ending injury that would restrict their participation in the study (e.i., broken bones, torn ligaments, concussions).

If a player sustained an injury during the academic semester, they remained in the study unless it was a season-ending injury. The injury was documented, including the nature of the injury and the treatment provided, and we considered whether the injury may affect the validity of the data in the analysis. In case of such an event, we used the Last Observation Carried Forward analysis to handle the situation. This approach is commonly used in longitudinal studies to maintain data integrity and minimize bias due to dropout or injury-related absences (O'Connell et al., 2011).

3.2 Timeline

The study involved two monitoring sessions conducted during the playing season: one at the end of August and one at the beginning of December. During these sessions, body composition assessment using a whole body DXA scanner was performed while the participants wore light training clothes. Each session was expected to last approximately 30 minutes and was conducted in the Health and Fitness Promotion Laboratory by graduate research assistants from Dr. Andersen's lab who are not hockey team members. At the beginning of August, undergraduate students from the McGill community were recruited to assist in the study. The assistants were responsible for tracking the HRV recordings and the questionnaire responses and reporting to the graduate student in charge.

In addition, the athletes were asked to record their HRV at home every two weeks (for a total of ten weeks) during the first academic semester. These recordings were done in the morning, after waking up, and lasted less than ten minutes. The participants were encouraged to keep their chest straps close to their beds. Every recording took less than ten minutes. A minimum of three randomly valid recordings were needed to provide a successful week.

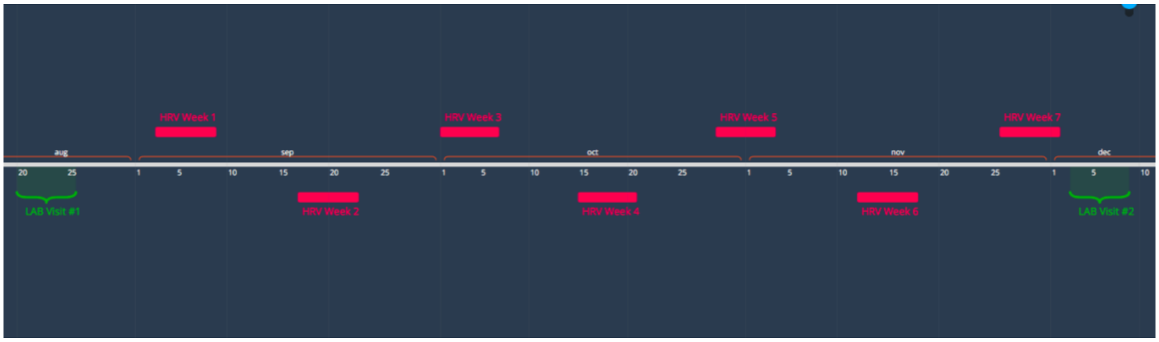

Figure 1 Timeline of the research

3.3 Anthropometric Measures

The athlete’s height and weight were measured during the first monitoring session at the end of August. The height was assessed using a Seca 216 wall-mounted stadiometer and the weight was tracked to the nearest 10th kilogram using a Seca 635 platform and bariatric scale (Seca, Birmingham, UK).

3.4 Body Composition

An iDXA scanner, GE Encore 11.20 scanner and software, was used to provide estimates of whole body and regional (e.i., arm, leg) body composition, including muscle mass, fat mass (%), and bone density. Scan time took approximately 20 minutes per person.

3.5 Questionnaire

The athletes' perception of wellness was assessed using a self-report questionnaire (Appendix 2) consisting of five questions evaluated on a scale from 1 (lower wellness score) to 5 (higher wellness score). This questionnaire was originally developed by McLean et al. (2010) and has been used in previous studies that have demonstrated its reliability and validity (McLean et al., 2010; Sawczuk, 2019; Thorpe et al., 2016). The questionnaire was sent by email every morning when the athletes recorded their data, serving as a reminder to complete the questionnaire and record their HRV.

3.6 Heart Rate Variability

HRV and RHR were assessed using a small chest strap device. The following test was conducted: a 5-minute seated test upon waking, as determined by previous literature. Several measures were recorded, including heart rate, resting heart rate, and heart rate variability. The test was conducted at home using a Polar Heart Rate monitor (Polar H10) and the Elite HRV app. The Elite HRV app generated an Excel sheet that allowed us to extract the data. We strongly recommended that the athletes wear the chest strap and sync it with their phone before going to bed so that it would remind them to complete the recordings first thing in the morning, before using their phone or doing anything else.

3.7 Analysis

Data was collected and interpreted through proprietary software and then analyzed using the statistical software SPSS (v. 27.0). Changes in physiological measures (i.e., HRV and body composition), and subjective wellness for the first semester of a university season were analyzed using repeated measures ANCOVA, with age and sex covariates. Multiple regression and Pearson correlations were used to explore relationships among the variables of interest, such as HR, HRV, % of body fat, fat distribution, lean tissue mass and subjective wellness. Sex-time interactions were explored using repeated measures ANCOVA.

3.7.1 Sample size calculation

For the proposed pilot investigation, all players were recruited from the McGill Redbirds and Martlet varsity hockey teams. Both of the teams' head coaches agreed to allow their athletes to participate. In addition, the Health and Fitness Promotion laboratory has an excellent history with these hockey teams. We anticipated that players would be interested in participating in this innovative proposed testing protocol. We expected that both the Men's and Women's Varsity teams would have 25 players each, in the 2023-2024 season. We had hoped to be able to detect at least a modest effect size, as defined by Cohen (1992). Using the G-Power™ sample size calculator (Kang, 2021) to estimate sample size, we set α to 0.05 and power ($1-\beta$) to 0.80. Using a repeated measures ANCOVA protocol, we would be able to pick up an overall modest effect (Cohen, 1992) with a total sample of 24 subjects. To detect between-sex interactions, we will need a total sample of 34 subjects. Therefore, with a total of 50 players (25 per team), we would have adequate statistical power to investigate trends of interest in this pilot investigation.

Chapter 4

Manuscript 1

Relationship among heart rate variability, body composition and perceived wellness in collegiate varsity ice hockey players

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Running Head: Heart rate variability, body composition and subjective wellness changes

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4.1 Abstract

The purpose of this study was to compare changes in heart rate variability (HRV), body composition, and subjective wellness between male and female collegiate hockey players over an academic semester. Participants underwent, pre- and post-semester, dual-energy X-ray absorptiometry (DXA) scans to measure body composition and used Polar H10 chest straps for biweekly HRV recordings over 12 weeks. Subjective wellness was assessed via a questionnaire addressing sleep quality, fatigue, muscle soreness, stress levels, and overall mood. HRV and subjective wellness were collected every morning biweekly. A repeated measures ANOVA and mixed linear regression modelling was used to evaluate the interactions among sex, time, and various physiological and psychological metrics. There were significant sex-by-time interactions in HRV metrics, with males consistently showing higher HRV than female players. Females showed increased HRV values from week 1 to week 12, while males exhibited a decrease. Both sexes experienced improvements in body composition, with decreased body fat percentage and increased lean mass over the semester. Additionally, subjective wellness scores were higher in males. These results suggest that tailored recovery protocols based on HRV and sex-specific responses could enhance athlete performance and well-being. Understanding sex differences in physiological and psychological responses is crucial for optimizing training and support strategies for varsity hockey players.

Key words: Heart rate variation, Subjective wellness, Body Fat, Gender differences, Ice hockey

4.2 Introduction

Hockey captivates audiences worldwide with its intense physicality and strategic complexity. It is prominently featured in the Winter Olympics and is celebrated as one of the most thrilling team sports globally. In Canada, hockey is more than just a game; it is a national pastime and an integral part of modern culture (Gruneau & Whitson, 1993). According to a 2022 report by the Canadian Heritage Department (Canadian Heritage, 2022), hockey remains the most popular sport in Canada, with millions of fans and thousands of young athletes aspiring to reach professional levels. In recent years, women's hockey has seen a significant rise in popularity and participation, buoyed by the creation of the Professional Women's Hockey League (PWHL). Debuting in 2023, the PWHL quickly made its mark by achieving record sellouts at games, signaling a growing demand for women's professional hockey. This development underscores the increasing visibility and support for women in the sport, further highlighting the need for comprehensive studies that include both male and female athletes to enhance understanding and support for all players.

The demanding nature of hockey, especially at the varsity level, necessitates a well-structured approach to training and recovery, known as periodization. Periodization helps manage the athletes' fitness and well-being over the entire competitive season, addressing the changing physical and psychological demands placed on them. Student-athletes face unique challenges as they balance the rigours of academic responsibilities with the high demands of competitive sports (Vetter & Symonds, 2010). The stress of travelling, competing, training, and maintaining academic standards can significantly impact their overall well-being, fitness and performance. While there has been considerable research focusing on male hockey players, a gap exists in the literature as it relates to the physiological and wellness changes in female hockey players (Chiarlitti et al., 2021). Even fewer studies have compared these changes between male and female athletes, highlighting a critical gap in the literature.

Heart rate variability (HRV) has recently emerged as a metric for coaches and sports scientists to monitor athletes' training status and subjective well-being throughout the competitive season. Longitudinal HRV assessments are increasingly utilized in various sports, such as soccer (Ayuso-Moreno, Fuentes-Garcia, Collado-Mateo & Villafaina, 2020) and basketball (Staunton et al., 2018), due to its potential to provide insights into autonomic nervous system function, recovery and training status. HRV monitoring is relatively low-cost and with new technology, the ease of remote data collection makes it accessible for both in-season and off-season training. Despite its potential, there is a paucity of research on the application of HRV in hockey players, particularly in studies comparing male and female athletes over a competitive season. Addressing this gap could allow sports scientists to develop tailored and effective training and recovery protocols for hockey players.

Therefore, the purpose of this study was to track HRV in male and female varsity hockey players across the first academic semester of an academic year. We examined changes in HRV, body composition, and subjective wellness over an academic semester. This study aimed to provide a comprehensive understanding of the physiological and psychological demands faced by these athletes, which may contribute to improved training strategies and overall athlete support.

4.3 Methods

Experimental Approach to the Problem

During the season, players reported to the on-campus Health Promotion Laboratory at two time points (i.e., pre-semester and end-semester) where they completed a whole-body DXA scan, followed by the receipt of a Polar H10 chest strap reception for home monitoring of HRV. The DXA testing sessions were performed in the morning (i.e., 8:00 A.M.-12:00 P.M.) prior to team practice to accommodate players' academic and athletic schedules. Also, the timing of the session allowed players to avoid food consumption for 2-3 hours before the test. The HRV testing was performed in the morning, at home every second week, at waking time to gain a clear picture of the autonomic nervous system activity.

Subjects

Forty elite Canadian collegiate hockey players, twenty-one females (age = 20.28 ± 1.14 years, height = 1.70 m ± 0.05 m, weight = 67.03 kg ± 7.03 kg) and nineteen males (age=23.10 ± 1.57 years, height = 1.82 m ± 0.04 m, weight = 85.65 kg ± 5.30 kg), completed the study. The Medical Ethics Institutional Review Board of McGill University approved the protocol of this study, and all players gave written informed consent to participate in this study.

Procedures

Heart rate variability. The heart rate variability longitudinal recordings were performed for a minimum of 3 days, with the possibility of extending to 7 days, every second week in the morning for 12 consecutive weeks. Upon awakening, the athletes were asked not to eat or drink and to assume a seated position. They were instructed to apply a slight amount of water to the sensors of the chest strap. The participants wore the chest strap (Polar H10, Kempele, Finland) around their chest at the level of the xiphoid process and recorded their heart rate variability for 5 minutes using the Elite HRV app (available on Android and iOS) downloaded on their phones. They were instructed to relax and refrain from any activity until the recording was completed to eliminate other variables and potential stimuli. The chest straps were then removed and kept at the participants' homes for the duration of the study. At the end of the semester, the chest straps were collected. The HRV data collected via Elite HRV apps were automatically synced to a secured cloud-based platform, allowing investigators to access the data remotely for subsequent analysis. The HRV data collected included the overall HRV, the standard deviation of the normal-to-normal (SDNN), the root mean square of successive differences (RMSSD) and the log-transformed root mean square of successive R-R intervals (LnRMSSD).

Subjective Wellness Questionnaire. The subjective wellness questionnaire developed by McLean et al. (2010), tracked the athletes' perception of wellness. This self-report questionnaire consisted of 5 questions using a Likert scale from 1 (lowest wellness score) to 5 (highest wellness score). The specific areas covered by the questionnaire included sleep quality, fatigue, muscle soreness, stress levels and overall mood, providing a brief overview of the athletes' well-being. The researchers sent the questionnaire via email, while the team captains shared it in their respective group chats. This occurred each morning, every two weeks, over 12 consecutive weeks. The athletes were reminded to complete the questionnaire, following their HRV recording. This timing was chosen strategically to minimize disruption of their routine and to ensure that the subjective data collection was aligned with the objective physiological measurements. Reminders were critical to maintaining high response rates and ensuring the consistency and reliability of the data collected. Upon completion, responses were automatically collected and stored in a secure database to ensure confidentiality. The collection process was done remotely and was designed to be as seamless as possible, to encourage honest and accurate self-reporting from the athletes.

Body composition assessment. Height was measured to the nearest centimetre 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). DXA scan (General Electric Encore 11.20; Madison, Wis., USA) and corresponding software (GE’s Lunar software en CORE v13.60) was used to assess body composition (i.e., fat mass (kg), lean mass(kg), percent body fat (%)). The DXA was calibrated daily using standard calibration blocks provided by the manufacturer to ensure the accuracy and precision of the measurements. Participants wore standardized athletic shorts and t-shirts for the assessment and all metal jewelry was removed. 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 players were asked to remain still during the procedure and to keep the initial distance between limbs to avoid crossover during the analysis (Bilsborough et al., 2014). Data from the DXA scans were securely stored in the database and were only accessible to authorized research personnel to maintain confidentiality.

Statistical Analysis

Data were collected and interpreted through proprietary software and then analyzed using the statistical software SPSS (v. 29.0). Changes in physiological measures (i.e., HRV and body composition), and subjective wellness over the first semester of a university season were analyzed using repeated measures ANOVA, to explore sex by time interactions. Mixed linear regression with effect for time and interaction effect for sex and time was used to determine relationships among the variables of interest, such as HRV, percentage body fat, fat distribution, lean tissue mass and subjective wellness.

Initially, fifty players were recruited for the study. However, ten players were dropped for reasons including three being cut from the team, one leaving for injury reasons, two did not complete the study and four players did not record enough data to be included in the analysis. As a result, forty players completed the study. This approach ensured that only consistent data contributed to the analysis, enhancing the reliability of the findings.

Regarding compliance with wearing the HRV belt, approximately 80% of the players adhered to the requirement, while 20% did not record sufficient data. This missing data was accounted for by excluding these players from the final analysis, ensuring that the dataset remained robust and the findings were reliable.

4.4 Results

The baseline and follow-up characteristics of the participants are presented in Table 1. Significant sex differences were observed in age, height and weight. It can be seen that the male players had 30% more lean mass than their female counterparts. Additionally, the female players had 2,71kg more fat tissue than the male players at baseline.

Body composition profiles. Significant changes in body composition were observed in both male and female athletes over the semester. Males' body fat percentage decreased ($p \leq 0.05$) by 1.4% from the baseline of the semester to the end of the semester. Among females, body fat percentage also decreased ($p \leq 0.05$) by 1.5% from the baseline of the semester to the end of the semester. Fat mass decreased ($p \leq 0.05$) in males and females by 1.24 kg and 1.13 kg respectively at the end of the semester in comparison with the baseline of the semester. Males' lean mass increased ($p \leq 0.05$) by 0.76 kg from baseline to end of the semester, while females also increased their lean mass by 0.64 kg from baseline to end of the semester. Body fat percentage changes were significantly different between males and females from baseline to end of semester ($p \leq 0.05$), as well as fat mass, visceral fat mass, total mass and lean mass ($p \leq 0.05$). The female player also had significantly less ($p<0.05$) visceral adiposity at baseline and follow-up compared to their male counterparts.

Heart rate variability. The time-domain measurements (Figure 1) that were used to monitor short periods that ranged from 1 min to 24h from an app called Elite HRV and ranged their heart rate variability data from 0 to 100. HRV is the difference in time (ms) between the heartbeats. RMSSD is the root mean square of successive differences and represents a relevant measure of the autonomic nervous system (Shaffer & Ginsberg, 2017). LnRMSSD is for the natural log applied to the RMSSD and distributes the number into an easier to understand range whereas SDNN stands for the standard deviation of the NN intervals.

A repeated measures ANOVA with Greenhouse-Geiser correction was conducted to explore the effects of sex and time on the different metrics measured by the Polar H10. Additionally, the interaction effect between sex and time was examined. The HRV metric indicated that the interaction effect between sex and time was significant ($F(2.908, 38)= 3.473$, $p = 0.020$).

For SDNN, there was a significant sex-by-time interaction effect ($F(3.042, 38)=3.237$, $p = 0.024$). There was also a significant linear relationship between sex and time ($p = 0.012$). RMSSD also demonstrated a significant linear relationship over time ($p = 0.014$) an interaction effect between time and sex was found ($F(2.735,38)= 3.481$, $p = 0.022$). For LnRMSSD, a repeated ANOVA with Huynh-Feldt correction revealed no significant effect of time ($F(3.918,38)=0.783$, $p= 0.535$) or sex ($F(1,38)= 1.408$, $p=0.243$).

All means were observed to be lower in females than males. From week 1 to week 12, we observed that the HRV, SDNN, RMSSD and LnRMSSD increased over the semester for females, whereas a decrease in HRV, SDNN and RMSSD for males was observed. At week 1, we observed the largest difference between males and females in HRV which was a difference of 6.71 ms (60.13 vs 66.84), in SDNN it was 43.76 ms (88.61 vs 132.37), in RMSSD was 29.03 ms (60.94 vs 89.97) and in ln RMSSD a difference of 0.34 ms (3.93 vs 4.27) was observed. Additionally, we confirmed that males (66.066 ± 0.711ms) have consistently higher HRV than females (62.764 ± 0.685ms).

Subjective Wellness Questionnaire. Changes in Subjective Wellness (SW) are plotted in Figure 2. A repeated measures ANOVA with Huynh-Feldt correction explored the effects of sex, time and the interaction effect between sex and time was performed. There were no effects for either time on SW ($F(4.889, 34)= 0.683$, $p = 0.634$) or sex by time interaction effects ($F(4.889,34)= 0.284$, $p = 0.918$). However, there was a significant effect for sex, $F(1, 34)= 4.717$, $p = 0.037$), with the men's team reporting higher ratings of SW at each time point.

Relationship Between Changes in HRV and Subjective Wellness Questionnaire. A mixed linear regression model was used to explore relationships between HRV and SW over time. We found that reports of subjective wellness predicted HRV ($p = 0.006$), suggesting that higher reports of SW were associated with increased HRV.

4.5 Discussion

The present study is the first to our knowledge, to investigate the relationship among changes in HRV, body composition, and subjective wellness of male and female varsity hockey players over an academic semester. In addition, sex differences between these evolving physiological and psychological measures were also explored. Previous studies have demonstrated the importance of these measures independently. For example, Plews et al. (2017) and Esco et al. (2018) highlighted the utility of HRV in assessing training adaptation and recovery in soccer and basketball athletes, while Kerr et al. (2019) and Schaal et al. (2011) underscored the significance of addressing psychological aspects to support athlete well-being. Additionally, Thomas et al. (2016) and Ackland et al. (2012) documented the benefits of improved body composition on performance and health. However, limited research has explored the interrelationship among HRV, body composition, and subjective wellness over a competitive season, particularly considering sex differences.

One of the most important findings of this investigation was that the time domain measurements of HRV revealed a significant sex–by-time interaction over the semester. Specifically, the data showed that male athletes experienced a decrease in HRV over the semester, while in contrast, female athletes experienced an increase in HRV. An increase in HRV generally suggests better autonomic nervous system function and less fatigue, indicating that females may have experienced improved recovery or adaptation to training compared to their male counterparts (Shaffer & Ginsberg, 2017). This indicates that coaches working with both male and female athletes need to be aware of these differences, since HRV, may be influenced by training load, recovery and stress (Esco et al., 2018; Plews et al., 2017). Previous research has highlighted sex differences in HRV, suggesting that male and female athletes may respond differently to training loads and recovery processes (Nunan, Sandercock & Brodie, 2010; Buchheit & Gindre, 2006). The lower HRV values observed in females compared to males may reflect differences in autonomic regulation, potentially influenced by factors such as hormonal fluctuations, training load, and recovery processes (Esco et al., 2018; Plews et al., 2017). The significant interaction effects indicate that the relationship between sex and HRV metrics is complex and may vary across different time points and measures. At week 1, significant differences between males and females were observed, with females having the lower measures for HRV, SDNN, RMSSD and lnRMSSD. This suggests that females may experience greater autonomic stress at the beginning of the competitive season, potentially due to differences in adaptation to training loads or other physiological factors. These findings are consistent with previous research indicating that female athletes may have different autonomic responses to training stress compared to males (Stanley et al., 2013; Al Haddad et al., 2011). Additionally, HRV has been linked to performance success in professional elite long jumpers athletes (Coyne, Coutts, Newton & Haff, 2021). The observed sex differences suggest that female athletes might initially experience higher levels of autonomic stress and fatigue compared to their male counterparts, implying that women might need more tailored recovery strategies at the beginning of the season. Conversely, males may be more rested initially and could experience a decline in HRV later in the season, indicating a need for different adjustments to training and recovery plans over time. In the context of hockey, these findings represent an important first step in understanding how physiological responses vary by sex. Coaches should consider these differences when planning practice, training loads and recovery strategies, as changes in HRV can provide valuable insights into the athletes' training status and overall readiness (Coutts & Duffield, 2008).

A second finding of interest is the observed sex differences in subjective wellness. Interestingly, subjective wellness did not change significantly over time, there were notable sex differences at each time point, with males generally reporting higher levels of subjective wellness. In other words, the higher score reported less stress, lower fatigue, less soreness better mood and improved sleep. This difference could be attributed to various factors, including differences in psychological resilience, perceived stress, and coping strategies between the sexes. Subjective wellness, encompassing factors such as sleep quality, fatigue, muscle soreness, stress, and overall mood, offers valuable information on an athlete's mental state and resilience (McLean et al., 2010). Future work should seek to increase the understanding of these differences. This will be crucial for developing tailored mental health and wellness programs that address the specific needs of both male and female athletes. Previous research has highlighted the importance of addressing sex-specific psychological needs in athlete populations to enhance overall well-being (Kerr et al., 2019; Schaal et al., 2011). Additionally, subjective wellness did not change over the semester, suggesting that the coaching staff and strength and conditioning programs effectively managed the stress levels of the athletes. This finding aligns with studies in other sports, such as swimming and endurance sports, where well-managed training programs have been shown to maintain or even improve athletes' subjective wellness (Saw, Main & Gastin, 2016; Hooper et al., 1995). Coaches should be aware that higher levels of subjective wellness are crucial for optimizing athletic performance and preventing burnout in varsity athletes. Regular assessments of subjective wellness can help identify athletes in need of additional support and adjustments in their training regimens (Plews et al., 2013).

We also explored the relationship between HRV and subjective wellness and we confirmed that subjective wellness does indeed predict HRV. In addition, we observed that males consistently had higher HRV compared to females. Previous studies have shown an association between HRV and competition anxiety levels in elite female soccer players (Ayuso-Moreno, Fuentes-Garcia, Collado-Mateo & Villafaina, 2020). Moreover, prior research from Plew et al. (2017) and Esco et al. (2018) supports the findings and shows that sex differences in HRV have important implications for training and recovery. This highlights the complexity of the factor influencing athlete health and performance, suggesting that multiple dimensions of wellness need to be considered. The consistently higher HRV in males further underscores the potential sex differences in autonomic regulation and stress resilience. It is also possible that males were in a better state of recovery over the semester, which could explain their higher HRV levels.

Optimal body composition is critical to optimize ice hockey performance. We found that fat mass decreased while lean mass increased over the semester in both the male and female players. This suggests that a good balance between training and competitive activities took place throughout the semester. These results indicate that the training regimens and physical activities undertaken by the athletes were effective in improving their body composition, which is critical for both optimal on-ice performance and overall health. The reduction in fat mass, coupled with an increase in lean mass, can enhance athletic performance by improving strength, power and endurance, while also potentially reducing the risk of injury and improving metabolic health (Ackland et al., 2012; Thomas et al., 2016). These results align with previous studies that have also shown similar positive body composition changes in athletes undergoing structured training programs (Ibitoye et al., 2017; Milsom et al., 2015). However, this contrasts with findings from other studies, such as Kim's research on football players and Delisle-Houde’s research on hockey players, where athletes did not show expected improvements in body composition early in the season (Kim, 2020; Delisle-Houde et al., 2019). This is particularly noteworthy as university students often face lifestyle challenges that can negatively impact their health, such as academic stress, poor dietary habits and alcohol consumption (Statistics Canada, 2022). Therefore, the consistent work with strength and conditioning coaches and the focus on well-being likely contributed to these positive outcomes.

A strength of this study was the use of the Polar H10 chest strap for HRV measurement, which allowed for data to be collected remotely. These methods provide a non-invasive remote way to monitor training loads and physiological responses, offering valuable insights for coaches and exercise scientists (Nunan et al., 2009; de Zambotti et al., 2019). Additionally, the inclusion of both male and female athletes also addresses the underrepresentation of women in hockey research. The longitudinal nature of the study, tracking athletes through an academic semester, allowed for a comprehensive analysis of both physiological and psychological aspects, which are critical for understanding the changes in the overall well-being of student-athletes (Buchheit, 2014). Although this may limit the generalizability of the findings, the study's focus on elite-level athletes from the same school and varsity program helped maintain similar conditions. Furthermore, to our knowledge, this was the first study comparing the longitudinal impact of HRV, body composition and subjective wellness in elite hockey players.

We acknowledge that the sample size of this pilot investigation may limit the generalizability of the findings. Future research should aim to replicate these findings with larger, more diverse samples to enhance the robustness of the results (Hopkins, 2000). Additionally, the study was limited to varsity athletes from one university, suggesting the need for future studies to include multiple universities across Canada to provide a broader perspective.

Another limitation of this study was that we only performed assessments over the first semester of the academic year. Since hockey spans the entire academic year, future studies should consider tracking HRV changes and subjective wellness over both semesters to provide a more comprehensive understanding of these evolving metrics. Finally, we recognize that HRV and body composition can be further impacted by nutrition, which was beyond the scope of this study. However future studies may want to explore the association between dietary intake and HRV in student athletes.

To our knowledge, this was the first study to compare the impact of a competitive ice hockey season between sexes using HRV, body composition and subjective wellness questionnaire responses. HRV monitoring offers coaches and strength professionals valuable insights into changing training loads and athletes' readiness. Future studies should explore longer time frames to better explore longitudinal associations between HRV and subjective wellness. This study's findings emphasize the importance of including female athletes in sports science research, as there were significant sex and time interactions observed. We found important sex differences in physiological and psychological responses to an academic semester’s training and competitive demands among varsity athletes. These results can inform tailored training and wellness programs to optimize performance and health outcomes for both male and female athletes. Understanding these differences is essential for coaches, trainers and sports scientists to provide sex-specific support and interventions that enhance athlete development and well-being. Further research with larger and more diverse samples is needed to continue exploring this emerging area. Including subjective wellness measures is also crucial for understanding the holistic well-being of both varsity athletes and athletes in general. Studies have shown that declines in subjective wellness can negatively impact performance, underscoring the need for comprehensive wellness assessments (Smith, 2006).

4.6 Practical Applications

The results of this study suggest several practical applications for coaches, strength and conditioning coaches, trainers, and sports scientists working with varsity athletes. From a clinical and performance perspective, this study underscores the importance of using modern technology, such as remote HRV monitoring, to assess training loads in a relatively easy, non-invasive manner. Coaches should also be mindful that HRV responses may differ among male and female athletes over time. These changes may help coaching staff develop personalized training and recovery protocols. The data also indicate that varsity athletes can maintain or even enhance their body composition throughout a semester, which is encouraging given the typical challenges faced by student-athletes. Maintaining or improving body composition is crucial for athletic performance and overall health, and this study's findings highlight effective strategies to achieve this (Bishop, 2008; Malone et al., 2015). Subjective wellness assessments can also be a useful tool for identifying athletes who may need additional mental health support, especially female athletes who reported lower wellness scores. Evidence suggests that psychological factors differ between the sexes and can impact overall wellness and performance (Lu et al., 2016; Moesch et al., 2018). Lastly, comprehensive wellness programs that address both physiological and psychological aspects of athlete health can enhance overall performance and reduce the risk of injury and burnout.

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Table 1

Players Characteristics (Mean +/- SD) at Baseline and End of semester

	Male (n=19)	Female (n=22)	Total (n=41)
Baseline			
Age (years)	23.10 ± 1.57	20.28 ± 1.14*	21.62 ± 1.96
Height (m)	1.82 ± 0.04	1.70 ± 0.05*	1.76 ± 0.08
Body mass (kg)	85.65 ± 5.30	67.03 ± 7.03*	75.87 ±11.27
Body Fat (%)	17.25 ± 2.81	25.96 ± 4.54*	21.82 ± 5.80
Total Body lean mass (kg)	67.87 ± 4.47	47.38 ± 3.93*	57.11 ±11.16
Total Fat mass (kg)	14.17 ± 2.59	16.88 ± 4.29*	15.60 ± 3.80
Visceral Fat (kg)	0.34 ± 0.12	0.14 ± 0.14*	0.24 ± 0.17
End of semester			
Age (years)	23.37 ± 1.56†	20.54 ± 1.14*†	21.88 ± 1.96†
Height (m)	1.82 ± 0.04†	1.70 ± 0.05*†	1.76 ± 0.08†
Body mass (kg)	85.23 ± 5.40	66.38 ± 6.90*	75.34 ±11.35
Body Fat (%)	16.03 ± 2.52†	24.48 ± 3.94*†	20.46 ± 5.40†
Total Body lean mass (kg)	68.51 ± 4.62†	47.89 ± 4.09*†	57.69 ± 11.28†
Total Fat mass (kg)	13.10 ± 2.31†	15.74 ± 3.81*†	14.48 ± 3.42†
Visceral Fat (kg)	0.36 ± 0.12	0.14 ± 0.16*	0.24 ± 0.18

*Significant different from male players ($p \leq 0.05$)

†Significant different from baseline ($p \leq 0.05$)

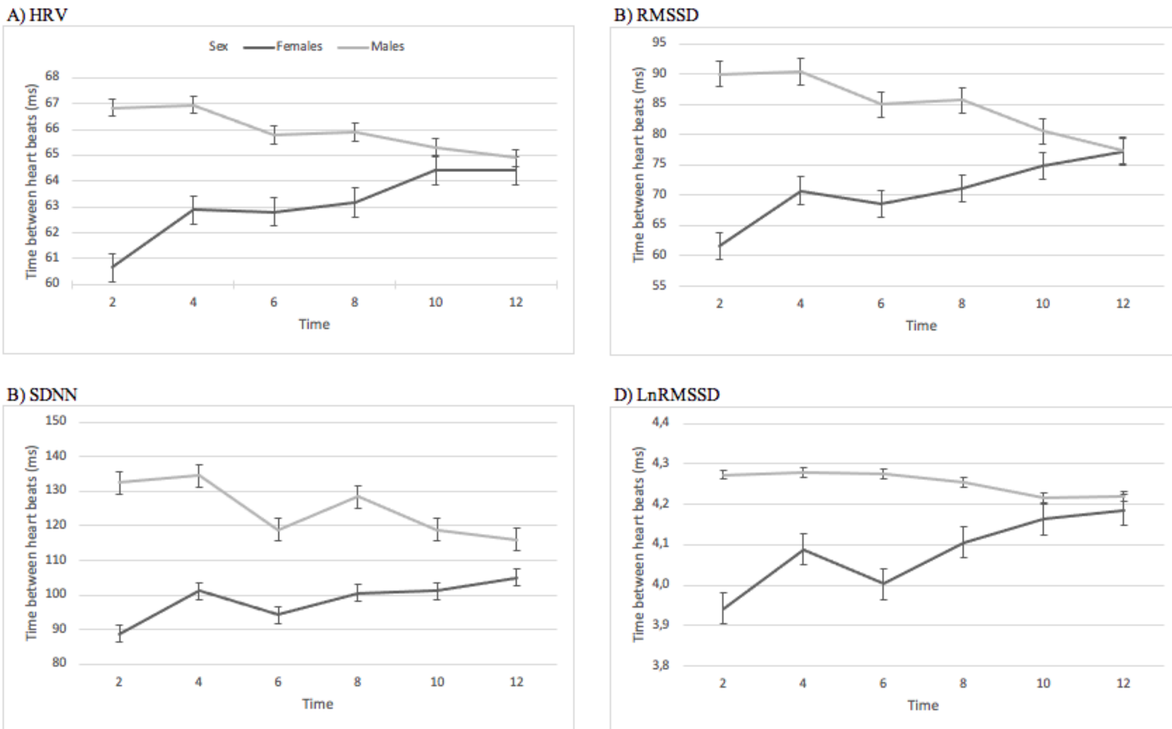

Figure 1. Changes in various measures of heart rate variability over the course of a semester in Male and Female Varsity Hockey Players (means ± SD). A) HRV, B) SDNN, C) RMSSD, D) LnRMSSD

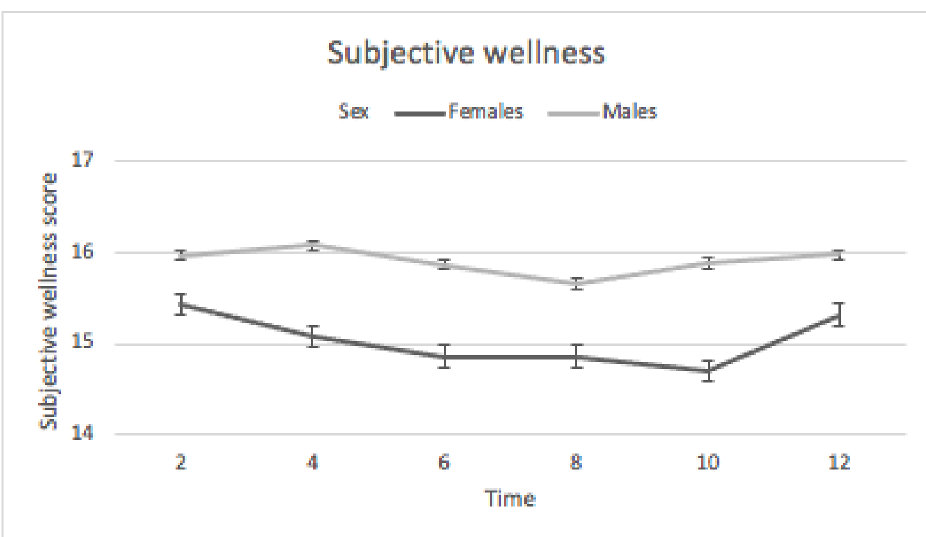

Figure 2. Subjective wellness reported by varsity collegiate hockey players

Chapter 5 – Summary, Conclusion, Recommendations, and Practical Applications

5.1 Summary

The purpose of the present study was to investigate the relationship among changing HRV, body composition, and subjective wellness in male and female varsity hockey players throughout an academic semester. The study explored interactions among physiological and psychological changes that occurred in student-athletes as they balanced academic and athletic demands over the course of an academic semester.

Participants in this study included forty players [n=40] from the 2023-2024 McGill University men’s and women’s varsity ice hockey teams, comprising twenty-one females and nineteen males and aged 18 years old and older. All participants underwent body composition evaluation at the beginning and at the end of the semester in the Health and Fitness Promotion lab. They also participated in home monitoring of HRV using Polar H10 chest strap and responded to a subjective wellness questionnaire biweekly for 12 consecutive weeks.

The study tested two primary hypotheses. The first hypothesis aimed to track changes in physiological parameters over the first semester of play in male and female varsity ice hockey players. Specifically, it was hypothesized that the physical strain of the season would affect HRV, predicting a decline in HRV and increased fatigue, soreness, and stress with potential declines in sleep and mood during the first academic semester. This was analyzed using repeated measures ANOVA. Additionally, it was anticipated that body composition would significantly change as a function of subjective wellness and physiological parameters. Based on the results, both males and females showed improvements in body composition, with males reporting higher subjective wellness scores.

The second hypothesis focused on exploring sex differences in the changing physiological and psychological measures over the course of the fall semester. It was hypothesized that males would experience greater reductions in physiological parameters over the competitive season compared to females. Males consistently showed higher HRV, but HRV metrics increased for females from week 1 to week 12 , while they decreased for males.

5.2 Conclusion

Within the delimitations and limitations of the research project, the following conclusions are:

1) The HRV metrics did not significantly decline in females over the semester, but there were notable male decreases in the time domain parameters of HRV. However, females consistently had lower values compared to males.
2) Both male and female athletes experienced favourable changes in body composition, including reductions in body fat percentage and fat mass, and increases in lean mass, suggesting effective training and competitive activities throughout the semester.
3) Males generally reported higher subjective wellness scores than females, though no significant changes over time were observed for either sex. This indicates that while subjective wellness remained relatively stable, sex differences in wellness perceptions were notable.
4) Subjective wellness was found to predict HRV, suggesting that better wellness is associated with higher HRV.

5.3 Recommendations

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

1) Future research should extend beyond a single academic semester to include multi-seasonal studies. In addition, tracking teams from additional institutions would enhance the generalizability of our findings. This approach would provide a more comprehensive understanding of the long-term trends and the effects of training and competition on physiological and psychological parameters.
2) Follow-up studies on the relationship of HRV should attempt to include detailed nutrition assessments and interventions since nutritional intake can significantly impact body composition and possibly HRV.
3) Further exploration in the integration of advanced monitoring technologies such as wearable devices that continuously track various physiological and psychological parameters (i.e., smartwatches) could be recommended. This may help with overall compliance and lead to different findings.
4) Considering the difference in subjective wellness between the sexes, future research into HRV should explore the efficacy of including psychological interventions such as mental health support programs to enhance well-being.

5.4 Practical Applications

Many organizations working with varsity and professional ice hockey players are continuously exploring new ways to optimize athletic performance during the competitive season. Recovery strategies are recognized to be important and may influence sport performance and reduce injury risks. The study's results highlight the importance of sex-specific training programs that account for differences in autonomic regulation. Therefore, implementing recovery strategies which recognize the distinct physiological responses between the sexes will help create more effective training regimens.

With the growing popularity and accessibility of HRV monitoring devices, strength and conditioning coaches can continuously monitor body composition and HRV to offer valuable methods for tracking the effectiveness of training programs. This may lead to enhanced performance by making data-driven decisions. Therefore, precise adjustments to training and recovery plans can ensure that each athlete's needs are met.

Recognition of routine subjective wellness assessments are crucial for coaches and trainers for identifying athletes who may need additional psychological support. This study's finding that female athletes reported lower wellness scores, underscores the need for targeted mental health support within training programs. Thus, regular assessments of subjective wellness may allow coaches to provide timely and appropriate interventions to enhance overall well-being and performance, especially for those showing signs of increased fatigue, stress, or mood disturbances. By ensuring comprehensive support, sports professionals can foster an environment that promotes both the physical and mental well-being of athletes, leading to improved outcomes both on and off the ice.

Further research is needed to generalize these findings and explore additional variables that may impact athlete performance and well-being. These have the potential to be adapted for individual athletes in various sports, thereby broadening the impact of these findings across various athletic disciplines. Implementing these recommendations may help to enhance the health, performance, and overall well-being of varsity and professional ice hockey players, contributing to their success and overall enjoyment of the sport.

Appendix 1

Informed Consent Form

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Phone: 514-398-4184

RESEARCH PARTICIPANT INFORMED CONSENT

Protocol Title:	**Relationship among heart rate variability, body composition and perceived wellness in collegiate varsity ice hockey players**
Sponsor:	McGill University
Principal Investigator:	Ross Andersen, Ph. D
Research assistant:	Tricia Deguire, B.Sc
Date:	May 14, 2022

Introduction:

You are being invited to take part in a research study since you are a member of the McGill Redbirds or Martlets Varsity Hockey Team. This research participant informed consent explains the research study and your part in the study. Please read it carefully and take as much time as you need. Please ask questions at any time about anything you do not understand.

Purpose of the study:

This study will investigate the role of the heart rate variability and body composition on both male and female student athletes' perceived wellness during the course of an academic semester. The investigators aim to understand the physiologic and psychological changes that may occur in student athletes during an academic semester when both academic and competitive athletic performance place demands on a student athlete's time and energy.

Procedures

If you agree to be in this study, you will be asked to participate in three study visits. It will take place at the Health and Fitness Promotion Laboratory. You will wear the polar heart rate monitor once every other week for the whole length of the study. Every recording week, you will wear the monitor after waking up in the morning for less than 10 minutes

during 7 days straight. Each of the three visits will take about 30 minutes to complete. You will be asked to complete the same test (a) at each study visits.

a) Body Composition Assessment

You will be asked to complete one full body iDXA scan, which lasts approximately 10 minutes, on each of the visits. You are required to lie on your back and remain still (to the best of your ability) for the scan's duration. You will complete the scans at the beginning of December, at the beginning of January and at the end of the season (March).

Measures to be obtained at each visit in the lab

Anthropometric Measures (height, weight)
Whole and Regional Body Composition [fat tissue mass, lean tissue mass and bone density].

In between the visits, you will be asked to complete step b) and c) at home. These tests are described below. They should require less than 10 minutes in your morning recording week. You will take part in this study until the end of the season.

b) Questionnaire

You will be asked to complete the subjective wellness questionnaire of MacLean et al., which consist of 5 questions, every time you are recording your heart rate variability.

c) Heart rate variability

You will be asked to wear the polar chest strap, every other week for a 7-day period, for less than 10 minutes over the course of an academic semester. Every morning, your resting heart rate and heart rate variability will be recorded. You will record it, at home, sitting on a chair, just after you wake up and empty your bladder. No food or liquid should be consumed before the recording.

What are the risks, harms or discomforts of the study?

Body Composition Assessment: You will receive a small dose of radiation from the body composition scans. The radiation exposure from participating in this study is equivalent to a whole body exposure of 0.6 mrems in total because each scan represents a whole body exposure of 0.3 mrems. Naturally occurring radiation (cosmic radiation, radon, etc.) produces whole body radiation exposures of about 300 mrems per year. An average chest X-ray is 10mrems.

Questionnaires: The results of your questionnaire responses may show that you are feeling unhappy or feeling bad. The researcher will offer to put you in contact with the coaches or the team's physician if this is the case as each team has a doctor that works closely with the athletes.

Heart rate variability: The chest strap will be worn in the morning after waking up. You may experience discomfort around the chest since the strap should be directly on the skin of your chest. The discomfort should be minimal, should this occur.

If you feel that you have an illness or symptoms related to your participation in the study you should contact Dr. Ross Andersen at (514) 398-4184 ext. 0477.

Benefits

At the completion of your final assessment, you will receive an in-depth analysis of your iDXA body composition scan (physiological), a trend of your perceived well-being and HRV results. Knowledge of your results may be beneficial to your well-being, overall health, athletic development, training design, and sports performance. The field of sports performance may benefit from this study by being informed on physical fitness, body composition, subjective fatigue and well-being changes in male and female hockey student athletes that can occur during the playing season.

In case of Injury

Every effort to prevent injuries that could result from this study will be taken by the investigator and study personnel. If you suffer an injury as a result of your participation in this study, you will receive appropriate medical care under your Quebec Medicare or private insurance plan. If an injury occurs during the academic semester and you are restricted from participating in the study after the first visit, you will be withdrawn.

Voluntary Participation/Withdrawal

Participation in this study is voluntary. You are free to refuse to participate, or to withdraw your consent to participate in this study at any time. You have the right to ask questions at any time. You have the right to discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Your participation in this study is completely voluntary and you may withdraw at any time. There will be no penalty whatsoever for withdrawing from the study.

Is there any cost to be in this study?

You will not be charged or billed for the costs of the procedures used in this study. Chest straps and software will be provided to you free of charge but will be collected back at your third visit in the lab.

Compensation

You will not receive any monetary compensation for participating in this study. However, all assessments will be done free of charge.

Confidentiality

All of the data collected are going to be coded using ID numbers. Hard copies of your test results will be stored in a locked file cabinet in a secure separate room of the Health and Fitness Promotion Laboratory (i.e., Currie room 101). The data will be entered into a computer database which will be accessible only through a password. Dr. Andersen and his students working on this project will be the only people with access to the data collected in this study and it will be encrypted and stored on a secure server. The data will be stored securely for seven years after scientific reports on this study are published, as per University policy. A member of the McGill Institutional Review Board, or a person designated by the IRB may access the study data to verify the ethical conduct of the study.

Contact

Please contact Dr. Ross Andersen at 514-398-4184 ext 0477 with any questions or concerns about this study.

You may contact Ms. Ilde Lepore, Ethics Officer, Institutional Review Board (514) 398-8302 for questions regarding participant rights.

Participant consent

I have been given time to review this consent form and to familiarize myself with the research study. The study has also been explained to me and any questions I had were answered to my satisfaction. I am aware that study participation is voluntary, and that I can refuse to participate or withdraw from the study at any time. I agree to participate in this study, as it is described, in this consent form. I do not waive any of my legal rights by signing this consent form.

WE WILL GIVE YOU A COPY OF THIS SIGNED AND DATED CONSENT FORM

____

Name of Participant (Please Print)

____

Signature of Participant Date

____

Name of Person Obtaining Consent (Please Print)

____

Signature of Person Obtaining Consent Date

Appendix 2

Subjective Wellness Questionnaire by McLean et al. (2010)

	1	**2**	**3**	**4**	**5**	**Score**
FATIGUE	Always tired	More tired than normal	Normal	Fresh	Very fresh	
MUSCLES SORENESS	Very sore	Increase in soreness / tightness	Normal	Feeling good	Feeling great	
SLEEP QUALITY	Insomnia	Restless sleep	Difficulty falling asleep	Good	Very restful	
STRESS	Highly stressed	Feeling stressed	Normal	Relaxed	Very relaxed	
MOOD	Highly annoyed/ irritable/ down	Snappy with teammates, family and friends	Less interested in others / activities	Generally good mood	Very positive mood	

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