INNOVATIONS IN ATHLETE MONITORING AND INTERVENTIONS WITH IMPLCATIONS IN NON-FUNCTIONAL OVERREACHING

by

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Abstract

Background: The monitoring of an athlete's training load and cardiac function have demonstrated to be valuable assessment tools in individual sporting events. Additionally, short-term heat acclimation has shown to be effective for stimulating hypervolemia and augmenting cardiovascular performance. A gap in the literature exists indicating further research is required into both heat acclimation protocols and the monitoring of on-field training load and its cause and effect relationship with heart rate variability in team sport.

Purpose: The purpose of this investigation was twofold; 1) identify a novel form of heat acclimation using hot yoga for augmenting cardiovascular and aerobic performance, and 2) identify an effective monitoring protocol suitable for team sport using internal training load and heart rate variability.

Methods: The Canadian Women's National Field Hockey team were participants for examining heat acclimation and the relationship between training load and autonomic modulation during the 2016 Olympic cycle. A maximal graded exercise test was completed prior to and following six hot yoga sessions to examine cardiovascular and aerobic performance measures.

Results: In Chapter 4, six days of hot yoga developed hypovolemia that lead to trivial improvements in aerobic power, run time to exhaustion, and a small increase in running speed at each ventilatory threshold. A non-existent relationship between markers of exercise stress and alterations in plasma volume during and post hot yoga were observed. Chapter 5 identified a large relationship between the planned and achieved on field training load over a complete mesocycle. Additionally, a moderate relationship was observed between both time spent above anaerobic threshold, training load and alterations in the Ln rMSSD:R-R ratio.

Chapter 6 demonstrated how alterations in the Ln rMSSD outside of the coefficient of variation may identify the development of non-functional overreaching, while an unclear relationship was observed between weekly training load and alterations in Ln $rMSSD_{CV}$.

Conclusion: Hot yoga may elicit a delayed hypervolemic response when recommencing exercise. In addition, individually tailored mesocycles may prevent the development of non-functional overreaching when examined using heart rate variability while further research is required to confirm the Ln $rMSSD_{CV}$ relationship to accumulate weekly on-field training load in team sport.

Preface

This thesis was written by me, Andrew Scott Perrotta. The research ideas, approach and designs were developed myself. All data collection and its analysis were conducted myself with the assistance of a certified exercise physiologist (CEP) during each performance test at Fortius Sport & Health and a registered phlebotomist. All projects were made possible by my supervisor Dr. Darren E.R. Warburton who trusted me and provided the freedom with all its responsibility to pursuit my ideas. Dr. Warburton provided strong support and encouragement to conduct each of my research goals. Dr. Warburton provided all necessary equipment required and tremendous financial support towards my hot yoga investigation. My entire committee including Dr. Jack Taunton, Dr. Michael Koehle, and Dr. Matt White all provided exceptional support and guidance throughout each investigation.

Chapter 3 A version of Chapter 3 has been published. Andrew.S.Perrotta., Nicholas.J.Held., Anne.M.Lasinksy., Darren.ER.Warburton. 2016. Health & Fitness Journal of Canada. 9(3):3-13. Andrew Perrotta was responsible for writing the complete manuscript, conducting the systematic review, and made all necessary edits after the peer review process. Both Nicholas and Anne acted as second reviewers during the systematic review process. Dr. Warburton was the senior author on this manuscript and conducted the final review of the article prior to submission.

Chapter 4 Research examining the efficacy of hot yoga for inducing hypervolemia and its resulting rate of decay was conducted at the Hot Box Yoga Studio located at 3313 Shrum Lane, Vancouver, BC and the University of British Columbia. This research project was conducted during November and December 2015.

- The University of British Columbia's Clinical Research Ethics Board (CREB) provided approval for the research project titled "The use of hot yoga for enhancing cardiovascular performance in Canadian National Field Hockey athletes". The CREB identification number for this investigation is H15-00877.

- Each blood sample was collected at the Cardiovascular Physiology and Rehabilitation Laboratory located at the University of British Columbia. Each hematological assessment was analyzed by the same LifeLabs facility located in Burnaby British Columbia.
- Each maximal graded exercise test involving gas analysis and the acetylene open circuit technique was conducted by Andrew Scott Perrotta a certified exercise physiologist (CEP) with the assistance of certified exercise physiologists (CEP) from Fortius Sport & Health.
- Andrew Scott Perrotta was responsible for developing the research idea, methodological approach, data collection, and its complete analysis. All statistical analyses and their modeling were processed using Microsoft Excel 2010.
- Fortius Sport & Health provided a ParvoMedics Metabolic cart for direct gas analysis during the pre- and post-intervention performance tests.
- Dr. Darren E.R. Warburton provided the Amis 2000 Mass Spectrometer for assessment of cardiac output for the pre- and post-intervention performance tests.
- Dr. Darren E.R Warburton provided the necessary financial support for purchasing and utilizing ingestible core temperature pills and the securing of six private hot yoga sessions.

Chapter 5 & 6 Data pertaining to heart rate variability and internal training load in the Canadian National Women's Field Hockey team were collected at the University of British Columbia's Wright Field and analyzed in the Cardiovascular Physiology and Rehabilitation Laboratory located at the University of British Columbia.

- The University of British Columbia's Clinical Research Ethics Board (CREB) provided approval for the research project titled "The Examination of Heart Rate Derived Training Load Values and Heart Rate Variability for Monitoring Non Functional Overreaching in the Canadian Women's National Field Hockey Team". The CREB identification number for this project is H16-02080
- Andrew Scott Perrotta was responsible for developing the research idea, methodological approach, data collection, and its complete analysis. All statistical analyses and its modeling were processed using Microsoft Excel 2010.
- All data were collected and analyzed between September 2014 and January 2016.
- Field Hockey Canada's Polar Team^2 System was used to collect all exercise and resting heart rate data. Training load values were derived from the Polar Team^2 System during each on-field training session. Andrew Scott Perrotta was present and responsible for collecting all on-field training data.
- Kubios HRV 2.2 was used for all HRV analyses. Raw R-R files were exported from the Polar Team^2 System into Kubios HRV 2.2 and analyzed manually by Andrew Scott Perrotta.

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List of Abbreviations

AD/M - Surface to Mass Ratio ($cm^2 \cdot kg^{-1}$)

ANS - Autonomic Nervous System

BC - British Columbia

BV - Blood Volume

BV% - Blood Volume Percentage (Dill & Costill method)

FHC - Field Hockey Canada

GXT - Graded Exercise Test

HA - Heat Acclimation

HR - Heart Rate

HR_{max} - Maximum Heart Rate ($beats \cdot min^{-1}$)

HRV - Heart Rate Variability

IST - Integrated Support Team

MET - Metabolic Equivalent ($3.5\ mL \cdot kg^{-1} \cdot min^{-1}$)

PSD - Power Spectral Density

PV - Plasma Volume

PV% - Plasma Volume Percentage (Dill & Costill method)

Q_{max} - Cardiac Output ($L \cdot min^{-1}$) at maximum intensity

Q_{rest} - Cardiac Output ($L \cdot min^{-1}$) at rest

RHR - Resting Heart Rate ($beats \cdot min^{-1}$)

rMSSD - Square Root of the Mean Squared Differences of Successive R-R Intervals

Ln rMSSD- The Natural Log Rhythm of the Square Root of the Mean Squared Differences of Successive R-R Intervals

R-R - Beat-to-beat Heart Rate Intervals (ms^{-1})

RT_{ex} - Running time to Exhaustion (min^{-1}•sec^{-1})

STHA - Short-term Heat Acclimation (< 7 days acclimation)

SV - Stroke Volume (mL•$beat^{-1}$)

SWC - Smallest Worthwhile Change

TL - Training Load (Arbitrary Units –AU)

TL% - Percentage of maximum training load (%Max) (i.e. most previous 100% achieved in YTP)

VO_{2max} - Maximum Oxygen Consumption (mL•kg^{-1}•min^{-1})

VT_1 - Ventilatory Threshold One

VT_2 - Ventilatory Threshold Two

WNT - Women's National Team

YTP - Yearly Training Plan

Glossary

Heart Rate Variability	HRV is a non-invasive technique that illustrates the activity of the autonomic nervous system. HRV describes the variations between consecutive cardiac cycles and is thought to represent the magnitude of parasympathetic modulation.
Maximum Heart Rate	The highest heart rate achieved and recorded during maximal testing and/or competition.
Resting Heart Rate	The average heart rate recorded over a five minute sampling period collected immediately upon awakening laying supine.
Resting Beat-to-beat Heart Rate Intervals	The time in milliseconds between successive cardiac cycles examined immediately upon awakening in the supine position.
Cardiac Output (rest)	The volume of blood (*litres*) pumped per minute by the heart at rest while standing.
Cardiac Output (max)	The volume of blood (*litres*) pumped per minute by the heart measured at peak exercise intensity.
Stroke Volume	The amount of blood (*millilitres*) pumped per heartbeat.
Ventilatory Threshold One	A transition point at which pulmonary ventilation increases disproportionately with VO_2. This nonlinear increase in ventilation is thought to be the result of an imbalance in pyruvate production and its oxidation resulting in the increase in buffering of lactic acid build-up. This point in time during a graded exercise test involving gas analysis can be determined using a combination of either the V-Slope, ventilation curve, fraction of expired O_2, respiratory exchange ratio and ventilatory equivalent methods.
Ventilatory Threshold Two	A transition point at which pulmonary ventilation increases disproportionately with VO_2. This nonlinear increase in ventilation is thought to be the result of an increase in buffering of lactic acid build-up due to an increase in anaerobic glycolysis. This point in time during a graded exercise test involving gas analysis can be determined using a combination of fraction of expired CO_2, expiratory

exchange ratio, ventilation curve and ventilatory equivalent methods.

Maximum Aerobic Power — $VO_{2\ max}$ is the maximum amount of oxygen that can be consumed for a given unit of time, transported throughout the cardiovascular system and utilized at the substrate level during a maximal graded exercise test.

Training Load — An arbitrary unit that expresses the amount of internal or external indicators of effort and intensity during training or competition that are coupled together and computed to provide a measure of physiological stress for that specific exercise period. For the purpose of this dissertation the training load examined was an internal measure of on- field physiological stress unless otherwise stated.

Training Load (%Max) — A fraction (%) of an individual's maximum on-field training load most recently recorded over a microcycle.

Microcycle — A training period consisting of training sessions and recovery days strategically placed throughout several days to one week.

Mesocycle — A training period consisting of several microcycles that can last three to six weeks.

Macrocycle — A training period consisting of several meoscycles or the span of a complete training year.

Yearly Training Plan — A preprogramed yearly training schedule that is strategically designed with microcycles, mesocycles and macrocycles that develop sport specific and physiological goals throughout a year of training. A YTP encompasses all major competitions allowing for the appropriate microcycles to be implemented leading into competition.

Functional Overreaching — A short-term period described as days to weeks with marked reductions in athletic performance that may be accompanied with a physiological disturbance to homeostasis. This level of physiological disturbance generally allows for supercompensation in athletic performance after a sufficient period of reduced training or rest (303).

Non Functional Overreaching A period of time described as several weeks to months with marked reductions in athletic performance that are usually accompanied with a physiological disturbance to homeostasis. This level of physiological disturbance typically does not elicit a supercompensation in athletic performance after several weeks of reduced training or rest (303).

Overtraining Syndrome A period of time described as several months to a year with marked reductions in athletic performance that are usually accompanied with a physiological disturbance to homeostasis. This level of physiological disturbance is thought to be the most severe in the overtraining continuum and typically does not elicit a supercompensation in athletic performance after several weeks to months of reduced training or rest(303).

Acknowledgements

I offer my enduring gratitude to my academic supervisor Dr. Darren E.R. Warburton who gave me the freedom and support to pursue my research ideas. The very essence of a scientist is to formulate ideas and to challenge one's hypotheses; having been provided the opportunity to act as such has been the most rewarding aspect of my doctoral experience.

I wish to sincerely thank my committee members, Dr. Jack Taunton, Dr. Matthew White and Dr. Michael Koehle who have graciously and continually provided their time and expertise to support my research and aspirations of becoming the best performance physiologist I can be.

I owe a particular thank you to Mr. Ian Rutledge. Ian has been a profound and instrumental figure early in my career. Our time together has shaped me into the physiologist, scientist, and man I am and will become. I will forever be indebted to you.

A special thank you goes to my parents and brother who have financially and emotionally supported me on this long academic journey. Their encouragement to pursue academics after my career in soccer is the reason for my current success. Finally I wish to thank my wife Elizabeth Ann Perrotta. Elizabeth is my best friend, my support system and the one person who constantly picks me up when I fall. She has seen the worst and best of me during the past four years and I thank her for not allowing me to settle for average. What we have accomplished together over the past four years is nothing short of incredible. With the end of this experience I look forward to new beginnings, wherever life may take us.

Dedication

To my son, Luca Anthony Perrotta. It is my hope that the hard work and success in completing this degree will inspire you to achieve your own greatness in whatever form that may be. Ti amo.

Chapter 1: Introduction

1.1 Executive Summary

1.1.1 Hot Yoga as a Short-term Heat Acclimation Protocol for Augmenting Cardiovascular and Aerobic Performance

Performance enhancing techniques are often perceived as pushing the envelope of an athlete's potential to perform. Intermittent team sport such as field hockey requires a large emphasis on aerobic power (VO_{2max}), speed and repeated sprint ability (139). The body's ability to transport oxygen to the working tissues has been identified as a rate limiting factor when examining VO_{2max} and peak cardiovascular performance (63, 112, 115, 182, 248, 443, 444, 486). A common performance enhancing technique used to overcome this limitation at sea level is preceding altitude exposure at rest or during exercise (176, 404). High altitude exposure provides an environment where the reduction in the partial pressure of oxygen elicits a physiological response from the kidney to increase erythropoietin (EPO) production, a response that initiates the proliferation of red blood cells (RBC's) in the bone marrow(405) thus increasing the circulatory system's ability to deliver oxygen at altitude and sea level and improving VO_{2max} and performance (274, 450). This performance enhancing technique is often difficult for athletes who reside at sea level and lack close proximity to the required change in elevation. As such, alternative methods for increasing total blood volume that can augment cardiovascular and aerobic performance are often searched for.

An expansion in plasma volume (PV) can be defined as hypervolemia and is a physiological response that can be induced with increased exercise volume or intensity along with exercising in hot environments (84-86, 178, 386). Recent reviews (71) have identified short-term heat acclimation to be a popular technique for inducing PV expansion as its induction occurs early in the acclimation process (153, 446). The resulting expansion in PV can augment cardiac output by enhancing oxygen transportation through the use of the Frank Starling effect and potentially improving VO_{2max} (93, 161, 163, 260). Unlike erythropoietin, the development of hypervolemia has no impact on increasing the oxygen carrying capacity of the circulatory system through alterations in red blood cells. Instead, the increase in total blood volume promotes greater venous return, enhancing diastolic and cardiac function, allowing for the increased rate of recycling of red blood cells at the working tissue for improved oxygen presence (247, 248). This performance enhancing technique is viewed by most sport practitioners as a more efficient and practical means for temporarily enhancing blood volume for short-term cardiovascular performance. Previous literature suggests that the diastolic reserve of an athlete as defined through total blood volume or VO_{2max} determines the potential improvement in cardiac performance when in the presence of hypervolemia (474). However, recent studies have revealed promising evidence for improved performance when using heat acclimation in individual or team sport athletes where fitness is varied (61, 279, 452, 474).

When inducing hypervolemia through heat acclimation in an entire team of athletes, typical methodology becomes problematic or impractical. Most recently, sauna bathing immediately post-exercise has been demonstrated to be an effective alternative for inducing hypervolemia (446). This method may be optimal for team sports as most professional teams have access to large saunas where multiple athletes can be exposed at once with no additive training stimulus required. The absence of an additional training load (TL) during a tapering period leading into competition can be of great value for practitioners and coaches. Therefore further research is essential for examining heat acclimation protocols best suited for inducing hypervolemia in team sports that require minimal training stimuli.

1.1.2 Training Load and Heart Rate Variability in Team Sport

Elite athletes, specifically those who represent their sport and country at the international level, often dedicate their existence to improving performance in their given sport. Olympic athletes work under a quadratic cycle whereby the individual athlete or team train on a regular basis in the effort to be at their best for both the qualification process and the Olympic Games. The purpose of training can be defined as the opportunity to improve and expand specific areas that have been identified by the coaching staff and integrated support team as critical for determining success in their sport (330, 364). These categories usually consist of physical, mental, technical and tactical focus areas (364). The focus, attention and volume that each area is given can undulate throughout the yearly training plan and successive yearly plans that encompass an Olympic cycle. The shift in focus from one area to another along with the amount of time on task has been defined as periodization and has proven to be an effective method for skill development, preparation, and future performance (37). When developing a yearly training plan, coaches and sport practitioners can look to categorize training periods into specific blocks. These blocks consist of specialized training periods that can last months (macrocycles), weeks (mesocycles), or days (microcycles) allowing the athlete to maximize time on task and potentially enhance future performance (330). When each focus area has been identified and the development process begins, it is critical to then monitor and assess the athlete as they complete each training block in order to gain insight and understanding in the amount of training stress experienced (435).

The response of an athlete from training is typically related to the stimuli provided during each training block or session and the amount of internal and or external training load they experience (39). A training load is the amount of internal (i.e. through blood lactate accumulation, rating of perceived exertion, percentage of oxygen consumption and heart rate indices) and or external stress (i.e. distance covered using global positioning systems, power output, or number of repetitions) an athlete experiences during a training session that can be quantified (24, 130, 179, 220, 249, 278, 375, 433). When developing a periodized yearly training plan, great importance should be placed on the fluctuation of training intensity and the amount of time experiencing a given level of intensity (37). An undulating and compensating pattern in both variables may prevent the build-up of excessive fatigue, a physiological state whereby an athlete fails to super-compensate from and has been identified as non-functional overreaching (NFOR) encompassing reductions in performance (39, 41, 201, 202, 294, 296).

When monitoring athletes it is critical to identify a valid and reliable assessment tool in order to measure and define fatigue and performance. These measurements can then be summated into weekly training loads for immediate and long-term monitoring purposes. Heart rate monitoring at rest and during exercise has been demonstrated to be a cost effective, non-invasive and time efficient tool that can be utilized on a daily basis within team sport (50). Portable heart rate recorders such as the POLAR Team^2 System (Polar, Electro, Oy, Kempele, Finland) can provide instantaneous live heart rate data during field training sessions while also providing the option for athletes to take home their monitors for further heart rate recording and analysis. This form of monitoring can be extremely helpful when working within a team sport environment where measuring blood and salivary fatigue indices may not be practical. Although research has demonstrated heart rate monitoring to be an effective tool for identifying athlete fatigue, performance improvements, overloading, and detraining, there seems to be an equal amount of literature that has shown the opposite (370). With current research demonstrating indecisiveness towards the validity of heart rate monitoring, a potential explanation for these discrepancies may be the lack of standardization in data collection, methodology, and misinterpretation of the analysis rather than the ability of the heart rate monitoring system to effectively provide insight on the training status and autonomic fatigue of an athlete (50, 370).

Perhaps the greatest value in monitoring athletes using heart rate is the ability to simultaneously monitor an entire team of athletes at once. Furthermore, heart rate monitoring equipment often provides the ability to observe multiple heart rate indices for examining performance and fatigue. The POLAR Team^2 System provides an internal training load value for each training session unique to each athlete's physiological characteristics, while also having the capability to collect beat-to-beat heart rate intervals for further monitoring purposes (327). This latter option can provide further analysis in the fatigue of an athlete using heart rate variability (HRV) when exported into separate software programs such as Kubios HRV Analysis 2.2. HRV is a non-invasive technique that assess the magnitude of autonomic modulation through examining the cardiovascular system and its variability between successive cardiac cycles (470). Alterations in vagal related HRV indices elicited through training or psychological stress can demonstrate variations in activity within the branches of the autonomic nervous system and its effect on cardiovascular control (370).

One advantage when using heart rate as a monitoring tool is its ability to shed light on both the development and consequence of a training load when expressed through changes in vagal related HRV indices. To date, this relationship between training load and HRV has been well established in endurance athletes; however it has yet to be thoroughly examined in intermittent team sports (50, 370). The current literature suggests a minimum of three randomly averaged HRV recordings per week for athlete monitoring purposes (369). This may be impractical for sport practitioners working within team sport where equipment and time is limited when monitoring over 20 athletes a day. Often in team sport weekends are established as a rest and recovery period. This time period (i.e. 48 hours) may prove optimal for HRV collection in an effort to demonstrate a cumulative training stress developed throughout the week and to demonstrate an athletes' adaptability to that stress prior to experiencing further training stimuli.

1.2 Hypotheses

1.2.1 Athlete Performance Enhancing Techniques

This component of the dissertation investigated the efficacy of a novel short-term heat acclimation protocol involving hot yoga to stimulate hypervolemia for augmenting cardiovascular and aerobic performance. Emphasis was directed towards identifying a protocol involving minimal heat and exercise stress (i.e. Total Thermal Load) that would elicit physiological and performance enhancements beyond the smallest worthwhile change (i.e. trivial variations). We hypothesized that: 1) the development of hypervolemia would be greater than the smallest worthwhile change (i.e. day to day change expressed as the coefficient of variation) after six hot yoga sessions, 2) a significant relationship would exist between the magnitude of exercise stress achieved during six hot yoga sessions and the degree of hypervolemia observed post-intervention, and 3) the development of hypervolemia after six hot yoga sessions would elicit significant (i.e. $\geq$ 0.2 ES) improvements in RT_{ex}, VO_{2max}, VT_1,VT_2, and maximum cardiac output during a maximal graded exercise test in a temperate environment. We also believed maximum heart rate would remain unchanged.

A secondary component investigated the rate of decay in the established hypervolemia after hot yoga. Emphasis was directed towards monitoring the relationship between on-field exercise stress and its ability to attenuate the rate of decay in hypervolemia post-heat stress. We hypothesized that larger on-field training loads experienced during competition would exhibit improved maintenance in hypervolemia for up to 144 hours post-hot yoga.

1.2.2 Athlete Monitoring Techniques

This component of the dissertation investigated national level team sport athletes and the cause and effect relationship between on-field internal training load and alterations in parasympathetic modulation as expressed through the log transformed square root of the mean squared differences of successive cardiac cycles (i.e. Ln rMSSD) throughout a complete mesocycle. Emphasis was directed towards establishing evidence based protocols for monitoring team sport in the effort to better support coaches and practitioners in the planning and monitoring of their athletes to prevent non-functional overreaching. The fist investigation was directed towards examining an individually tailored mesocycle and the congruency between the achieved vs. planned on-field training load with a secondary emphasis towards identifying the relationship between two markers of exercise stress, a comprehensive training load marker (i.e. Polar Load) and a high-intensity marker (i.e. Time > LT_2) and alterations in autonomic modulation. We hypothesized that: 1) a strong relationship would exist between the planned vs. achieved on-field training load over a complete mesocycle, and 2) exercise stress when expressed as a comprehensive training load marker would demonstrate a stronger relationship with alterations in Ln rMSSD:R-R than time spent above LT_2.

The second investigation was directed towards examining weekly alterations in parasympathetic modulation in relation to accumulated on-field exercise stress. We hypothesized that: 1) the development of non-functional overreaching would be identified when expressed as alterations in Ln rMSSD outside of the coefficient of variation, and 2) weekend Ln $rMSSD_{CV}$ would exhibit a strong relationship to the accumulated weekly on-field training load.

Chapter 2: Literature Review

2.1 Heart Rate Variability (HRV)

Heart rate variability (HRV) became an area of interest for health care practitioners when it was shown to identify fetal distress through modifications in beat-to-beat (R-R) intervals without alterations in resting heart rate (212). It was further observed in 1976 that physiological rhythms were incorporated in the beat-to-beat intervals of a normal heart rate recording (210, 412). In a clinical setting, HRV became a useful tool when monitoring patients after experiencing a myocardial infarction, as it was demonstrated that reduced parasympathetic modulation during this period lead to higher mortality (488). When Akeslrod et al. in 1981 demonstrated an effective method for analyzing heart rate fluctuations through power spectral analysis it allowed for beat-to-beat patterns to be evaluated and the autonomic nervous system to be quantified for its parasympathetic and sympathetic activity within the cardiovascular system (5). This initial understanding has potentially led to the most common misinterpretation and misuse of HRV in sport practitioners today. HRV in actuality represents the magnitude of modulation in the parasympathetic outflow of the autonomic nervous system rather than its tone (18, 206). In a sporting environment and within healthy athletes the purpose of the autonomic nervous system and its relationship with changes in hemodynamics is to help facilitate optimal cardiovascular functioning (18). The cardiovascular system is largely governed by higher brain centres located in the brainstem and regulates its actions through the parasympathetic and sympathetic nerves (186). Chemoreceptors, baroreceptors, and muscle afferent nerves, along with localized tissue metabolism and circulatory hormones can influence cardiovascular R-R intervals (275).

During ventricular systole, a transitory increase in blood pressure develops initiating a stretch reflex in the baroreceptors and an increase in afferent nerve firing (300). These actions initiate a vagal reflex nerve discharge and a reduction in the rate of involuntary depolarization of the sinoatrial node, that ultimately increases the R-R interval length (148). Responses in the vagal nerve to baroreceptor stimulation have been demonstrated to take approximately 240 milliseconds (108). This reaction sequence is rapid enough to increase the time delay in the impending cardiac cycle, ultimately providing the variability between R-R intervals and the definition of HRV (192). In contrast to the rapid parasympathetic reaction, the sympathetic nervous system, which also influences heart rate directly through changes in vascular peripheral resistance, acts more slowly than its vagal counterpart (192). Therefore, the examination of HRV should be considered a measurement of the magnitude of autonomic modulation in parasympathetic outflow that allows practitioners to make inferences in the autonomic nervous system tone (192, 206).

2.2 The Effective Use of HRV in Sport

When using HRV for the physiological assessment of an athlete, it is essential to understand the determinants of resting heart rate as they can easily be affected by environmental conditions (50). Sport practitioners are encouraged to develop a comprehensive understanding of these determinants as HRV analysis can be negatively or positively manipulated by these determinants and potentially provide a false indicator of fatigue or state of readiness to perform (50). Independent variables such as plasma volume, cardiac morphology, body position, autonomic activity, genetics, noise, breathing depth and rate, temperature, and ambient levels of light are all variables that can manipulate resting HRV values (3, 18, 402). Night time recording for this reason has been identified to be theoretically the opportune time for recording R-R intervals due to an improved standardization in the environment and its physiological state (46, 361). However both sleep quality and sleep pattern have demonstrated to influence HRV indices independently and may prevent a clear cause and effect relationship when examining the magnitude of exercise stress and its influence on the autonomic nervous system (65, 344). Current research has identified resting morning heart rate collection upon awakening as best practice for athletes when collecting R-R intervals for HRV analysis (370, 447). Collection during this period allows for improved standardization of environmental factors while promoting a supine position, allowing for greater vagal influence and possible athlete compliance during examination (50, 292, 371, 388). Early morning collection in R-R intervals may provide sport practitioners a better opportunity to assess the autonomic systems response from the previous 24 to 48 hours' worth of training, as strenuous exercise has been shown to affect vagal indices for up to 48 hours before homeostasis is regained (447, 470). Therefore, great importance should be placed on standardizing R-R recordings when working with athletes as they typically record in uncontrolled environments outside of laboratory settings (50).

It is generally recommended athletes record a resting heart rate sample of five to ten minutes when intending to examine daily alterations in HRV (18). A time period of this nature typically allows for a minimum of 500 and ideally 1000 heart rate cycles to be collected, promoting improved analysis in R-R examination (470). Current literature recommends a five-minute R-R recording period as the minimum for permitting power spectral density and time domain analysis of HRV indices (470). Careful consideration must be taken to improve the success rate in collecting the minimum requirement of R-R cycles in predetermined recording periods. Variance in HRV vagal related indices change in accordance with the duration of the R-R recording sample analyzed (18, 470). This correlation between R-R recording length and hear rate variability makes it inappropriate to compare recording periods that differ in length (18, 470). As such, ten-minutes of R-R recording for examining HRV may promote improved validity and enhanced reliability allowing for the partitioning of a five-minute period free of artifact or ectopic beats (470).

Current evidence has established the importance for identifying ectopic or missing beats along with implanting a correction technique, either manually or through a computer software program prior to analyzing HRV indices (17, 246). This filtering process establishes a recording period that best represents the underlying R-R intervals prior to its examination, such a sampling period would allow for the best representation on the current state of the autonomic nervous system (470). The importance of filtering R-R periods prior to its examination has been demonstrated when comparing identical five-minute recordings that differ only by a single ectopic beat, as HRV indices have been shown to be modified by up to 50% (50). The filtering of artifacts can be achieved through multiple methods such as interpolation, removal of the ectopic beat or a nonlinear predictive interpolation (119, 357, 470). Regardless of the methods chosen, consensus towards the standardization of an artifact removal process must be maintained if practitioners wish to compare immediate or future HRV values (18, 357). Further consideration to maintaining the validity of HRV analysis should be taken though proper instrumentation use (50). Heart rate monitoring equipment should utilize a minimum sampling rate of 250Hz; however it is recommended that a sampling rate between 500 and 1000Hz is ideal to provide a time resolution and sampling error of 1 millisecond (18, 362). Although filtering methods may greatly reduce the amount of artifacts, limited errors may still exist in the R-R recording sample (50). When utilizing HRV for the purpose of athlete monitoring, it has been suggested that remaining errors in the recording period after filtering are deemed a minimal issue if a standardized method for the collection and analysis are kept constant (50).

Measuring HRV can be accomplished using various methods and algorithms. The most common methods are time domain analysis (TDA) and frequency analysis (FA) (470). TDA is thought to be the simplest method to perform (470). This method uses heart rate at any given time and determines the time in milliseconds (ms) between successive normal cardiac cycles (470). TDA provides two methods for examination - statistical and geometric analysis. The less frequently used geometric method provides a graphical representation of the sample distribution of differences in R-R intervals (470). This analysis involves each cardiac cycle plotted in a graphical representation against the sample mean and measured for variance using two levels of standard deviations against the sample mean (470). This method is thought to be less practical when working within team sport as R-R recordings for this type of analysis require a minimum of 20 minutes (470), leaving the analysis and interpretation unreasonable when working with multiple athletes. For this reason, statistical analysis is typically used among sport practitioners, specifically rMSSD, as it provides enhanced statistical properties and is less influenced by respiratory sinus arrhythmia (RSA) (358, 470). Major limitations when utilizing a TDA may be the lack of discrimination between the different components of the autonomic nervous system (18). Even with this limitation, TDA is extremely beneficial for sport practitioners when working with athletes outside the laboratory in a field setting (50). Previous investigations have demonstrated rMSSD to possess superior statistical properties that can resist the influence of RSA, as such it has been postulated that this vagal related index may be more appropriate for monitoring athletes when undergoing spontaneous breathing while using short-term recording periods lasting five minutes in duration (7, 358).

Possibly the greatest benefit when using FA is the ability to dissect the autonomic nervous system into its different branches (18). Frequency ranges between 0.04 and 0.40 are broken into three categories, very low frequency (VLF) <0.04Hz, low frequency (LF) 0.04 – 0.15Hz and high frequency (HF) 0.14 - 0.40Hz (470). It is thought that VLF represents circadian changes and thermoregulation, with LF representing both parasympathetic and sympathetic activity together with regulatory mechanisms such as baroreflex response and the angiotensin system while HF primarily reflecting vagal control on the heart and parasympathetic activity (109, 419, 470). This form of analysis by definition breaks down any stationary, steady, or fluctuating time-dependent signal into its sinusoidal components (470). Power spectral density analysis enables the plotting of the power of each component in the defined frequency zones (18). Power spectral density analysis can be performed and examined using three different methods: Fast Fourier Transformation (FFT), auto aggressive modelling (AR) and wavelet decomposition (18, 470). FFT is typically used in the scientific community as it prevents information from being lost in computation; it is simple to apply, makes the informational graphs visually pleasing, and is typically accessible for application on most computers (90). However, a major disadvantage when using power spectral density analysis with athletes in a field setting is the strong influence that RSA has on HRV indices (358). Therefore, it is the responsibility of the sport practitioner to clearly understand the benefits and limitations that each HRV indices provides before implementing HRV as a monitor tool.

2.3 HRV Monitoring in Team Sport

Sport practitioners continue to be in search of new athlete monitoring techniques and focus areas that can better indicate rapid recovery and help predict future or immediate performance. Although limited, research in highly trained and elite endurance athletes has shown good correlation between high vagal related HRV indices and enhanced central and peripheral cardiovascular performance (205, 368, 370). However research is still inconclusive as to whether enhanced HRV vagal-related indices are the cause or effect of properly developed training periods that lead to enhanced performance (205). Regardless, the presence of high vagal-related HRV indices when monitoring athletes may act as a potential indicator for performance (205). HRV has been a popular focus area over the past decade with limited research examining elite athletes and equivocal findings to support its use within this homogenous group (51, 232). A potential major limitation may be due to the data collection method itself.

Buchheit et al. demonstrated how problematic collecting resting heart rate values for R-R analysis in elite athletes can be as only 14 of 40 when monitored for several weeks collected the required R-R samples needed for a valid HRV analysis (52). These findings suggested that athlete compliance may be the rate limiting factor when using HRV as a monitoring tool (369). This problem may be further enhanced when working within team sport environments where greater variability in athlete adherence and equipment functioning may exist. Appropriate tutorials and guidance by sport practitioners towards proper use of personal monitoring equipment should be implemented early in a training regime in the effort to improve athlete compliance, the validity and reliability of any HRV measurements.

Previous literature has revealed robust evidence demonstrating how HRV and resting heart rate fluctuate throughout training periods of a mesocycle where volume and intensity are periodized (52, 149, 232, 236, 295, 360, 361, 373). Substantial evidence demonstrating the sensitivity of both resting heart rate and HRV to training loads and high-intensity exercise encourages sport practitioners to monitor the daily and weekly changes in the autonomic nervous system due to internal or environmental training stress (50, 418). The sensitivity of HRV to training stress has opened the door for promising research where day to day training guidelines based on the status of vagal related HRV indices can determine the type and amount of training an athlete undergoes (368). A major limitation with this concept is how to incorporate HRV lead training in a team sport environment. Coaches often develop training sessions based on a known quantity of athletes allowing for specific drills and intra-squad scrimmages to take place. Removal of a single athlete immediately prior to training would likely prevent the ability to plan training sessions and achieve the desired tactical and technical focus areas throughout a training block.

Although daily HRV guided training is still in its infancy and may be more practical for individualized sports, the monitoring of the autonomic nervous system in a team sport setting may still be a valuable assessment tool. The POLAR Team^2 system has proven to be a valuable instrument in team sport settings where collecting R-R intervals for HRV analysis is of interest (60). Each heart rate monitor in the Team^2 System provides an optimal sampling rate of 1000Hz and can be taken home with the athlete as each monitor can record up to 24 hours' worth of R-R interval data. Upon returning the heart rate monitor each session recorded can be transferred from the monitor to the sport practitioner's computer for further analysis. Kubios HRV Analysis 2.0 or 2.2 is a user friendly and valid software program that sport practitioners can utilize for analyzing R-R variability (48, 357, 453). Sport practitioners working within a team sport setting may benefit through implementing a user-friendly analysis program as the software is capable of automatic R-R interval editing at predetermined or self-selected levels. Additionally, Kubious HRV 2.2 utilizes a favored and recommended spline interpolation method called cubic interpolation. This filtering method utilizes a third degree polynomial to smooth out any ectopic beats or artifacts and is recommended when examining time domain HRV indices such as rMSSD (357).

The tracking of a training load and HRV indices throughout a periodized mesocycle may help coaches and sport practitioners identify which athletes can recover efficiently between successive microcycles. The relationship between autonomic nervous system status and aerobic fitness has indicated variation in R-R intervals to positively correlate to high aerobic power and overall aerobic performance (30, 251, 360, 428, 447). A reduction in resting heart rate along with improved vagal HRV indices can be the product of alterations in the autonomic nervous system through adjustments in the intrinsic mechanisms of the sinus node and the myocytes in the right atrial node (114, 276). Athletes who possess a cardiovascular system with high vagal dominance may have a superior ability to adapt to aerobic conditioning and competition (202). Weekly examination of vagal related HRV indices may provide improved monitoring into the adaptation process and enhanced capacity to perform between both microcycle and mesocycles (202). This option may be helpful for the sport practitioners and coaches to help predict future performance and to better understand the reaction of the autonomic nervous system within each athlete throughout the entire mesocycle and its corresponding training load. Recent studies examining alterations in HRV when assessing fatigue and performance in a team sport setting have provided promising results while demonstrating to be both practical and efficient (117, 126, 321).

Exercise that focuses on challenging the aerobic system has been proposed to safe guard the heart and cardiovascular system from cardiac stress and harmful cardiac events through augmenting vagal modulation and resting heart rate (35). This may be an important asset in most intermittent team sports such as field hockey where competition and training have shown to elicit physiological intensities between 71 – 92% of aerobic power and 85.5% of maximum heart rate, a range that demonstrates reasonable aerobic stimulus (277, 285, 445).

Although early evidence supports the implementation of weekly HRV monitoring in relation to an experienced training load, further evidence is required to support the number of weekly HRV recordings necessary to provide a valid assessment of a total weekly training stress. When examining endurance athletes, Plews et al., have suggested a minimum of three random HRV assessments throughout a seven-day period to provide confidence in a total weekly analysis (369). This sample requirement may not be practical in a team setting where sport practitioners are required to analyze 20 to 30 athletes per analysis limiting the capacity for timely feedback. The idea of a weekend rolling average may be more appealing and efficient in a team sport environment. Plews et al. recommendations were based from randomly selected recordings throughout the week; little evidence exists for averaging HRV recordings from successive days. A weekend rolling average may provide important insight into how the athlete adjusts to training throughout the week and their ability to recover before entering into the subsequent microcycle.

It is customary during the tapering phase of intermittent team sports that a shift from a tactical focus involving greater training load's to a more technical focus where a reduction in TL's occurs. This shift may allow for improved control of training load's on an individual basis throughout the tapering period. At this point it may be possible to organize specific training regimes for athletes who require similar recovery periods and reductions in TL. The utilization of HRV during the tapering period may allow for greater focus on individual recovery, a phase where this focus is of high priority.

2.4 The Use of HRV for Monitoring Overreaching

Changes in the autonomic nervous system during the course of a complete mesocycle have shown that moderate training loads are typically accompanied with increased vagal related HRV indices while large training loads are associated with a reduction in vagal related HRV indices (360, 361). Investigations involving high performance endurance athletes have demonstrated when athletes achieve and or maintain TL's equal to 100% of their capacity, vagal-related HRV indices require significant time to recover after a period of reduced training volume (58, 149, 236, 360, 361). When distance runners and swimmers experienced a three-week training block consisting of a 100% TL, HRV vagal indices decreased by 22% – 38% respectively (149, 361). After completing either a one-week taper involving a 60% reduction in TL or a two-week tapering period consisting of 70% reduction in TL, HRV improved by 7% and 38% respectively in both swimmers and runners (149, 361).

Previous literature examining elite endurance athletes who possessed an extensive training history revealed that the time course in vagal-related HRV indices in response to a training stress did not continuously follow previous tendencies, instead the time course demonstrated a bell-shaped curve in HRV values (232, 236, 265, 295, 370). Cardiac autonomic regulation in endurance athletes is thought to most likely be enhanced during the initial stages of the mesocycle where endurance training, considered as base training at aerobic threshold, is the primary mode of training whereby hyper stimulating parasympathetic activity and resulting in increased vagal related HRV indices (50, 226, 418). This transient increase in parasympathetic dominance shifted to a sympathetic state as training continued only to later return to a parasympathetic state during the tapering phase after likely experiencing functional overreaching (232). However, HRV values during a taper period have been known to remain suppressed even with reductions in training volume(365, 368). The classic tapering formula involving reductions in training volume while maintaining intensity may be responsible for this suppression in vagal related HRV indices (244, 245, 418).

High performance sport typically involves weekly fluctuations in training load 's that represent shifts in training duration and intensity that gradually increase to values exceeding previously experienced workloads. This philosophy is deemed as the overload principle and is the cornerstone to developing athlete training blocks (134). Mesocycles consisting of multiple training blocks following this principle while not providing ample time for recovery can often lead athletes to develop exhaustion in one or more physiological systems (18). The development of both non-functional overreaching (NFOR) and overtraining syndrome are consequences from prolonged stress and eventual exhaustion due to an imbalance between recovery, training stress, environment stress, or emotional and psychological stress (261, 269).

Previous literature suggests that overtraining or NFOR can promote hormonal imbalances in an athlete (154, 261). These alterations in hormones can lead to autonomic imbalances seen through fluctuations in HRV (269, 398, 472). Inquiries remain as to which way the direction of the autonomic nervous system drifts during this period, whether it becomes parasympathetic or sympathetic dominant. Israel differentiated between the two possible states naming the parasympathetic style of overtraining 'Addison Type' and the sympathetic state 'Basedow Type' (398). Although both types of overtraining are direct responses to a lack of planned recovery and reduced training volume it is thought that the Basedow Type is a consequences from excessive psycho-emotional stress (269). An excessive amount of non-training factors such as social, nutritional, and educational stress or a heavy competition schedule may give rise to the Basedow Type of overtraining (269). Addison Type overtraining is thought develop during the initial stages of NFOR that may continue into a state of overtraining syndrome (269). It is postulated to develop from an over stimulation of the sympathetic nervous system which in turn promotes a reduction in vagal related HRV indices (269). With prolonged sympathetic stimulation comes increased excitation and arousal due to the excess release of epinephrine and norepinephrine; this increased level of excitation stimulates a negative feedback response where a down regulation in the alpha and beta adrenoceptors diminishes sympathetic nervous system control whereby the autonomic nervous system then gravitates towards parasympathetic dominance (261, 269). Such a theory gives rise to the idea of a bell-shaped response in HRV when progressing through the stages from overreaching to overtraining syndrome (261, 269). This bell-shaped response in vagal related HRV indices during a heavy training period or high-intensity period can make it challenging for sport practitioners to interpret the response in HRV especially leading into major competition (370).

Perhaps the leading cause for misconception among sport practitioners and coaches when using HRV to assess an athletes state of readiness is that a direct linear relationship exists between vagal related HRV indices and parasympathetic control on HR (58, 165). Previous literature has indicated that in reality this relationship is quadratic and that during both low vagal tone with high heart rate and high vagal tone with low heart rate, HRV vagal related indices can be reduced (164, 165, 370). The possible underlying mechanism for this occurrence is thought to occur from the saturation of acetylcholine receptors at the myocyte (370). This increase in vagal tone may elicit a surge in sustained parasympathetic control over the sinoatrial node whereby modulation through RSA may be eliminated, possibly resulting in diminished vagal related HRV indices (291). Plews et al. demonstrated how the saturation effect can skew athlete monitoring when using HRV alone (366, 368). Their investigation demonstrated a unique and effective method for monitoring HRV along with R-R interval length to better understand the physiological adaptations throughout a mesocycle and during the tapering phase (368). This is a substantial discovery of great importance for sport practitioners who utilize HRV to monitor athlete fatigue and their state of readiness.

Research continues to demonstrate the importance of considering training context such as training load, load distribution, and training phases when examining changes in heart rate derived indices (50). To date, numerous articles exist demonstrating the effectiveness of monitoring TL with changes in HRV in endurance sport. However, the difficulty in using both parameters in team sport is much greater as the TL in intermittent sport is comprised of challenging different physiological energy systems in unison (50).

2.5 Distinguishing Between Overreaching and Overtraining

It is common practice for athletes to progressively increase the amount of training load accomplished when completing a mesocycle in the effort to stimulate improved future performance. As an athlete begins to experience an increase in TL, feelings of fatigue and signs of decreased performance are often experienced as a consequence of each intense and prolonged training session (214). Continued training of this nature without a sufficient period of rest and recovery or the introduction of a non-training stress has been suggested to be responsible for inducing a state of overreaching or the development of overtraining syndrome (466). Previous research has demonstrated that a recovery period of 14 days is sufficient for allowing an overreached athlete to climb out of this state and return to a normal homeostatic levels of performance and physiological wellbeing (189, 240). This discovery has led to the common belief that overreaching precedes the developed state overtraining syndrome often experienced after a prolonged period of residing in an overreaching state. The transition from overreaching to an overtraining syndrome state has been suggested to be a continuum where increased levels of stress elicits a disturbance in homeostasis resulting in a loss of overall functioning (137, 303).

The absence of clarity when defining overreaching and overtraining in the literature has made it challenging for sport practitioners to distinguish these unique physiological states and how best to recover for optimal performance (268). By definition overreaching has been identified as the result of an adverse amount of training stress that can be accompanied by non-training stressors (268, 270). These stressors can induce short-term decrements in performance that may show signs of psychological or physiological symptoms similar to overtraining (190). Often this state of imbalance can be overcome through forced rest or a reduction in TL within 14 days (190, 324). In 2006 a position statement was developed to better identify the continuum from overreaching to overtraining syndrome (387). Functional overreaching has been suggested to be the initial stage of overreaching whereby decrements in performance can be observed from days to weeks with a following super compensation in performance when fatigue is removed (324, 370, 387). NFOR is the proceeding stage whereby decrements in performance can be observed lasting several weeks to months before performance is recovered, usually without super compensating beyond that of the initial performance capacity (324, 370, 387). Overtraining syndrome has been demonstrated to be induced through identical situations however the time to recover from this syndrome requires several weeks or months before a level of homeostasis can be regained (190). By definition this proposes that the style of training responsible for each state of fatigue is identical however it is the amount of time required for restoration in performance and overall wellbeing that separates the three stages (395). Anecdotal evidence suggests that overreaching occurs more frequently in a team sport competition or in power and explosive sports while overtraining syndrome is more often experienced in endurance sports (190). This belief is further supported when monitoring vagal related HRV indices and observing its progression through the inverted U shape with increased TL's often experienced in endurance training athletes (370, 415).

The signs and symptoms of both overreaching and overtraining have been studied in an attempt to identify the early onset of fatigue in an effort to prevent the progression into an overtraining state. Changes in psychological, physiological, hormonal, mood state, glycogen depletion, autonomic balance, biochemistry, and performance have all been examined in small populations of athletes or highly trained individuals. Until recently there remained a lack of definitive diagnostic criteria when determining a state of overtraining (303). Ethically it is not possible to induce a state of overtraining in athletes; this has limited all current case studies to examine overreaching and its time course of symptoms. This ethical dilemma sheds light on the current demand for descriptive research on high performance athletes in their normal training environment where the introduction and magnitude of emotional and psychological stress is in combination with their experience exercise stress.

Currently three areas with the largest amount of evidence for change during a state of overreaching and or overtraining are in performance, mood state, and changes in the body's immune system. Current consensus states a decline in performance is necessary when identifying a state of overreaching or overtraining. When examining aerobic power, VO_{2max} has been shown to decrease up to three to four percent after only two weeks of increased training load (240, 440). Furthermore, greater significance was found when examining time trial performance as a five percent decrement was observed in the same participants (240). Although VO_{2max} is an important indicator of aerobic performance, testing time to exhaustion may be more sensitive to actual sport performance due to the similarity in duration and demand (136, 466). Further research has identified decrements in time trial performance of 27-29% respectively when examining performance after a overloading period (136, 466). Current literature has demonstrated that the length and the type of exercise performance tests are important to consider when examining overtraining or overreaching. It is the job of the sport practitioner to identify and examine the demands of the sport to critically monitor the performance of their athletes in order to establish their state of fatigue or readiness.

Possibly the largest quantity of evidence through research along with anecdotal evidence for identifying athletes as overstrained have focused on the athletes mood state (213). Previous studies have demonstrated that changes or alterations in an athletes mood are commonly seen during periods of large TL's or when identified as overreached (136, 189, 240, 466). This method of assessment can be extremely practical for coaches and sport practitioners as online questionnaires are user friendly and time efficient. Caution must be used when assessing this area for identifying overtraining as false positives can been detected within athletes after acute stress from individual training sessions where performance is unaltered (312, 338). However, this form of fatigue assessment has been shown to be effective when monitoring long-term training fatigue. When examining collegiate swimmers throughout their academic degree a Profile of Mood State (POMS) was able to identify on average 81.45% of athletes who were stale (312, 339). To date literature suggests that mood state of an athlete is an integral piece of the puzzle when monitoring fatigue; however, performance tests must supplement these scores to negate any false positives induced through acute training stress.

Many anecdotal reports of increased infection, specifically upper respiratory tract infections, in overreached and overtrained athletes have been observed and been common belief. The possibility that intense or prolonged exercise or competition required to elicit overreaching and overtraining may expand the period of susceptibility to sickness through brief immunosuppression. Mackinnon and Hooper were able to identify 12.5% of athletes who were deemed as overreached as possessing upper respiratory tract infection symptoms (288). Greater interest was found when 56% of the athletes after positively responding to an increased TL self-reported symptoms of a upper respiratory tract infection (288). These finding are of great importance as symptoms of illness can still be manifested when monitoring athletes who are perceived to have responded positively to increases in TL.

To date examining hematological parameters for signs of immunosuppression provide conflicting outcomes. Reductions in leucocytes have been reported when experiencing increased TL's (271). Neutrophils have also been described to both increase or decrease during intensified periods of training (135, 143, 214, 289) while natural killer cells have been unaltered in athletes deemed as overreaching who displayed symptoms (135, 143). However, when examining the cells activity level in the immune system a proliferation has been reported in peripheral lymphocytes and T cells following increases in training intensity (135). These finding suggest that the competency of the immune system may be a superior indicator for overreaching or overtraining as opposed to immune cell count during periods of increased training intensity. Finally when examining immunosuppression through hematological variables it is critical to correct for the enhanced plasma volume expansion often seen after increased training intensities and or volume (86).

Recent evidence examining non-functional overreaching in team sport athletes throughout a complete season have revealed a strong relationship between reduced levels of resting anabolic hormones and its post-exercise response in pituitary activity (415). Schmikli et al. were able to demonstrate a decrease in resting human growth hormone along with reduced post-exercise adrenocorticotropic hormone with a compensatory response in mood and increased anger scores. These hormone alterations were accompanied with a marked reduction in performance ultimately identifying a potential state of non-functional overreaching.

Plasma glutamine concentration have been demonstrated to be a viable blood marker for identifying the balance between overtraining and recovery (394, 436). Skeletal muscle has been shown to contribute the majority of glutamine necessary for immune system functioning (353, 394), the gastrointestinal tract (441), and kidney function during acidosis as induced through exercise (480). Additionally, glutamine has been proposed to be influential in augmenting the attenuation and accretion of muscle protein synthesis (480). Smith and Norris were able to develop a training tolerance model using plasma glutamine and glutamate concentrations for identifying recovery and overtraining. When using such tolerance models involving physiological variables, sport practitioners are required to adequately sample throughout multiple training blocks in an effort to establish lower and upper boundaries of such a continuum.

When examining hematological variables for the identification of NFOR proper standardization in collection protocols should be considered (401). Hypervolemia induced through excessive TL's or training intensity may be responsible for negating alterations in immune cell count due to its diluting effect and reduction in concentration (401). Future research should focus on correcting for shifts in plasma volume when examining hematological variables when trying to identify overtraining.

2.6 Training Load

Coaches often employ videographers to film training sessions and major competitions in order to gain access to visual records for coding of individual and team performances. Performance coding is a simple method of gaining a qualitative and quantitative understanding of individual and team performance on a technical and tactical level. However, it may be just as important for sport practitioners to quantify the physiological stress achieved during these training sessions and competitions (23). When the goal is to optimize an athlete's training environment the first step should be to quantify what and how much an athlete accomplishing (39). It is commonly believed that increased training time and the resulting improvements will lead to enhanced physiological and sport performance (39). This method is widely recognized and endorsed amongst coaches. However, increases in training volume can also lead to negative outcomes such as increased injury occurrence, the development of NFOR, or overtraining syndrome itself (62, 190, 484). It is the responsibility of the sport practitioner to understand the physiological limits and recovery capabilities of their athletes in order to utilize this approach without inducing harm and improve the chances of success (39).

Both training duration and intensity are variables that when manipulated can elicit change in athlete performance. A decrease in one of these two variables without any compensation from the other variable can lead to a partial loss in training adaptations of the physiological, anatomical or sport performance components (264). Endurance training involving either low-intensity long duration or high-intensity short duration has been shown to stimulate blood volume expansion, specifically PV% after cessation of exercise in the following 24-48 hours (83, 86). This increase in PV is a result of stressing the body's cardiovascular system in a manner to which it is unaccustomed, or through a familiar yet extremely challenging training stimulus (86). Cardiovascular stress of this nature causes a protein in the form of albumin to translocate from the extracellular and intracellular compartments into the vascular compartment via the lymphatic system (83, 84, 156, 157, 199, 257, 343). An increase in plasma albumin content is accompanied with changes in osmotic pressure between the interstitial and the vascular compartments initiating the movement of water into the vascular compartment (83, 157). This increase in plasma albumin content stimulates a blood volume expansion as one gram of albumin can adhere to 14 – 15 mL of water (413, 424). This phenomenon may be of great interest for sport practitioners as this increase in blood volume, albeit with no improvement in red blood cell count may lead to improvements in maximum cardiac output, maximum heart rate and potentially VO_{2max} (279). Developing the understanding of specific TL's unique to an athlete that can induce such changes in PV% and potential performance may allow sport practitioners to strategically implement training sessions for the purpose of blood volume expansion prior to competition or training camps. This is an important component for sport practitioners to understand when modelling TL throughout a mesocycle and allows practitioners to contribute effectively to the daily on-field training environment.

Intermittent team sport such as field hockey involves repeated bouts of high-intensity actions along with periods of recovery, and light to moderate running (139, 277, 285). Reinforcing the sport practitioner's repertoire to better understand athlete training load and how to monitor that load can improve their ability to contribute within the integrative support team. This can be accomplished through providing insight on training volume and intensity when modeling training blocks and individual sessions, and how to optimally remove fatigue prior to entering competition (25).

When quantifying training stress in sports of a continuous nature, numerous methods exist (220). Bannister's training impulse (TRIMP) method for measuring training stress into a quantifiable TL value examines changes in heart rate during exercise, exercise duration and a weighting factor (23). Based on Green et al.'s demonstration of an exponential relationship between training intensity and blood lactate concentration, Bannister employed a weighting factor in his TRIMP calculation for TL (177). Implementing a weighting factor allows the TRIMP calculation to theoretically be used in intermittent exercise where intensity varies throughout its duration (23, 220). The TRIMP model has been used with much success in cycling where TL was developed for professional races and competitive time trials to help create proper training protocols for such events (347, 348). Bannister's development in quantifying a training load using a TRIMP calculation allowed sport practitioners to physiologically quantify internal training stress and the TL an athlete experiences (23, 25). The mathematical equation for calculating a TRIMP is based on changes in heart rate. Heart rate variables such as resting heart rate, maximum heart rate, and the developed mean heart rate of the training session along with the length of activity are then multiplied by a coefficient weighting factor to provide a TL for an individual training session or competition (23, 25). Individual TL values can then be aggregated into weekly values that can be tracked throughout the yearly training plan. The attraction of using Bannister's TRIMP model is that all the necessary variables can be easily monitored and collected using a heart rate monitor. The capability to monitor TL's on a daily and weekly basis has dramatically improved the ability of the coach and sport practitioner to prescribe and adhere to individually periodized training programs. These carefully planned and monitored programs may allow athletes to achieve higher levels of performance and improved recovery rates throughout a training and competitive season.

The nature of intermittent team sport involves random periods of high-intensity actions that vary in duration and intensity throughout the entirety of the match (22, 44, 384). The randomness in duration and frequency of high-intensity periods makes calculating a valid TL much more difficult (445). When using the mean heart rate value together with exercise duration, the TRIMP mathematical model can neglect to represent the true physiological demands of spontaneous actions of intermittent sport where multiple energy systems are taxed simultaneously (25, 445).

The development of heart rate zones that can categorize individual maximum heart rate values into sub groups to identify accumulated time spent in each zone has helped sport practitioners to better quantify TL and understand the breakdown of short high-intensity duration activities (111, 131, 280). Edwards was the first to demonstrate a simple approach where he developed five HR zones differing by 10% from an individual's maximum heart rate value and provided a weighting of 1 – 5 for each zone in sequential order (111). This method helped to identity time spent in each zone and provides a higher weighting factor for zone five (90 – 100% maximum heart rate) to better reflect the intermittent nature and true physiological stress in team sport. Edwards's model was later modified by reducing the number of zones to three; Zone 1: time spent below VT_1, Zone 2: time spent between VT_1 and VT_2, and Zone 3: time spent above VT_2—to better identify and represent physiological changes in substrate utilization and performance indicators (131, 280). However, each model, regardless of the number of zones, utilized a linear weighting factor for each zone, a model that fails to mirror the true physiological responses to exercise above VT_2 (478). Stagno et al., corrected this issue by providing a weighting factor for each of the five zones that mirrored the typical blood lactate curve profile to an increase in intensity during exercise (445). Specific weighting factors were placed on zones two and four where VT_1 and VT_2 occur and a change in lactate formation and clearance can be seen (468).

With advancements in modern technology, the POLAR Team^2 System has been demonstrated to be a valuable instrument in team sport settings where collecting exercise heart rate values along with R-R intervals for HRV analysis is made effective and efficient for sport practitioners. The POLAR Team^2 System provides a unique POLAR Load value (i.e. TL) that is developed using POLAR's own proprietary mathematical calculation largely based on substrate utilization and modified with weighting factors including athlete sex, body weight, and aerobic power (327). The Team^2 system also offers a unique adapting TL equation that adjusts for different modes of exercise. Polar categorizes its three mathematical equations to three different modes of exercise—continuous, intermittent, and body pump (resistance training)—to better reflect the physiological and mechanical loading athletes experience (327). This unique and adapting TL concept allows sport practitioners to quantify a weekly TL that can encompass every form of training an athlete experiences; providing a greater insight into the monitoring and planning process throughout the yearly training plan.

2.7 Physiological and Biochemical Adaptations Associated with Short-Term Heat Acclimation

When the internal environment of the human body is disturbed and homeostasis is challenged by a stressor, an effector response is stimulated to regulate any disturbance in an effort to retain its previous level of homeostasis. If these stressors are repeated, the constant disturbance to the body's homeostasis stimulates adaptations that allow for improved control and accommodation that promote enhanced tolerance to future stimulus (481). When the natural environment provides similar stressors that challenge the body and its ability to exercise in that environment, the body adapts and its capability to exercise improves; this adaptation is deemed acclimatization (13). If similar adaptations are developed using identical environmental stressors that are created using an environmental chamber this process is termed acclimation (13). When undergoing the acclimatization or acclimation process, the adaptive responses the body can develop to a particular stressor may enhance exercise performance when experiencing similar or less challenging conditions (279, 450) or potentially under completely different environmental conditions (221, 284). Physiological performance adaptations that are stimulated through heat acclimation can allow sport practitioners to plan preparatory acclimation periods prior to entering an unfamiliar environment where performance may be compromised (61, 279, 452).

The process of heat acclimation has been commonly categorized into three phases: short-term acclimation (≤ 7 exposures) (9, 122, 452), medium term acclimation (8 – 14 exposures) (9, 70, 279), and long-term acclimation (≥ 15 exposures) (132, 356). The current literature has demonstrated that typical heat acclimation protocols usually involve a minimum of 10 exposures; it is believed that this period of repeated heat exposures can lead to a level of full acclimation (13). However, when examining the heat acclimation process it is evident that initial adaptations occur as early as four exposures (452). The time frame for short term heat acclimation provides an advantage for sport practitioners as the time commitments may be relatively small in nature, allowing for improved implementation into the yearly training plan. Sport practitioners are typically drawn to short term heat acclimation protocols as this time frame typically provides immediate cardiovascular adaptations (61, 70, 138, 151) that may be viewed as most important for intermittent team sport, specifically field hockey where aerobic performance and repeated bouts of high-intensity actions largely determine on-field performance (139). However, these cardiovascular adaptions that are observed early in the short term heat acclimation process are not the only physiological adaptions that may enhance on-field performance in intermittent team sport.

When examining the human body's physiological and biochemical changes to repeated exposures of heat stress it has been demonstrated that the first adaptations to develop are usually the first to dissipate, which typically come from a cardiovascular origin (152, 350, 399). Heat acclimation protocols lasting 7 – 15 days have demonstrated marked increases in sweating power and sweating efficiency (489). Although these adaptations typically take longer to develop, a reduced rate of decay has been observed in these later adaptations (153, 456). PV expansion, also known as hypervolemia, can typically occur within the immediate 3 – 6 days of repeated heat exposures (13, 424). short term heat acclimation protocols have demonstrated changes in PV ranging between 4.5% and 15% (70, 138, 151, 378, 489). This rapid expansion in PV is responsible for a marked improvement in cardiovascular performance and stability, enhanced thermoregulation, and improved fluid and electrolyte reabsorption (151). The resulting hypervolemia, although transient in nature, reduces submaximal and maximal exercising heart rate (13, 61), increases stroke volume (325), and improves cardiac output (279), which may be due to enhanced ventricular compliance (223) and myocardial efficiency (222). The correlation between hypervolemia and reductions in submaximal heart rate during exercise is typically strong, yet this correlation may not be completely responsible for the observed lower heart rates at a given work load. Recent evidence has demonstrated that in the disappearance of hypervolemia, a reduced exercising heart rate may still be present (152). It has been proposed by Hodge et al., that a reduction in plasma norepinephrine during exercise may partially be responsible for a reduced exercising heart rate in the absence of PV expansion (211). Animal models have also indicated potential improvement in myocardial compliance and conservation in high energy phosphates that may also contribute to a reduction in exercising heart rate (223, 273).

Irrespective of the contributing factors for a reduced heart rate, hypervolemia seems to be the main objective of sport practitioners implementing a short term heat acclimation protocol. Two potential mechanisms are responsible for this hematological adaptation, although it is thought that each feed off the other and are responsible for the marked increase in plasma volume (287). The first potential mechanism is related to changes in the body's ability to reabsorb sodium (Na^+) and water during heat stress and/or dehydration (287). Plasma renin activity has been shown to increase during acute heat stress; this increase in activity has been thought to be responsible for the cleaving and upregulation of angiotensin II and the subsequent stimulus for increased aldosterone (21, 118, 259). The capability of the renin-angiotensin system to control for the excretion of sodium is very sensitive (287). During dehydration, the loss of fluid in the vascular compartment along with enhanced Na^+ retention due to increased renin activity both act as stimulus for the release of vasopressin, a hormone responsible for inducing vasoconstriction and enhancing renal water reabsorption in an effort to maintain blood pressure and cardiovascular performance (155, 166, 416). As sweating increases to assist thermoregulatory demands, the movement of water from the intracellular compartment into the extracellular compartment will be dependent upon the concentration of Na^+ in the sweat (332). Water loss from the extracellular compartment is due to enhanced sweating as thermoregulation is challenged, this loss of water is typically from the interstitial compartment which can pull extra water as needed for thermoregulation from the vasculature compartment furthering inducing dehydration (332). Changes in plasma osmolality have been shown to be directly related to alterations in dehydration and core temperature, alterations that stimulate osmoreceptors located in the hypothalamus and periphery to elicit an upregulation of vasopressin (460). Zona glomerular cells located in the adrenal cortex secrete aldosterone in response to elevated levels of Na^+ and potassium in the vasculature compartment (287). The increased tonicity found in the vasculature compartment then drives the movement of fluid from the intracellular space to vasculature space through changes in the osmotic gradient (287). Changes in plasma osmolality act to prevent further reductions in blood volume in an effort to limit the strain placed on the cardiovascular system (332). These actions of the renin-angiotensin system during prolonged heat stress act to maintain the size of the vasculature compartment and prevent the decrement in performance of the cardiovascular system during periods of low blood volume (188). The developed conservation reactions for electrolytes and water are responsible for an overall increase in the extracellular compartment; this general increase in extracellular fluid has been shown to increase the vasculature compartment as well and may partially be responsible for the development of hypervolemia (287). Interestingly, recent evidence now supports the use of permissive dehydration during short term heat acclimation as controlled dehydration has been shown to be an independent stimulus for hypervolemia (153). This theory supports the combination of both a heat stimulus and purposeful dehydration to act as a compensatory mechanism for maximizing hypervolemia (153).

Total circulating plasma albumin content has been demonstrated to be a key factor in the induction and maintenance process of hypervolemia when induced using short term heat acclimation (287). Wyndeman and Harrison demonstrated that enhanced cutaneous blood flow can result in the eventual increase of plasma albumin content and a resulting overall PV expansion (197, 489). It is believed that during the initial exposure to heat stress, a marked increase in core temperature under resting conditions stimulates a redistribution of blood flow to the cutaneous beds for evaporative cooling effects; this redistribution of blood results in enhanced cutaneous venodilation (423). This change in blood flow stimulates a drop in capillary hydrostatic and filtration pressure leading to a subsequent increase in reabsorption of water, potentially promoting short-term hypervolemia (84, 423). Interestingly, Convertino et al. demonstrated that when core temperatures are elevated to an identical level using either resting exposure to heat or exercise in a hot or temperate environment, only exercise induced an increase in plasma albumin content and a resulting significant PV expansion (84). The potential exercise-induced cutaneous vasodilation in the exercise group compared to the venodilation of the resting group is believed to be responsible for this discrepancy (84). This marked difference led to an increase in cutaneous blood pressure and a corresponding increase in capillary filtration rate from the vasculature into the interstitial compartment (422). The resulting increased capillary filtration potentially led to a flushing of the interstitium and its protein content into the lymphatic system for the eventual return to the vascular system (421). One gram of protein has been shown to bind to 14 – 15g of water (413, 424). This resulting increase of plasma albumin content from the flushing of the interstitium would increase plasma tonicity and volume in proportion to the amount of protein circulating in the vasculature compartment. The results from Convertino et al. demonstrate the impact of plasma albumin content and how its colloid osmotic pressure significantly contributes to plasma volume expansion during short term heat acclimation protocols. It was this investigation that demonstrated the total increase in PV expansion when exercising in the heat equaled the combined PV (84).

The induction of hypervolemia during short term heat acclimation using exercise would, in theory, increase total blood volume and a concomitant increased capillary hydrostatic pressure gradient (385). Enhanced capillary filtration would be a residual effect of increased vascular hydrostatic pressure and in theory would eliminate any expansion of plasma volume. Generally under resting circumstances, large pores in the microvasculature are responsible for 80% of transcapillary albumin clearance, a clearance that is driven entirely through hydrostatic pressure gradients between the vasculature and interstitium (389). The remaining 20% of albumin disappearance occurs through small pores and is generally diffusive (389). Perhaps one of the largest discoveries to the induction and maintenance of exercise-induced hypervolemia was the identification of changes in muscle hydrostatic pressure gradients and albumin content and its insulating effect to increased vascular volume (199). Balanced hydrostatic pressure gradients between the muscle interstitium and vascular compartment along with increased levels of muscle interstitial albumin content have demonstrated to attenuate the transcapillary escape rate of albumin after the induction of hypervolemia (199). This same mechanism may be partially responsible for the induction and maintenance of short term heat acclimation-induced hypervolemia when using exercise. It is likely that the actions of the renin-angiotensin system to conserve both plasma Na^+ and water allows for the increased presence of plasma albumin from the flushing of the interstitium to maintain and eventually increase plasma volume in response to exercising in the heat.

Improved regulation of core temperature can be an early adaption to repeated heat exposures that can usually be developed through an short term heat acclimation protocol consisting of a minimum of four exposures (13). Core temperature at rest and at identical maximal workloads after short term heat acclimation has been shown to be reduced up to 0.2^{o}C (47, 138, 208) when compared to the previous un-acclimated state (45, 138, 151). Augmented core temperature at rest and during exercise is accomplished by upregulated convective and evaporative heat loss (71). When exposed to an ambient temperature which is hotter than the skin, the body’s sole mechanism for heat loss is through evaporation; a process known as convective heat loss (481). This method of cooling is responsible for not only dissipating any heat development through the body’s metabolism while exercising but also the heat collected from the environment (481). The magnitude of convective heat dissipation between the environment and skin has been demonstrated to be proportional to the disparity between ambient air temperature and the temperature of the skin (481). Relative humidity levels have shown to influence the rate and capacity for convective heat loss in humans, however enhanced sudomotor responses such as increased sweat rate are rapid and common adaptions to performing heat acclimation in high humid environments (457). The variation in sweat power development between dry and humid acclimation is considered to be due to the loss of evaporative capabilities of the skin as the vapour pressure approaches an equilibrium between the skin and the environment (457).

To date, short term heat acclimation studies involving dry heat have shown enhanced physical performance when in hot (452) and temperate (61) environments. short term heat acclimation protocols using high levels of relative humidity have only demonstrated improved performance in hot environments (74, 151). When comparing short term heat acclimation protocols implementing either a dry or humid environment it is currently believed that improved physical performance in temperate conditions would follow each form of acclimation and provide similar benefits (71). It was suggested that using higher levels of humidity during heat acclimation would increase total evaporative skin surface area, enhancing the lower limb's evaporative capability (383). Patterson and colleagues were able to expand on this theory by demonstrating greater interregional variation in sweating capacity in the forearm and chest regions when compared to the thigh or forehead using high humidity levels during acclimation (355). These observations indicate that a humid heat acclimation protocol can elicit greater interregional sweating capacity rather than specifically improving lower limb evaporative capabilities (355). short term heat acclimation using exercise has also demonstrated a reduced threshold for the development of sweating (89, 491).

The relationship between cutaneous vasodilation and sweating has been thought to work in unison (396), such that vasodilation mirrors gland activity to help maximize evaporative and convective heat dissipation (481). short term heat acclimation training has been shown to reduce the threshold for cutaneous vasodilation (138). The sole mechanism for early cutaneous vasodilation continues to be debated, plasma volume expansion allowing for enhanced blood redistribution to the body's core and shell, without compromising blood pressure, has been thought to be responsible for this adaption (432). Further examination in the sweating adaptations to short term heat acclimation have identified eccrine sweat glands as more influential in thermoregulation, potentially due to them out numbering the amount of apocrine sweat glands (262). It is believed that the earlier onset of increased skin blood flow, accompanied with the early onset of sweating, act together to better control thermoregulation during rest and exercise (Lorenzo, et al., 2010). Accompanying the early onset of sweating is an improved ability of the sweat gland to reabsorb Na^+ allowing for a more diluted sweat (75, 253). Enhanced Na^+ reabsorption due to the elevated presence of plasma aldosterone has been shown to help regulate a balanced level of electrolytes in the extracellular compartment to better maintain both plasma volume and cellular functioning during rapid water loss (75, 253). With an enhanced ability to sweat earlier while generating a more diluted sweat on top of a lowered skin threshold for cutaneous vasodilation, the body's core to shell temperature gradient has the potential to remain as large as possible, therefore improving its evaporative and cooling capabilities when generating metabolic heat and/or working in a hot environment (481).

Alterations in muscle metabolism through short term heat acclimation have been inconclusive as limited evidence suggests attenuated carbohydrate metabolism during submaximal workloads post-acclimation (122, 138, 430). Currently there is limited research demonstrating a reduction in muscle glycogen storage in Type I muscle fibres after undergoing short term heat acclimation (122). Febbraio et al. were able to demonstrate reduced levels of epinephrine and norepinephrine during exercise in the heat after completing a 7 day heat acclimation protocol, this resulted in post-acclimation muscle glycogen content equal to that of an identical exercise test performed in temperate conditions (122). The focus on adaptations to neurotransmitters from short term heat acclimation remains promising, however previous research investigating reductions in blood volume and its concomitant result of a reduced VO_{2max} and anaerobic threshold may potentially explain the increased sympathetic activity and muscle glycogen utilization during exercise in the heat (279). Adaptations to neurotransmitters and their alteration on sympathetic activation, and resulting muscle glycogenolysis activity from short term heat acclimation, require further investigation.

2.8 Current Short-term Heat Acclimation Protocols and Unresolved Issues for Future Direction

The most common research design when undergoing short term heat acclimation is an exercise protocol that would resist initiating an exercise-induced training stimulus; a design of this nature would help establish greater confidence in the dependent variables being examined. When examining short term heat acclimation, most protocols involve 10 consecutive exercise sessions using an exercise intensity of $\leq$ 50% VO_{2max} broken into two 45-minute periods at an ambient temperature between 35 – 40^{o}C and 20 – 60% relative humidity (71). Interestingly, although most short term heat acclimation protocols consist of an exercise intensity level of 50% VO_{2max}, most research studies neglect to standardize this level of exercise intensity within its population (71). Exercising at 50% of maximal aerobic power may place a different exercise load on participants if this intensity resides above or below their aerobic threshold. Depending on their current level of physical fitness when entering the short term heat acclimation period, any change in the dependent variable may have been influenced by an exercise-induced stimulus.

Current research on short term heat acclimation in team sport is extremely limited. Buchheit et al. were able to demonstrate a 7% increase in YoYo intermittent recovery test performance in a temperate environment with elite soccer players through acclimatization during daily soccer training for seven consecutive days (61). Sunderland et al. were able to demonstrate a 33% increase in aerobic performance in a hot environment when using an indirect on-field measurement after a four day intermittent short term heat acclimation period (452). This study also consisted of only on-field training sessions in an ambient temperature of 30^{o}C, 24% humidity, with well-trained female field hockey athletes. To date these are the only two research projects using acclimatization in team sport that demonstrate success in achieving short term heat acclimation and exercise performance adaptations when utilizing their respective sport. Medium term heat acclimation protocols utilizing high-intensity intermittent exercise have shown success in acclimated individuals using short exposure periods with strenuous exercise. Houmard et al. were able to demonstrate that a typical 90-minute heat acclimation session at an intensity of 50% VO_{2max} was just as effective for inducing heat adaptation as high-intensity exercise (70% VO_{2max}) in sessions lasting only 30-35 minutes (224). Interestingly, the only significant physiological difference between each protocol was the change in PV as exercising at a lower intensity for a greater duration was the only protocol that demonstrated a positive adaptation (224). Brade et al. further support the use of high-intensity intermittent heat exposures for short term heat acclimation when exercising at 80% VO_{2max} in a 35^{o}C/60% relative humidity environment (45). Upon completion of this protocol, the researchers were able to show a 4.8% increase in work capacity during a sprint cycle test among moderately trained male team sport athletes (45). As research continues to demonstrate the effective use of high-intensity, short duration short term heat acclimation protocols, sport practitioners will undoubtedly gravitate to this option as decreased time demands will favour a busy training schedule. Further research should continue to examine hematological adaptions to high-intensity short term heat acclimation protocols and its resulting influence on plasma expansion.

There is strong evidence for the effectiveness of short term heat acclimation being linked to fitness levels of the individuals undergoing acclimation (76). Highly trained athletes already possessing similar adaptions as seen through heat stress have a reduced response to short term heat acclimation (457). Endurance athletes have been observed to perform physiologically as though they have already been heat acclimated (456). Individuals possessing a high level of aerobic fitness, as indicated by having a $VO_{2max} \geq 65 mL \bullet kg^{-1} \bullet min^{-1}$ have demonstrated an accelerated adaption rate to heat exposures (350). Pandolf et al. were able to observe acclimation being achieved after only four days of repeated heat exposures within aerobically fit individuals (350). When observing the other end of the spectrum, individuals possessing a low level of aerobic fitness have demonstrated a longer adaptation period (258). These results suggest athletes that possess an aerobic fitness level $\geq 55 mL \bullet kg^{-1} \bullet min^{-1}$ may have the greatest opportunity for performance enhancement after undergoing short term heat acclimation (76). To date, only Lorenzo et al. have demonstrated improved aerobic and cardiovascular performance in hot and temperate environments after a MTHA protocol in highly-trained cyclists ($66.9 mL \bullet kg^{-1} \bullet min^{-1}$) (71). Further research exploring effective short term heat acclimation methodology in the effort to enhance aerobic and cardiovascular performance in hot and temperate climates with highly trained athletes is required.

It has been shown that the response to repeated heat stress exposure in females is similar to males, however, due to variations in anatomical and physiological measures, some adaptations may be slightly different (123). Females typically have a larger surface area to mass ratio than males, potentially allowing for an enhanced evaporative surface area for cooling effects (313). Certain phases of the menstrual cycle have also been shown to influence core temperature, for example a 0.5 – 1.0^{o}C increase in core temperature during the Luteal phase has been demonstrated in resting subjects (481). Changes in core temperature due to menses may influence adaptation rates during short term heat acclimation. To date only Sunderland et al. have examined short term heat acclimation in highly trained female athletes (452). Further research should focus on high performance female athletes and their responses to short term heat acclimation to better shed light on potential discrepancies between male and female adaptations during repeated heat stress.

It has been proposed that for every two days without exercising in the heat, one day of acclimation can be lost (158). LTHA adaptations have been shown to return to baseline levels with 21 days after removal of heat exposure (4, 13). Adaptations such as reduced exercising heart rate, reduced core temperature at rest and during exercise, early onset of sweating and a more diluted sweat dissipate within 21 days after removing heat exposure (4, 13). Plasma volume and cardiovascular enhancement has been reported to return to pre-acclimated levels within 7 days of removing heat exposure (152, 399). It has been suggested that methodological differences in the development of heat acclimation may influence the rate of decay. Limited evidence for prolonged adaptions that have been induced using a MTHA protocol with both dry heat compared to humid have supported this belief (349). Minimal evidence for the maintenance of physiological adaptions from heat acclimation have suggested for the implementation of a single heat exposure for every 5 days removed (456). Clearly the majority of research on short term heat acclimation has focused on its development rather that its decay rate. Further research should investigate the rate of decay in high performance athletes after the completion of a short term heat acclimation protocol.

The demands of a typical 90-minute heat acclimation session that is repeated for ≤ 7 days can be challenging from a practical standpoint within most team sports training schedules. Difficulty in finding a large environmental chamber that can acclimate multiple athletes simultaneously is a primary concern. Scheduling conflicts can arise when having to acclimate an entire team over multiple days if a chamber is unable to accommodate every athlete. Conflicts with team training and personal demands such as school and outside work schedules are typically issues that sport practitioners working within team sport environments experience. Although high-intensity, short duration acclimation protocols have shown to be an effective alternative for heat acclimation, future research should focus on the amount of internal stress and thermal load an athlete experiences while undergoing a short term heat acclimation protocol. Houmard et al. demonstrated that short bouts of high-intensity exercise (75% VO_{2max}) can induce short term heat acclimation adaptations similar to lower-intensity exercise (50% VO_{2max}) consisting of long duration periods. However, this short-term "quick gain" protocol may have been at the expense of suppressed heart rate variability (HRV) due to a large perturbation in homeostasis. Evidence for suppressed vagal related HRV indices when training above aerobic threshold (418) may provide insight on a possible negative outcome when using high-intensity exercise for short term heat acclimation protocols. If an short term heat acclimation protocol were to be used as an ergogenic aid prior to major competition and during the tapering period, a sport practitioner must understand the amount of physiological stress that will be experienced by each athlete. This internal stress, or training load, must be accounted for and compliance to the previously periodized training plan should be maintained. Future research focusing on the development of effective methodology for simultaneously acclimating an entire team of athletes is needed for sport practitioners working in team sport.

2.9 The Physiological Effects of Acute Heat Exposure on Athletic Performance

Limited research on soccer team performance in the heat during meaningful competition has demonstrated a reduction in total distance covered during match play (308), total distance covered at high-intensity speeds (494), yet a preservation of top end sprint speed when comparing matches played in a hot and cold environment (322). Research pertaining to performance in Australian rules football players further supports the limited evidence that team sport athletes tend to maintain top end speed yet suffer reductions in the total distance covered at this high velocity (19). This disparity in professional athletic performance when competing in hot and cool environments may shed light on the physiological strain and its concomitant effect on performance where thermoregulation is challenged and hyperthermia and dehydration can develop during match play.

Team sports such as field hockey involve repeated bouts of high-intensity actions interspersed by lower intensity periods allowing for recovery before imminent repeating periods of high-intensity actions (139). The high-intensity actions recorded during match play may place a large demand on muscle glycogen storage throughout the entirety of a match. Furthermore, the amount of high-intensity actions attainable may be compromised during competition in hot environments. Previous literature has identified enhanced rates of glycogenolysis and a resulting increase in blood lactate accumulation during exercise in the heat. (124, 492). A number of theories have been proposed to account for these glycolytic changes and premature levels of fatigue when compared to performance in a cool environment. Changes in plasma catecholamines may be partially responsible for alterations in muscle substrate utilization during exercise in heat. (252, 255). The response of the adrenal medulla during exercise has revealed to be upregulated in hot environments possibly explaining the increased presence of plasma catecholamines (147). Hyperglycemia is a common occurrence when exercising in the heat and may be a possible side effect of an enhanced catecholamine response and its resulting effect of increased liver glucose output (194). Febbraio et al. (1996) were able to further support the notion of an enhanced reliance on muscle glycogen during exercise in the heat. Increased levels of epinephrine and norepinephrine were observed when exercising in the heat as compared to temperate environments (122). A resulting reduction in Type I muscle glycogen levels observed with minimal reductions in Type II fibres (122). Although marked increases in blood glucose and muscular glucose oxidation rates have been observed, muscle glycogen depletion is thought not to be the main cause of fatigue when exercising in the heat as storage levels after exercise have demonstrated to remain relatively unaffected (352).

A potential explanation for the conflicting evidence regarding muscle glycogen depletion and its effect on exercise performance in the heat may be a result in the methodology followed in previous investigations. Single bouts of exercise lasting 10 to 30 minutes may lack the intensity and duration that can compromise muscle glycogen stores; these short bouts of exercise inhibit a true exercise response that would be observed in a 70 to 90-minute intermittent team sport event (239). Furthermore, potential issues may arise regarding muscle recovery and the re-synthesis of glycogen during repeated competition as seen within tournament schedules. Further research investigating muscle glycogen depletion using repeated bouts of exercise in the heat that mimic the demands of intermittent sport are warranted in an effort to provide greater insight for practitioners and team dieticians when developing proper nutritional recovery strategies.

The development of a critical level of body core temperature expressed as 40°C has been viewed as the primary reason for impaired performance in the heat (172, 325, 336, 337). This critical core temperature is observed as a security feature to help negate excessive hyperthermia induced through exercise (326, 334). The development of severe hyperthermia (≥40°C) may have an effect on the central nervous system (CNS) and its ability to recruit motor neurons for health-related reasons and athletic performance (193). Heat production is attenuated with lowered levels of metabolism as observed when approaching this critical core temperature during exercise, which may be due to a safety negative feedback response as expressed through reductions in motor drive (193). Evidence for exercise induced hyperthermia inhibiting sustained maximum muscle force production has thought to be attributed to the CNS and temperature related contractile properties of the muscle (462). However only prolonged muscle contractions demonstrated a diminished force production when compared to brief contractions that remained unaffected (462). Limited investigations examining muscle fatigue due to heat stress have suggested hyperthermia to significantly affect sustained voluntary muscle contractions (462). Reductions in cycling performance in the heat when core temperature was equal to that recorded in a cool environment showed reduced power outputs during self-paced exercise (250). Current literature proposes that the development of heat storage is regulated through afferent neural input from thermoreceptors of the blood and skin which helps regulate exercise intensity and metabolic rate in the effort to attenuate exaggerated heat production when performing in hot environments (465). The development of Hyperprolactinemia, a physiological state identified by elevated levels of prolactin, can be observed during exercise in hot environments and is thought to be an indirect indication of the possible involvement of CNS serotonergic activity and its effect on exercise fatigue in the heat (363). Further literature examining CNS limitations during exercise in the heat have demonstrated improved exercise performance when noradrenaline and dopamine re-uptake inhibitors were administered beforehand (479). Additional research directed towards examining the effects of hyperthermia on CNS performance during exercise and its subsequent alterations in perceptions of fatigue can help shed light on a potentially large piece of the heat-induced fatigue model during athletic performance.

When performing in the heat the physiological demands of exercise drive blood flow to multiple locations of the human body such as skeletal muscles to maintain energy production, the cutaneous layer for thermoregulation, and to the CNS for optimal functioning (77). With a continued rise in core temperature as a result of metabolic heat production, a high level of hyperthermia may arise, resulting in a substantial redirection of blood flow to the cutaneous layer for thermoregulatory purposes. This large redistribution in blood flow elicits a reduction in oxygen delivery to working muscles and central command (CNS) (175, 336, 381). As such, when an athlete is determined and highly motivated during maximal exercise, efferent neural activity relaying heat sensory information to central command can be neglected. When this state is achieved the body has been demonstrated to succumb to the exercising muscle demands whereby maintaining blood pressure and muscle blood flow at the expense of the cutaneous layer (174). Empirical evidence has demonstrated a linear relationship between core temperature and skin blood flow; augmented levels of cutaneous blood flow permit enhanced heat dissipation through convection; thus promoting a reduction in core temperature as whole body circulation is maintained (116, 172, 297, 351). The redistribution of blood flow to the cutaneous layer and its resulting effect on exercise performance was further investigated by Sawka et al. where they observed elevated skin temperatures due to clothing or extreme heat lead to the initiating of exercise termination or the collapsing of participants before core temperatures climbed above 38.5°C (409). These findings provide further evidence that redistribution of blood flow to the skin during mild exercise elicits a large cardiovascular strain that can diminish oxygen delivery to the working muscles whereby increasing the potential for premature fatigue before severe hyperthermia is observed. The main contributing factor to diminished aerobic performance (VO_{2max}) in the heat is thought to be the result of the redistribution of blood flow to the skin and the consequential reduction in both peripheral supply, diastolic preload, stroke volume and the resulting reduction in cardiac output (14, 170, 286, 411, 487). The fundamental limitations to aerobic performance in the heat are believed to be a result of a decrease in VO_{2max} and cardiac output, each being a consequence of a reduction in the cardiovascular reserve (27, 100). A continuous reduction in VO_{2max} can be observed with elevated ambient temperatures that elicit large increases in skin temperature with minimal changes in core temperature, this physiological response further supports the correlation between aerobic performance and the redistribution of muscle blood flow to the cutaneous layer for thermoregulatory purposes (14).

It has been observed that a reduction of >2% body mass due to dehydration can diminish aerobic performance and VO_{2max} (407, 408, 410). This reduction in total body water includes the vascular compartment, specifically plasma volume; such a loss in plasma has a concomitant effect on limiting diastolic filling and stroke volume (168, 169, 171). Reductions in the vascular volume have demonstrated to limit skeletal muscle blood flow and alter muscle metabolism during exercise (121, 173). This change in metabolism may be a consequence of greater reliance towards carbohydrate utilization in the working tissue as a result of an altered anaerobic threshold for a given speed or power output. Together both dehydration, as represented as plasma volume loss, and hyperthermia have been observed to account for at least 50% of the reduction in cardiac performance, anaerobic threshold and VO_{2max} (167). Competition for blood flow between the cardiovascular system to support aerobic performance and the cutaneous layer for supporting thermoregulation during exercise in the heat demonstrates a balanced relationship which regulates both desired performance and overall health. Developing an understanding of the relationship between a rising core temperature and the resulting redirection of blood flow to the cutaneous may allow practitioners to develop strategies to help preserve muscle blood flow prior to competing in the heat in the effort to sustain optimal performance. Strategies to enhance both the pre- and intra-competition hydration levels may also help favour performance whereby possibly preventing or delaying the body's decision to compromise performance for the maintenance of health (191).

Practitioners must recognize that extreme environmental conditions that elicit rapid elevations in skin temperature or whereby heat dissipation is dramatically attenuated due to increased ambient levels of vapour pressure may produce reductions in performance and health that may be dramatically compromised before core temperature rise to significant levels. For this reason, when monitoring core temperature during competition and training, it is recommended to examine additional risk factors such as relative humidity and heat stress (WBGT) in combination with monitoring core temperature.

2.10 Potential Adverse Health Outcomes as a Result of Exercising in Hot Environments

The development of heat illness can be categorized by the monitoring of two risk factors; external factors such as type of clothing and equipment, ambient temperature and relative humidity, and internal factors such as medical conditions of an athlete, drug use, and dehydration or sunburn (26, 225). Dehydration resulting from poor hydration prior to and during competition have shown to be a decisive factor in the onset of heat illness (225). Integrative support staff often follow a linear continuum in the development of heat illness which evolves from a mild to a more serious life threatening situation. Heat edema is recognized as the mildest form of heat illness; it can proceed to heat rash, heat syncope, heat exhaustion and eventually the most life threatening situation called heat stroke (225). Practitioners must recognize that the development of a mild form of heat illness does not necessarily elicit the development of a more serious form of heat illness if the athlete is left untreated (225). Perhaps the most important aspect in monitoring athletes competing in the heat is the proper diagnosis of symptoms being experienced by the athlete, this can allow for proper procedures and protocols to be followed in order to maintain the safety and health of the individual.

Heat edema can occur in the presence of a normal core temperature and can generally lack significant signs and symptoms (87, 225). Swelling of the interstitial compartment due to increased fluid buildup as a consequence of enhanced peripheral vasodilation for thermoregulatory mechanism often results in heat edema (87, 225). This enhanced vascular volume can lead to increased hydrostatic forces causing increased capillary filtration rates and a resulting fluid buildup in the interstitial compartment (199, 225). Elevation of the limbs accompanied with compression garments and proper rehydration of fluids and electrolytes may help improve immediate symptoms (87, 225). Heat rash is another form of heat illness that has been observed in athletes with a normal core temperature (87, 225). Onset of this form of heat illness is typically from the blockage of eccrine sweat glands from athletic equipment or clothing that results in the leakage from the sweat gland into the dermis layer often developing a prickling sensation (185). Successful treatment for reducing symptoms of heat rash can include immediate cooling of the affected area, reducing any clothing around the rash, and the use of a mild topical corticosteroid anti-inflammatory (185). Heat syncope is the third form of heat illness that can occur in the presence of a normal core temperature and is often developed from extreme exertion or quick postural changes during enhanced venous pooling and peripheral vasodilation (425). A sudden loss of balance or coordination during a momentary transition period during competition may lead to injury if an athlete is unable to support themselves or lose control of their movement (282). Typical treatment for heat syncope involves the immediate transition to a supine position and the elevation of peripheral limbs in an effort to stimulate venous return and the gradual loss of syncope (73, 425).

Heat cramps are typically experienced in large muscles during prolonged activity (>2hrs) and are often observed during normal to $<40^{o}C$ core temperatures (159, 482). Classic symptoms distinguishing heat cramps from exertional cramps is the often wide spread of affected musculature and its influence to cause similar symptoms to adjacent muscles that have yet to experience any symptoms (33). This type of heat illness is often observed with individuals who possess large Na^+ concentrations in their sweat output, possible leading to exaggerated extra and intracellular water and Na^+ loss (449). A potential consequence of Na^+ reduction in the interstitial compartment may lead to nerve axon terminals of nearby motor neurons becoming mechanically deformed with a concomitant increase in surrounding neurotransmitters and ions concentration (263). As a result, a portion of the developed hyper excitable axon terminals can discharge spontaneously eliciting new action potentials in the affected musculature (263). Often the progression of heat cramps from being hardly noticeable by the athlete to the state of unbearable pain can take place within 20 to 30 minutes after the first mild twitch is felt (33). A combination of Na^+ (1150mg) with water or a sports drink can be an effective response for controlling muscle cramps in athletes who demonstrate a high sweat Na^+ concentration (33).

Individuals who experience reoccurring heat cramps are often advised to ingest large Na^+ concentrations prior to or during competition (32), however special attention to potential gastro interstitial disturbance and bloating is advised as these are common side effects when consuming such large amounts of Na^+ and may develop into an independent factor for the cessation of exercise (493). Massage, static stretching or the cooling of affected muscles can also help reduce immediate discomfort and spasms (425).

Heat exhaustion has been shown to be the most common form of heat illness in athletes (10). This stage of heat illness is accompanied with a rise in core temperature below 40.5°C and prevents the athlete from further competing in competition (10, 26). The onset of heat exhaustion can be sudden and quick, potentially developing before major signs or symptoms are recognized (12). The inability of the cardiovascular system to simultaneously meet the exercising metabolic and thermoregulatory demands when experiencing severe dehydration is thought to be responsible for the development of heat exhaustion (267, 482). Symptoms that typically accompany this stage of heat illness are nausea, intense sweating, muscle weakness, chills, vomiting and vertigo (267, 482). Alterations in CNS functioning can involve dizziness, disparity and the onset of a strong headache (225).When an athlete is conscious and vomiting and diarrhea is not present, immediate removal from the heat and rapid cooling using water immersion, along with oral consumption of fluids are appropriate for reducing core temperature (12). When an athlete is unable to safely consume fluids, utilization of intravenous fluids ranging from 5% dextran in 0.45% to 0.9% saline may help facilitate rehydration and reduce hyperthermia especially if oral fluid consumption is problematic (87, 225).

Heat stroke is the most severe form of heat illness and is usually accompanied with elevated core temperatures that lead to the destruction of cellular tissues and impaired organ function (40). Heat stroke can be observed with core temperatures above 40.5ºC in the absence of sweating and with large impairment in mental status (87, 225). Tissue injury, cardiac arrest, organ failure and mortality have been observed to be closely correlated to the length of time that core temperature has been elevated before cooling begins (11). Current literature suggests that enhanced survival rates are seen when core temperature is reduced below 38.5ºC within 30 minutes (99, 282) to 60 minutes (282, 471) and that the use of ice water immersion is most effective in reducing core temperature during this period (437). A time difference between 30 and 60 minutes may be significant when experiencing such severe physiological impairment. Enhanced alterations in CNS functioning at this stage can be observed and typically involve ataxia, confusion, increased irritability and potentially the development of a coma state (225). Further research investigating the immediate response is warranted in the effort to provide medical practitioners effective and efficient protocols for both on-field and in house occurrences of heat stroke.

2.11 Strategies for Optimizing Athletic Performance in the Heat and Mitigating its Adverse Effects

The responsibility of both the athlete and sport practitioner to be well educated in effective hydration strategies prior to entering competition in a hot and humid environment should be a priority when planning future competitions. Understanding the level of adequate fluid to provide in advance and during competition along with proper utilization of electrolyte pills and any cooling techniques preferred should be practiced well in advance in an effort to ensure an effective response to potential signs and symptoms of heat illness.

Adequate ingestion of fluids prior to the start of competition have demonstrated to be an effective method for the prevention of cardiovascular and thermoregulatory impairment (191).

The immediate consumption of fluid during competition is typically used to restore plasma volume, the resulting improvement in cardiovascular and thermoregulatory benefits has been observed to be proportional to the amount of fluid ingested by the athlete in the absence of excessive intake beyond that of their sweat rate (310). Ingestion of electrolyte sport drinks containing carbohydrate and adequate Na^+ levels 60 minutes prior to competition where the duration is greater than 60 minutes has been shown to be advantageous during match play (94, 311). Empirical evidence suggests that consumption of fluid ad libitum can maintain or improve aerobic performance during heat stress and that the drive to consume this amount should be developed through the proper education of the athlete and the immediate environmental conditions experienced during competition (328).

Utilization of external precooling strategies defined as medium, cold air or fluid exposure to reduce core temperatures in the effort to optimize performance have shown to be successful in athletes during major competition in the heat (1, 393). Cold air exposure ranging from 0^o to 5^oC for periods of 15 minutes have demonstrated a reduction in both skin and core temperatures (207, 341). This transient exposure to extreme cold is thought to initiate vasoconstriction and a reduction in heat transfer from the core to the periphery via conduction (72). This rapid shunting of blood from the periphery can promote larger temperature gradients between core and shell prior to or during exercise allowing for greater convective heat transfer at the cutaneous layer (207, 393). Enhanced thermal comfort and aerobic performance in cycling and running have been observed with cold air exposure, however research regarding its effectiveness within intermittent team sport remains limited (341, 393). Although this technique has demonstrated promising results for athletes competing in individual sporting events, the practicality of a chamber able to accommodate multiple athletes simultaneously may not be possible for most team sports.

Cold tubs have been viewed as common pieces of recovery equipment in most intermittent team sport environments and may provide an alternative option to cold air chambers. Heat loss through water has been demonstrated to be two to four times greater than through the use of cold air, suggesting enhanced effectiveness and practicality when working with multiple athletes who require exposure immediately prior or during competition (309, 439). Literature examining cold water immersion (17^{o}C) for performance enhancement have shown improvements up to 2.7% in power output and a 4% increase in aerobic power demonstrated in running time trials (38, 298). Previous investigations examining repeated sprint ability has been shown to be promising as reductions in rate of decay in speed have been observed when cold water immersion is implemented between bouts of sprinting (469). Current literature suggests cold water immersion is a practical and efficient technique for cooling core temperature in intermittent team sport and may be an effective method to limit performance decrements in hot environments.

Another practical option for team sport athletes may be the usage of cold garments. Cold garments are easily transported to competition locations and allow for easy access within a change room or a team bench setting. Ice vests containing either gel or ice are a popular cold garment option and have demonstrated to successfully reduce core temperature during competition (15, 438). Ice vests can be utilized during individual sporting events or prior to competition and during half time during intermittent team sport. Often financial restraints commonly seen within team sport can limit sport science equipment, this outcome is typically the consequence of having to simultaneously cool multiple athletes at once and the demand for equipment can become very costly. A potential advantage for practitioners working within team sport is the opportunity to use garments that are already possessed by athletes such as sweaters, long sleeve t-shirt or fleece jackets and cooling them using water. Cold garment utilization during a 15 minute warm up period has demonstrated reductions in skin temperature and an overall improvement in thermal comfort of the athlete (15). Current literature supports the use of cold garments as being effective at reducing core temperature during warm up or physical activity when core temperature is elevated (36). To date the majority of research supports this form of temperature regulation as improved aerobic performance when running or cycling has been commonly observed when implemented.(15, 438). Limited research identifying enhanced aerobic performance for use in intermittent sport suggests future research is necessary before implementing in a team sport setting.

External cooling techniques that can reduce internal core temperature have shown promising results for improving aerobic performance(15, 438). However, the potential for decreased musculature performance due to exposure of a cold garment or water immersion may elicit negative outcomes. Therefore, internal cooling methods may be more advantageous through minimizing decrements in musculature performance (233). Ice slurries made from liquid and crushed ice is a convenient and affordable method for initiating reductions in core temperature when working with multiple athletes who require cooling simultaneously. Siegel et al. were able to demonstrate improved running speeds at aerobic threshold using ice slurries with a concomitant reduction in core temperature of 0.41^{o}C (431). Current literature suggests any potential benefits associated with the ingestion of cold beverages or ice slurries are dependent on the temperature of the beverage rather than the amount consumed (393). A beverage temperature of 4^{o}C has been shown to be optimal for reducing both core (-0.5^{o}C) and skin temperature (-

0.7°C) while aiding cycling performance in the heat (64). Lee et al. were able to further demonstrate enhanced performance with the use of a 4°C beverage as compared with a beverage at room temperature or 10°C (266). The option for developing a customized cold beverage with certain flavours and electrolyte balances may be a promising option for sport practitioners when working in hot environments with multiple athletes requiring simultaneously cooling. Sport practitioners must continue to experiment with cooling techniques to help identify effective and efficient cooling strategies that are both evidence based and practical for their athlete population.

2.12 Blood Volume Expansion and its Effect on Aerobic Power

Enhancing aerobic performance has and continues to be of high priority for sport practitioners working with individual or team sports where aerobic metabolism is the primary energy component for success in their sport. VO_{2max} is largely determined by two performance measures, 1) oxygen transportation capability, a by-product of cardiac output, and 2) arterial oxygen content (C_aO_2) a by-product of hemoglobin concentration and red cell volume (163). Previous literature has demonstrated the importance of central circulation, specifically hemoglobin and its ability to limit VO_{2max} when comparing performance in both a normoxic and a hyperoxic (*50% O_2 mixture*) environment (113). Hyperoxia when administered during an exercise test has shown improvements in VO_{2max} of 12.5% and was reported to account for 7.4% of the improvement; the remaining 5% was thought to be due to enhanced skeletal muscle uptake and utilization (113). This is further evidence to strengthen the idea that an athlete's aerobic performance is influenced by oxygen delivery rather than musculoskeletal metabolism (113). The quantitative importance of hemoglobin for improving VO_{2max} was proposed by Gledhill et al. where it was proposed that every increase in hemoglobin of 3g/L over a range of 120 to 170 g/L, an increase in VO_{2max} of approximately 1% can be observed (160, 163). These observations highlight the fact that negating any alterations in cardiac performance at a perpetual cardiac output, an increase in hemoglobin can lead to an improvement in oxygen carrying capacity to the working muscles, permitting an increase in aerobic performance and VO_{2max} (163).

Blood volume can independently influence each performance measure and plays a pivotal role in improving VO_{2max} and cardiovascular performance (86, 162, 163, 241, 260, 307, 476). Originally it was postulated that changes in blood volume affected VO_{2max} through alterations in hemoglobin and its oxygen carry capacity (247, 248). Further research has demonstrated that total blood volume and specifically plasma volume (PV) can positively influence VO_{2max} and endurance performance in untrained and moderately fit individuals (31, 91, 93, 260, 281) . Previous investigations examining endurance training and its effects on diastolic function have demonstrated an enhanced rate and total filling capability of the heart's chambers during diastole with little to no change in ventricular systolic function during exercise (120, 299).

A stimulus to increase total blood volume can enhance the utilization of the Frank Starling mechanism through reinforced diastolic functioning which is believed to be the result of an improvement in preload (162, 260, 474).This observed improvement in cardiac function has been postulated to be a result of enhanced venous return and can be a function of total blood volume (162, 260, 474). According to the Starling effect, an improvement in venous return can augment cardiac preload whereby increasing the stretch of the myocardial sarcomeres and promoting optimal overlapping of the myosin and actin filaments to elicit improved contraction and emptying of the left ventricle (477).

Common techniques athletes often incorporate for blood volume expansion are exposure to hypoxic environments at high altitude for sufficient periods of time. However, this technique often lacks practicality for athletes living at sea level. Previous literature has demonstrated a minimum requirement of 14 hours per day at an elevation of at least 2100 for 22 days is necessary for eliciting significant changes in erythropoiesis and red cell volume (414). Although erythropoiesis and subsequent changes in blood volume have been demonstrated using exposure to normobaric hypoxia (397), a more practical option for athletes residing at sea level, this option may be too expensive, time consuming, and impractical for team sports which require multiple athletes to acclimate simultaneously. PV expansion may provide a more practical option for athletes when trying to expand total blood volume for performance enhancement and can be achieved through acute changes in training intensity or volume (105, 254, 386) or through repeated heat exposures (61, 138, 151, 378).

Hypervolemia is defined as a hematological state whereby the plasma compartment of the blood is expanded causing a reduction in hemoglobin concentration (86). The resulting dilution in hemoglobin and reduction in hematocrit can be temporary or persistent depending if the physiological stimulus responsible for its induction is repeated or maintained. It is well known that PV expansion is a common result of regular endurance training (86). This increase in PV elicited through endurance exercise is partially responsible for endurance athletes possessing a larger blood volume when compared to untrained or moderately fit individuals (163). Elevations in blood volume found in endurance athletes have demonstrated to be extremely beneficial for improving cardiovascular performance. This is thought to be due to increased venous return and its direct influence on enhancing preload (93, 260, 476) which in turn intensifies the velocity in diastolic filling (485). With a constant increase in preload during rest and exercise, athletes typically possess an enlarged left ventricular dimension (163), a possible consequence of the augmented and repeated myocardial stretching during diastole with increased blood volume. Amplification of myocardial compliance has shown to intensify atrial contraction which in turn increases elastic recoil and negative left ventricular pressure (63, 299) These adaptations from enhanced blood volume provide an improved rate and capacity in diastolic filling, a phenomenon that allows athletes to utilize the Frank Starling mechanism to a greater extent during exercise (162). As such, a greater reliance on the use of the Frank Starling mechanism may be responsible for the continued rise in stroke volume found in athletes during maximal exercise, an observation that was of great controversy for many years (162, 260, 476).

Hypervolemia is responsible for creating a hemodilution effect as hemoglobin and red blood cells remain stable. Theoretically the resulting hemodilution should reduce the carrying capacity of oxygen however, greater reliance on the Frank Starling effect is thought to compensate for this change in hemoconcentration. With the expansion of PV promoting an increase in stroke volume and cardiac output, a greater rate in the recycling of hemoglobin and red blood cells from the heart to the working tissue may elicit an increase in VO_{2max}, however; performance may suffer if a PV expansion is too large causing hypervolemia anemia whereby possibly reducing VO_{2max} (477). This compensation in stroke volume and cardiac output in the presence of hemodilution has been found to be controversial when examining its effects on athletic performance and VO_{2max}.

Few studies have demonstrated PV expansion as an effective performance enhancing technique when elicited through an plasma expander such as Macrodex or through the direct infusion of saline. Large improvements eliciting positive alterations in VO_{2max} have been observed in untrained individuals who possess a $VO_{2max} < 55mL \bullet Kg^{-1} \bullet min^{-1}$ (477). Previous investigations have demonstrated a wide range (i.e. -3.0% ; 7.0%) in VO_{2max} in response to a PV expansion (93, 260, 306). Coyle et al. were able to produce a 4% change in VO_{2max} when expanding PV by 4% while Krip et al. expanded PV by 10% with a resulting 7% increase in

VO_{2Max} (93, 260). Studies involving participants who possess a VO_{2max} between 55.0-64.0 $mL•kg^{-1}•min^{-1}$ generally observed no improvement or a decline (-1.0%;-2.0%) in VO_{2max} (247, 248, 281). However, Coyle et al demonstrated a 2% increase in VO_{2max} after expanding PV by 15% (91). When examining participants with a VO_{2max} above 64 $mL•kg^{-1}•min^{-1}$, an expansion in PV of 8% showed either no significant change (474) or a decline of 2% in repeated tests (91).

These discrepancies in VO_{2max} outcomes may be due to multiple factors in the different methodology used during each study, such as maximal testing protocols, mode of exercise, or the period in which testing was completed after expansion or infusion. Further research on PV expansion for performance enhancement has led to three possible physiological explanations that can explain this lack of clarity and inconsistency.

The first explanation was developed by Warburton et al.., who postulated that athletes who possess a VO_{2max} > $64mL•kg^{-1}•min^{-1}$ already hold an expanded blood volume whereby their diastolic reserve capacity may be infringing upon their physiological limit (477). Warburton et al., suggested the differences seen in VO_{2max} and endurance performance after PV expansion may have been due to fitness levels and the VO_{2max} possessed by the participants in each study (474). This explanation states that further expansion in PV when possessing a VO_{2max} > $64mL•kg^{-1}•min^{-1}$ may not improve preload allowing for greater utilization of the Frank Starling effect; instead further increases in hemodilution may not be compensated for by enhanced stroke volume, cardiac output and may negatively impact VO_{2max} (477).

A secondary explanation focuses on the total amount of PV expansion induced. Previous investigations have stated enhancements associated with PV expansion follow an inverted U-shape whereby a sweet spot can be found before experiencing a plateau or a negative impact on aerobic performance (92). This hypothesis further states that a PV expansion between 200 and

300 mL may be optimal for augmenting stroke volume and cardiac output in an effort to offset hemodilution (93). This theory was demonstrated after further expansion of ~579ml in the same participants elicited no significant change in endurance performance or VO_{2max} (93). These results suggest that an optimal expansion may exist unique to each athlete's total blood volume. A potential critique for many previous studies is a lack of standardization in the PV expansion provided to each participant. When fitness levels remain constant yet differences exist in body size and weight, a consistent PV expansion for each participant may identify adaptations in VO_{2max} at distinct locations on the inverted U-shape continuum.

Perhaps the most intriguing explanation is the effect on capillary filtration when using PV expanders or the direct infusion of saline for enhancing VO_{2max}. Early investigations examining the effects of blood volume and PV expansion on VO_{2max} utilized the reinfusion of whole blood or saline. In the late 1990's research gravitated towards the use of PV expanders in the form of Dextran or its trade name Macrodex, a polysaccharide consisting of glucose monomers. Changes in PV have shown to be controlled by capillary fluid pressure (333, 420). Muscle contractions on venules and increased mean arterial pressure augments capillary hydrostatic pressure imposing a drastic filtrate of plasma into the interstitial and extravascular compartments (283, 333). PV has been demonstrated to be directly related to intravascular levels of hydrostatic pressure with alterations in pressure initiating gains or losses in the vascular compartment (477). This physiological phenomenon is critical when designing study methodology whereby PV expansion and its relation to aerobic performance is of importance. Guyton postulated that any increase in cardiac output through acute PV expansion using transfusions may last only minutes before an increase in hydrostatic pressure initiates increased capillary filtration (184). Furthermore, this cardiac output would return to pre-infusion levels within 40 minutes (184). Macrodex, depending on the percentage of Dextran, holds an intravascular lifespan between 4 and 8 hours in a normal resting state. However, this lifespan may be altered through increased arterial pressure during submaximal or maximal exercise. Most studies when examining PV through the administration of Dextran or direct infusion of saline wait 40 to 60 minutes before completing either multiple submaximal bouts that can finish with a maximal graded exercise test. Questions should be raised on the actual magnitude of PV expansion immediately prior to and during the maximal exercise test when both direct infusion and PV expanders were utilized.

Short term heat acclimation training has become a popular performance enhancing technique among sport practitioners. Typical short term heat acclimation protocols involve mild exercise between 40 – 50% VO_{2max} in environmental conditions ranging from 30 – 40^{o}C for 45 – 90 minutes, and have demonstrated dramatic expansion in PV within one to seven days (61, 70, 138, 151, 378). It has been suggest the most important aspect during heat acclimation is raising one's core temperature to an elevated yet safe value, usually no higher than 39.5^{o}C (456). This elevation in core temperature promotes vasodilation of the cutaneous layer allowing for enhanced thermoregulation through evaporation; however the resulting effect of increased capillary pressure due to enhanced blood flow stimulates an increase in filtration and hemoconcentration (400, 448). An excess capillary filtration rate can initiate a flushing effect in the cutaneous interstitium, forcing proteins into the lymphatic system for the eventual circulation and re-entry into the vascular compartment (199, 442). This increase in albumin concentration can increase the tonicity in the vasculature compartment stimulating an increase in PV anywhere from 14 – 15 ml of water for every gram of albumin (413, 424). Changes in capillary filtration and net absorption during exercise cause fluctuations in protein content between extracellular and intracellular compartments (199). These changes alter both the vasculature and interstitial hydrostatic and osmotic pressure gradients. During resting conditions, large pores in the vascular compartment are responsible for 80% of the transcapillary clearance of albumin and are solely convective and controlled by the hydrostatic pressure gradients (389). Small pores are responsible for the remaining 20% of albumin transcapillary clearance principally through diffusion (389). Exercise has been demonstrated to decrease osmotic pressure and increase fluid hydrostatic pressure in the interstitial compartment, such alterations may act to insulate the newly expanded PV (199). This insulating effect may be responsible for altering the transcapillary escape rate, possibly elongating a PV expansion after completing a short term heat acclimation protocol involving exercise.

This insulating effect is a new viewpoint on short term heat acclimation involving exercise and its ability to induce PV expansion for enhancing VO_{2max}. Recently Lorenzo et al., utilizing a control group demonstrated a PV expansion through short term heat acclimation of 6% ranging between 200 – 300 mL; this increase elicited a 9% improvement in cardiac output and a further 5% increase in VO_{2max} when compared to a control group (279). Such results are remarkable considering the mean VO_{2max} in the experimental group averaged 66.9 ±2.1 $mL \bullet kg^{-1} \bullet min^{-1}$ and contradict previous explanations for limitations in PV expansion increasing VO_{2max}. These observations support the possible insulating effect that short term heat acclimation protocols utilizing exercise may provide and ability to withstand increased capillary hydrostatic pressure to resists excess filtration after the development of hypervolemia.

Chapter 3: Evaluation of the Cardiovascular Demands and Adaptations from Practicing Hot Yoga (Bikram Yoga)

3.1 Introduction

Hatha yoga is a popular branch of yoga that includes physical postures held for periods of time that flow into proceeding postures. Each pose challenges participants to maintain correct posture and form throughout each transition and the entire session. Hatha yoga is commonly practiced and is widely accepted for its health benefits in the Middle East especially in India (34, 88, 96, 382, 459). Due to its popularity in North America it has become more accepted recently in the fitness industry as an alternative means of exercise and health (88, 150). Longitudinal research has demonstrated regular participation in Hatha yoga is correlated with improved muscular strength, flexibility (34, 97, 464, 467) and improved exercise tolerance and aerobic capacity (467). Additionally, enhanced pulmonary function has also been demonstrated with regular yoga participation (34, 196, 242, 290, 458, 490).

When examining cardiovascular adaptations to Hatha yoga and its ability to positively influence parameters such as aerobic power (VO_{2max}), resting heart rate (resting heart rate) and resting blood pressure (BP) current literature reveals diverse results (42, 196, 318, 379, 380, 458, 464). The slow paced, separated nature of this style of yoga involving durations of static stretching are thought to be too light of a stimulus to positively enhance aerobic performance (79, 374). However, the observed diversity of results may be in part due to the wide range in participant age, health status, physical activity habits, experience practicing yoga and the variation in the style and intensity each Hatha yoga class provides.

Bikram yoga has recently developed into a popular alternative in North America to the traditional style of Hatha yoga (342). Bikram yoga was developed and brought to the public by Bikram Choudhury in the early 1970's. Commonly referred to as hot yoga, this unique and standardized practice sets itself apart from other forms of hot yoga. Bikram yoga involves 26 Hatha style postures that are standardized and led by certified Bikram yoga instructors who have completed a nine-week intensive training course through Bikram's Yoga College of India (463). This style of yoga is performed in a specialized studio that controls its ambient temperature to the exact specifications required for all Bikram yoga classes. An ambient temperature between 35-40^{o}C with a relative humidity level between 40-60% must be held for the entirety of each Bikram yoga class offered. This style of yoga is believed to be more intense than the traditional option and involves rapid transitions between each of the 26 postures providing a considerable cardiovascular response and development of muscle fatigue (463). With its recent gain in popularity there remains limited inquiry towards the cardiovascular demands required. Therefore, the purpose of this systematic review was to examine the cardiovascular demands of a single hot yoga class and to examine the long-term cardiovascular adaptations observed when practicing hot yoga.

3.2 Methods

A systematic review of Bikram Yoga was conducted and several electronic databases were investigated (MEDLINE, Embase, SPORTDiscus). Eight hundred and six articles were identified which involved yoga and its relation to cardiovascular demands and adaptations, physical fitness or physical fitness testing. Six articles were included in the review: (n=4) examined an 8 week Bikram Yoga intervention and its ability to positively influence cardiovascular parameters; (n=1) examining a single Bikram yoga session and its cardiovascular demands; and (n=1) examining the long-term cardiovascular benefits in experienced Bikram yoga practitioners.

A thorough process was completed to ensure all relevant articles were included (Figure 3.1). This review was able to identify six articles (Table 3.3) that examined hot yoga and its influence on the cardiovascular system. A modified Downs and Black scoring system (104) was utilized to assess the quality of the included articles. The questions from the original Downs and Black scoring system that were applicable to the topic of this systematic review were included. The question number from the original scoring system was maintained to provide clarity to the reader. The included questions were selected by the reviewers prior to any scoring of the articles. The results of the modified Downs and Black scoring system are provided (Table 3.1).

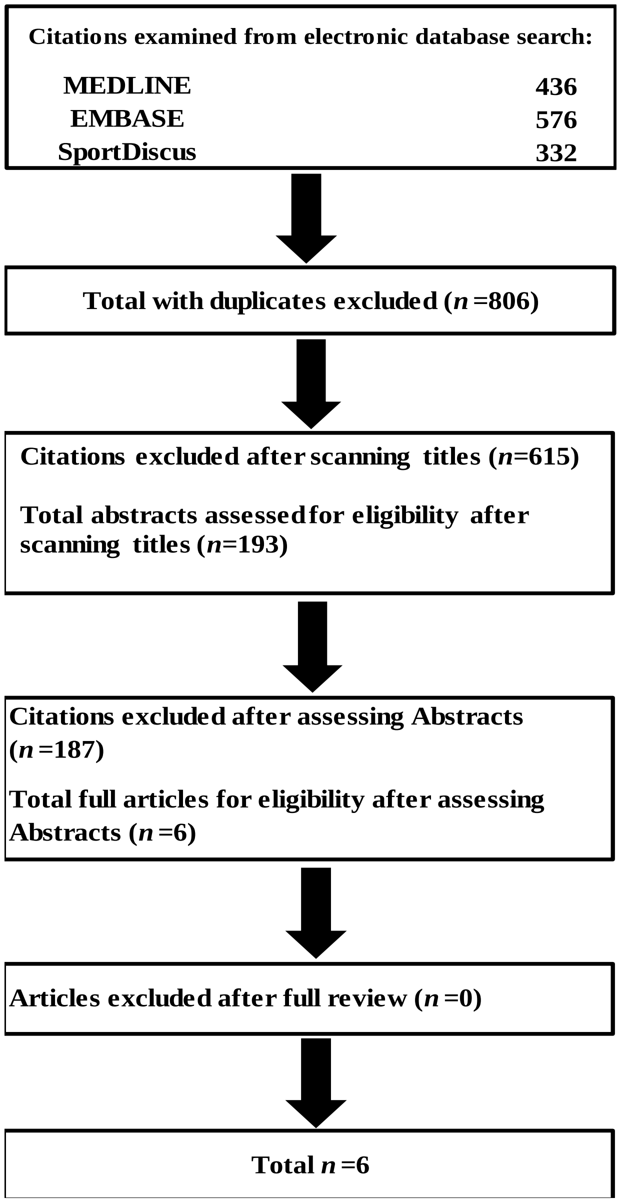


Figure 3-1 Citations examined for systematic review

Table 3-1 Modified Downs and Black scoring system

No.	Article	Q1 (/1)	Q2 (/1)	Q3 (/1)	Q4 (/1)	Q5 (/2)	Q6 (/1)	Q7 (/1)	Q8 (/1)	Q9 (/1)	Q10 (/1)	Q13 (/1)	Q16 (/1)	Q17 (/1)	Q18 (/1)	Q19 (/1)	Q20 (/1)	Q21 (/1)	Q22 (/1)	Q23 (/1)	Q26 (/1)	Q27 (/5)	Total (/26)
1	Tracy & Hart, 2013	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5	25
2	Hunter el al., 2013	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	5	23
3	Guo et al., 2014	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	5	22
4	Hewett et al., 2011	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	5	22
5	Pate & Buono, 2014	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	5	22
6	Abel et al., 2012	0	1	1	1	2	1	1	0	1	0	0	1	1	1	1	1	1	0	1	1	5	21

3.3 Cardiovascular Demands of a Single Bikram Yoga Session

The physical postures required to perform a Bikram yoga class are advertised as both mentally and physically challenging. Each posture demands participants to have full control over each body movement while forcefully contracting their muscles for a lengthy period of time, all the while coping with the environmental heat stress (2). The physical demands of a Bikram Yoga class are thought to be in contrast to the more common and less standardized form of Hatha yoga. Previous literature has demonstrated Hath yoga to elicit low to moderate metabolic and cardiovascular demands which further depend on the teaching variability of the yoga instructor (196, 467).

Only a single article was identified that directly measured the metabolic demands of an entire Bikram yoga class. Pate and Buono (2014) recruited both novice and experienced Bikram yoga practitioners to perform a full 90-minute Bikram session in an environmental chamber that matched the requirements for a standardized Bikram yoga class. Each participant was outfitted with a one-way Hans Rudulph non-rebreathing valve that was attached to a True One Parvomedics metabolic cart in an effort to examine the oxygen demands for each of the 26 postures. On average the metabolic demand for all 26 postures during the 90-minute session was 9.56 $mL•kg^{-1}•min^{-1}$, an average metabolic equivalent (MET) score of 2.73 $mL^{-1}•kg^{-1}•min^{-1}$ (Table 1) (354). According to the American College of Sports Medicine a MET that is <3, 3-6 and >6 is considered light, moderate and vigorous activity (301). Although the range in both the MET and metabolic demands was greatly dependent on the posture, the average session provided little demand on the cardiovascular system. However, when examining a single participant's response, a peak VO_2 reaching as high as 35$mL•kg^{-1}•min^{-1}$ during a standing pose was observed (Table 3.2).This rapid increase in oxygen consumption may have been in part due to changes in hypotension while thermoregulation was challenged. This observation not only sheds light on the diverse fitness levels involved in the study but the potentially large yet short-term stress than can be placed on the cardiovascular system during periods of Bikram yoga.

Furthermore, this observation exhibits the variation within each participant's cardiovascular response and fitness levels, a potential constraint for ascertaining the metabolic demands of a 90-minute Bikram yoga class. Further investigation is warranted to identify the metabolic demands between fit and unfit individuals and between age and sex differences.

Table 3-2 Metabolic demands of a 90-minute Bikram Yoga class

Study	VO_2 (mL•kg^{-1}•min^{-1})			METS		Mean Intensity
	Mean *(26 poses)*	Range *(26 Poses)*	Range *(Random Participant)*	Mean	Range	
Pate J,L. & Buono, M,J. (2014)	9.56	5.71;13.93	2.5 - 35	2.73	1.63;3.98	Light

3.4 Cardiovascular Adaptations to Short and Long-term Bikram Yoga Training

3.4.1 Short-term 8 Week Intervention

The implementation and practice of yoga into society's exercise regime has been reinforced by its multi approach to improving health and overall wellbeing. Yoga's ability to enhance one's feeling of wellbeing, improve psychological functioning along with mitigating overall perceived levels of stress have been well (66, 67). Finding an alternative option to participate in an exercise program that not only improves the physiological but also the psychological wellbeing is an attractive option for beginners who are looking to become more physically active and improve their health.

Three, eight week Bikram yoga interventions examining its ability to positively influence cardiovascular functioning were identified for this review as seen in Table 3.3. Only a single investigation recruited participants who were already somewhat active and continued their regular training during the hot yoga intervention. Each remaining investigation involved a sedentary population with an extensive range in age.

An eight week intervention was utilized in each study based on preliminary research on Bikram yoga's ability to positively influencing balance, muscular strength and steadiness in young adults (198). The single randomized control study in this review found no change in VO_{2max}, resting heart rate and resting systolic blood pressure in both the control and intervention groups after an eight week intervention (463). Although the participants were young adults who had little to no experience with yoga and were considered sedentary; the implementation of 24 Bikram yoga sessions failed to elicit any positive cardiovascular adaptations after eight weeks as seen in Table 3.4. (463) When examining the resting systolic and diastolic blood pressure response after eight weeks Hunter et al., demonstrated no significant change between pre- and post-values in both young and old participants (229).

However, the main objective of their investigation focused on arterial stiffness and its response to an 8 week Bikram yoga intervention. Their results demonstrated a significant reduction in arterial stiffness only in younger participants (229). They hypothesized that these results may have been from the following adaptations. First, the stretching involved in yoga could have induced a traction stimulus to the arteries where the smooth muscle and cell matrix adaptations may have positively affected the cross sectional arterial compliance (229). Previous literature from the same investigators supports this hypothesis (2). A second possible explanation in the reduced stiffness may have been initiated from reductions in sympathetic vasoconstrictor tone on the arterial walls from enhanced relaxation and mediation experienced during each yoga session (229).

Finally, a third hypothesis was based on the heat itself. Although the mechanism by which thermal therapy affects arterial stiffness is unknown, it is postulated that the enhanced expression of endothelial nitric oxide synthase-3 messenger RNA may be responsible for such adaptations (234). The results observed in this investigation were unique as only the younger participants who were thought to have the least amount of potential for change demonstrated the greatest decrease in arterial stiffness (2). This phenomenon was thought to be the result of an increased plasticity to change in the arteries of the younger participants compared to the older participants (229). The only study to demonstrate a positive adaptation in VO_{2max} was demonstrated using the Rockport 1 Mile Walk Test, an indirect method for assessing aerobic power (209).

Although this result may be somewhat encouraging for promoting Bikram yoga and its use for improving aerobic performance, consideration for the method of assessment should be taken. The Rockport 1 Mile indirect aerobic power test has demonstrated a large technical error of measurement ranging from 18% in males to 23% in females (102). A typical error of this nature may prevent any confidence when comparing pre- and post-test results.

3.4.2 Long-term Bikram Yoga Practice

When examining the long-term cardiovascular adaptations from practicing Bikram yoga Guo et al., were able to demonstrate positive adaptations in young and older overweight and obese women (183). Significant changes in resting heart rate, resting systolic and diastolic blood pressure were observed after completing 208 sessions at a rate of four sessions per week (183). It should recognized that these participants were already engaged and accustomed to Bikram yoga along with potentially having extra motivation to become healthier due to weight management.

The potential for cardiovascular improvement in these participants may have been positively skewed due to their level of fitness. When comparing novice to long-term Bikram practitioners Abel et al., further demonstrated no significant difference in VO_{2max}, resting heart rate, resting systolic and diastolic blood pressure, peak minute ventilation and peak respiratory exchange ratio (2). The only significant difference observed was a higher maximum heart rate in the experienced practitioners as seen in Table 3.5. Although no explanation from the authors was provided for this phenomenon it is likely the differences in biological age could have effected this outcome.

Table 3-3 Studies included in the cardiovascular adaptations and responses to hot yoga

Publication	Study Design	Purpose	Population	Sample Size	Age (mean± SD[range])
1 Year Study					
Guo et al., (2014)	Prospective Cohort	Examine the change in physical and mental wellbeing in middle aged and young overweight women	Active overweight female yoga club members	36.8	36.8 [18-48]
8 Week Study					
Hunter et al., (2013)	Prospective Cohort	Examine the change in arterial stiffness between young and old populations after 8 weeks of Bikram Yoga involving 90 minutes sessions 3 times per week.	Sedentary males and females for ≥6 months leading into experiment	Young-24 Old - 18	Young-30±1 Old - 53± 2
Hewett et al., (2011)	Prospective Cohort	Examine the change in mindfulness, physical fitness and perceived stress after 8 weeks of Bikram Yoga involving 90 minutes sessions 3 times per week.	Males and females with no previous experience with Bikram Yoga for two years before intervention. 20% were already engaged in physical activity leading into the study and continued throughout.	80	31.57 ± 9.29
Tracy,B,L. & Hart,C,E.F., (2013)	Randomized Controlled	Examine the change in physical fitness in healthy young adults after 8 weeks of Bikram Yoga involving 90 minutes sessions 3 times per week.	Males and females who participated in ≤2hrs of purposeful activity per week with no experience practicing yoga for 4 months leading into the intervention.	Yoga-21 Control - 11	Yoga – 29.0±6.1[21-39] Control-25.1±5.0 [21-39]
Single Session Study					
Pate J,L. & Buono, M,J. (2014)	Cross Sectional	Examine the physiological response of a single Bikram Yoga session in novice and experienced Bikram Yoga practitioners.	Male and female Bikram Yoga practitioners were considered novice if their total session completed were <20 or considered experienced if they complete ≥20 sessions	24	32.7±13.3 [18-57]
Abel et al., (2012)	Cross Sectional	Examine the differences in physiological characteristics between long and short-termed Bikram Yoga practitioners	Male and female Bikram Yoga practitioners where considered short-term experienced if practicing for < 3months or long-term experienced if practicing for ≥ 1 year	Short-term - 17 Long-term - 14	Short-term - 43.88 ± 11.54 Long-term - 38.39±9.31

Table 3-4 Cardiovascular adaptations from practicing Bikram Yoga

Study	Length	Yoga Sessions Completed	Training Status	Resting Heart Rate (beast•min^{-1})		Resting Blood Pressure (mmHg)		VO_{2max} (mL•kg^{-1}•min^{-1})			
								Direct Examination			
				Pre	Post	Pre	Post	Pre	Post	Pre	Post
Guo et al., (2014)	1 Year / *4x week*	208	Active	78±5.15	*74.41±4.88 *$p<0.05$*	124.01±10.57 / 78.35±8.26	*120.38±9.62/ *75.46±8.49 *$p<0.05$*				
Hunter et al., (2013)	8 weeks / *3x week*	24	Sedentary			Young - 113±2/66±2 Old - 120±6/70±3	Young - 112±2/65±2 Old - 116±4/68±3				
Hewett et al., (2011)	8 weeks / *3x week*	[20-24] Minimum 80% Completion		64.04±9.95	63.22±8.70					38.44±7.07	ŧ40.12±7.15 *$p<0.01$*
Tracy,B,L. & Hart,C,E.F., (2013)	8 weeks / *3x week*	22.5±2.3	Relatively Sedentary			Yoga & Control - 120±7.8 *$p=0.60$*	No Change between Yoga & Control *$p=0.33$*	Yoga & Control - 37.9±7.9 *$p=0.60$*	No Change between Yoga & Control *$p=0.27$*		

Table 3-5 Cardiovascular differences at rest and maximum exercise between novice and experienced Bikram Yoga practitioners

	Resting Measures				Peak Measures			
Yoga Experience	Low (<*3 Months*)		High (≥ *1 Year*)		Low (<*3 Months*)		High (≥ *1 Year*)	
Study	Blood pressure (mmHg)	Heart Rate (beats•min^{-1})	Blood pressure (mmHg)	Heart Rate (beats•min^{-1})	Heart Rate (beats•min^{-1})	VO_2 (mL•kg^{-1}•min^{-1})	Heart Rate (beats•min^{-1})	VO_2 (mL•kg^{-1}•min^{-1})
Abel et al., (2012)	123.41±10.72 / 80.71±7.38	67.35±5.14	119.93±9.975 / 75.71±9.86	67.8.23±8.23	*132.69±45.21 $p<0.05$	34.76±10.48	174.54±13.15	35.45±7.64

3.5 Future Direction

Current literature examining Bikram yoga and its impact on cardiovascular performance is still evolving. Only a single study examining the metabolic demands of a complete Bikram yoga session and four articles examining its long-term impact on VO_{2max} and its ability to affect resting hemodynamic parameters were identified for this review. Current literature has yet to examine alterations in blood volume when practicing this form of yoga. Previous investigations examining heat acclimation have demonstrated low-intensity exercise (50% VO_{2max}) to be an effective means for enhancing cardiovascular and aerobic performance when exercising in temperatures at or above 30^{o}C ranging between 20-50% relative humidity (61, 70, 138, 151, 378).

The ambient conditions of most heat acclimation studies are very similar to what Bikram yoga studios offer its practitioners; as such one can postulate this environment may support the use of Bikram yoga as a means for heat acclimation in a sporting population. To date only two investigations have examined alterations in core temperature during Bikram yoga; whereby demonstrating marked increases throughout a complete session (354, 372). Further inquiry towards alterations in plasma volume after experiencing repeated hot yoga sessions are warranted in the effort to explain hemodynamic regulations.

3.6 Conclusion

This review identified that practicing Bikram yoga may elicit diverse. Currently, the literature has demonstrated minimal support for hot yoga as a means for improving resting and peak cardiovascular measures; however, its current popularity may tentatively overshadow this lack of evidence. The very fact that its attendance and availability continues to increase throughout local neighbourhoods may support the notion that both active and sedentary individuals have found a form of enjoyable exercise. Although this review focused solely on the cardiovascular impact from hot yoga, there is other research demonstrating healthy adaptations to practicing this form of yoga such as weight management, improvement in balance and enhanced mindfulness that should not be overlooked (198, 209).

Chapter 4: Hot Yoga as a Short-term Heat Acclimation Protocol for Enhancing Cardiovascular and Aerobic Performance

4.1 Introduction

The vast majority of research examining heat acclimation protocols have focused on implementing 10 acclimation sessions at an exercise intensity of ≤ 50% VO_{2max}, that are further separated into two 45-minute periods, with an ambient temperature between 35-40°C and 20-60% relative humidity (71). Recent investigations have begun to examine shorter protocols using intermittent high-intensity exercise with lower ambient temperatures and have demonstrated improved aerobic performance measures in team sport athletes (452).

Short term heat acclimation training (≤ 7 exposures) (153) has become a widespread preparation tool for competitive athletes prior to competing in a hot environment (153). Physiological adaptations developing from repeated heat exposures (≤ 7 exposures) while exercising have demonstrated cardiovascular adaptations such as PV expansion (138, 151), marked reductions in heart rate during submaximal exercise (61, 452), diminished core temperature threshold for cutaneous vasodilation (491), augmented skin blood flow at specified core temperature (491) and a diminished core temperature threshold for the onset of sweating (89, 491). Additional metabolic adaptions such as diminished carbohydrate metabolism during submaximal exercise have thought to be promising for its performance enhancing effects (323, 406) a crucial adaptation for athletes in team sport such as field hockey where repeated bouts of high-intensity actions are an integral aspect of performance and success (139).

It has been suggested that heat acclimation is typically utilized by athletes competing in individualized sporting events (71), however major competitions in team sport such as the 2014

FIFA World Cup, 2016 Olympic Games in Rio, the 2022 Cricket World Cup in New Zealand | Australia and the 2022 FIFA World Cup in Qatar have highlighted the need for sport practitioners to identify and develop effective and efficient heat acclimation protocols suitable for acclimating multiple athletes simultaneously. The ability to simultaneously acclimate an entire team of athletes can be a rate limiting factor for integrative support staff working in a team sport environment. Recent investigations have demonstrated compelling evidence for utilizing short term heat acclimation training as an ergogenic aid for augmenting cardiovascular and aerobic performance in temperate and cold conditions, as such practitioners continue to develop appropriate HA protocols focusing on the timing and induction of such desired adaptations (61, 74, 359). With performance optimization, often a major focus for integrative support staff, the pursuit of novel and effective modalities to temporarily enhance performance at critical periods throughout a yearly training plan or a four-year Olympic cycle is of great interest.

However, for every performance enhancing modality utilized, the induction of such adaptions should remain only a part of the development process when planning peak performance. Great emphasis has been placed on examining the induction of HA rather than its decay making for contentious debate amongst sport practitioners regarding the physiological responses once removed from repeated heat stress (153). Previous investigations have revealed physiological adaptations elicited through heat acclimation can return to baseline within three weeks after the removal of a heat stress (13). Earlier evidence examining the decay tendencies post heat acclimation suggest that for everyone two days without experiencing heat stress one day of acclimation is lost (158). When examining short term heat acclimation protocols, early physiological adaptations are frequently cardiovascular in origin, however these immediate adaptations are generally the first to dissipate (152, 399). With limited research focusing on the rate of decay after short term heat acclimation it is currently acknowledged that the first adaptations to come are the first leave, and the last to develop are the last to dissipate (153). Attention should be placed towards identifying which adaptations induced through specific protocols are appropriate for impending competition, and the time frame available to acclimate as these outcomes can determine the timing, type and duration of the protocol in the lead up to competition.

As such the purpose of this investigation was to examine a novel short term heat acclimation protocol utilizing hot yoga in an effort to induce hypervolemia for augmenting cardiovascular and aerobic performance and to examine the response in PV once removed from repeated heat stress (i.e.hot yoga). We hypothesized the following: 1) six consecutive days of hot yoga would elicit a significant PV expansion, 2) a positive relationship would exist between the magnitude of the TL experienced during six days of hot yoga and the degree of hypervolemia developed, 3) six days of hot yoga would improve cardiovascular and aerobic performance measures during a graded exercise test in a temperate environment, and 4) the magnitude of TL experienced during on-field competition would demonstrate a strong relationship to the maintenance of hypervolemia for up to 144 hours post-hot yoga.

4.2 Methods

A total of 10 athletes from the Canadian Women's National Field Hockey Team were available to act as participants for examining hot yoga and its ability to elicit hypervolemia for enhancing cardiovascular and aerobic performance. Our sample size was restricted to athletes who were residing in Vancouver, who were not limited by U-Sport, NCAA or professional playing contracts overseas during the time of the study and who were attending the annual Canadian Women's National Field Hockey Team winter camp involving a multiple day on-field intra-squad competition and testing sessions. A letter of support from Field Hockey Canada's High Performance Manager can be found in the Appendix (Field Hockey Canada Letter of Support #1). All participants completed the Physical Activity Readiness Questionnaire for Everyone (475) prior to the intervention. Each hot yoga class was held at the Hot Box yoga studio located at 3313 Shrum Lane in Vancouver, British Columbia. The owner of the studio instructed each 60-minute class to standardize instructional guidance. The Hot Box yoga studio offers multiple class levels of intensity. A moderate level of intensity called "50/50" was completed for each of the six classes during the intervention. The structure of each "50/50" class involved 30 minutes of dynamic possess and movements that was followed by a final 30 minutes of static stretching. Every 60-minute class was continuous in nature flowing from pose to pose. A class structure of this nature limited time for fluid consumption between poses; for this reason, fluid consumption was restricted during each hot yoga class. Fluid consumption outside each yoga class was not controlled for in order to prevent disruption to the participants' daily nutrition and hydration programs.

Each participant arrived at the Field Hockey Canada offices 60 minutes prior to each hot yoga class for consumption of an ingestible temperature pill (HQ CorTemp© Pill). Throughout each 60-minute hot yoga class, core temperature was measured every 10 minutes for safety and to determine the thermal load. Participants were asked to step outside of the studio if their core temperature reached or exceed 40°C. Each participant wore a Polar Team^2 HR monitor (Polar, Electro, Oy, Kempele, Finland) programmed to record at one second intervals in an effort to capture internal training load for each training and competition session. Each transmitter provided HR indices (i.e. % Max, HR, TL) in real time to the sport practitioner's computer via

Bluetooth. Immediately prior to and on completion of each yoga class, dry body weight was measured wearing only a sports bra and cycling shorts.

During the intervention and 72, 96, and 144 hours post-intervention participants arrived at the Field Hockey Canada offices for a 4 ml blood sample. Participants laid supine for 20 minutes prior to completing a blood sample from the antecubital vein using a butterfly needle technique. A complete blood count (CBC) was analyzed after each blood sample throughout the experiment for examining changes in hematocrit, hemoglobin and red blood cells in order to estimate changes in percent plasma volume (101). A registered phlebotomist performed each blood sample throughout the investigation. A schematic identifying the timeline of the investigation and procedures is attached in the Appendix (Hot Yoga Timeline).

An aerobic and cardiovascular assessment was held 24 hours prior to beginning the intervention and 24 hours post-intervention. Each assessment was conducted by two certified exercise physiologists (CEP) at Fortius Sport & Health's exercise Laboratory. Each performance assessment involved a graded maximal exercise test conducted on a computerized controlled Woodway treadmill. Tests were performed using a ParvoMedics TrueOne 2400 metabolic measurement system. The examination of maximum cardiac output was completed using the open circuit acetylene washin method and the OpCirc Method 2 mathematical computation during both the pre- and post-graded exercise test. Immediately upon termination of the graded exercise test a maximal cardiac output assessment was performed in the standing position. Participants were provided support if they struggled to maintain the standing position. The Canadian Sport Centre Calgary protocol was followed for each graded exercise test. This protocol involved a 2% grade held throughout the test with a starting speed of 5 mph and increments of 0.5 mph every three minutes until volitional fatigue. Participants were verbally encouraged throughout each test. Ventilatory thresholds were determined post-intervention through examining changes in expiratory gases such VE/VO_2, F_EO_2, F_ECO_2, RER and VCO_2 commonly seen between stages (434). Continuous HR monitoring was recorded throughout each graded exercise test with the last 30 seconds of each stage used for comparing pre- and post-test differences. VO_{2max} was identified as an increase in workload followed by a plateau, decrease, or an increase in oxygen consumption of < 150 $mL \bullet min^{-1}$ when averaging the last two 30-second sampling intervals of each stage (16, 305, 454). If a plateau was not found the test score would be labelled as a VO_2 peak.

4.3 Statistical Analysis

All data in text, figures and tables are represented as means with confidence intervals (CI) of 90% (CI 90%) unless otherwise stated. A CI of 90% was selected as it has been suggested to be an appropriate default level as the probability of the true value residing below or above these limits are 5% each and interpret as unlikely (219). All data were analyzed employing a practical significance standpoint using magnitude-based inferences. Current literature focusing on athletic performance has demonstrated traditional statistical approaches commonly fail to identify the size and importance of an effect and its implication to physical performance (217). Furthermore, a qualitative approach becomes increasingly important when working with reduced sample sizes commonly employed in high performance research (215, 365). For this reason a qualitative approach was chosen focusing on the within trial standardized mean differences to reveal the magnitude of effect size (ES) (80), using a pre-developed statistical spreadsheet (216). The following effect size threshold values were followed: <0.2 trivial, >0.2 small, >0.6 moderate, >1.2 large, > 2.0 very large, and > 4.0 extremely large (215).

The smallest worthwhile change for all physiological measures (**i.e.** non-performance measures) were derived from the day-to-day variation during the pre-hot yoga period (**i.e.** prior to first hot yoga class) and expressed as the coefficient of variation (218). The repeated analysis of each participant's change in plasma volume (PV%) was calculated using each participant's own coefficient of variation multiplied by 1.65 (**i.e.** *coefficient of variation x 1.65*); this threshold in the typical error has demonstrated an odds ratio of a real change to be 9:1 and is deemed acceptable for identifying significant change as represented a CI 90% (218).

Probabilities were calculated to express a benefit-to-harm ratio as well to identify if the true unknown value of the effect size was beneficial (Positive), trivial, or harmful (Negative) as calculated using an excel spreadsheet for practical significance and insight (28, 216). The qualitative likelihood of a change being either higher or lower, or harmful or beneficial were as follows; 1% almost certainly not, 1-5% very unlikely, 5-25% unlikely, 25-75% possible, 75-95% likely, 95-99% very likely, >99% almost certainly (215). A Pearson Product Moment Correlation (*r*) analysis was used to examine the relationship between changes in PV% and physiological measures (**ex**. heart rate, TL, Body Fat %). The magnitude of the correlation between each measurement used the following scale of strength of effect; <0.1 trivial, 0.1-0.3 small, 0.3-0.5, 0.5-0.7 large, 0.7-0.9 very large and 0.9-1.0 almost perfect (215). Fishers Z statistic transformation was used for developing a CI 90% for all regression analysis (125). Throughout the complete analysis, if the CI 90% overlapped both a negative (harmful) and positive (beneficial) range the effect size was declared unclear, otherwise the effect size was declared the detected value (215).

4.4 Results

4.4.1 Induction of Heat Acclimation

4.4.1.1 Physiological Measures

All participants (*n=10*) were included in the analysis for examining changes in PV% throughout the intervention. Only outfield players (*n=9*) acting as participants were included when examining performance measures. Participant characteristics are provided in Table 4.2. Body fat % and total fat free mass was provided from the participant's most recent DEXA analysis (i.e. October 2015), such anthropometric assessments are routine for all members of the Canadian Women's National Field Hockey Team. One participant (participant#3) became extremely ill after completing the post-test assessment and was excluded from further analysis. All participants followed their normal daily nutrition and hydration practices without any interference and were only instructed to abstain from fluids during each 60-minute hot yoga class. During each graded exercise test, environmental laboratory conditions were kept constant to negate any ambient fluctuations that could have influenced performance measures. Environmental conditions were recorded using a handheld Extech Heat Stress thermometer providing WBGT, RH% and ambient temperature (^{O}C) recordings (Table 4.1).

Table 4.3 outlines the physiological responses observed over six, 60-minute hot yoga sessions. No core temperature values were recorded on Day#5 due to complications when using the ingestible core temperature pills. The coefficient of variation was established to determine the smallest worthwhile change in resting core temperature [coefficient of variation = 0.6% (36.8;37.3 ^{O}C)] along with changes in body weight representing sweat loss (kg) [coefficient of variation = 7.5% (60.9;70.9 kg)]. Mean change in core temperature throughout a 60-minute hot yoga class are displayed in Figure 4.1. We identified a moderate increase in core temperature from the 20th to the 30th minute and a possible increase from the 30th to the 50th minute during a 60-minute class. Peak core temperature was identified at 30 minutes [37.6 ^{O}C, CI 90% (37.4;37.8), ES = 1.2 CI 90% (1.0;1.4), % chance 100/0/0] and diminished to a small increase above resting values at 60 minutes [37.3 ^{O}C, CI 90% (37.0;37.6), ES = 0.3 CI 90% (0.1;0.6), % chance 0/100/0].

We observed a moderate increase in core temperature when averaged over a 60-minute hot yoga class [0.28 ^{O}C, CI 90% (0.03;0.55), <u>ES = 0.84</u> CI 90% (0.48;1.2), % chance 22/78/0] with an trivial reduction in pre- to post-body weight (kg) [-0.37kg CI 90% (-0.33;-0.42), ES = -0.08 CI 90% (-0.80;-0.79), % chance 0/100/0] as seen in Table 4.3. When examining the mean cardiovascular stress experienced during hot yoga; a relative intensity of 47 ±4 (% maximum heart rate) was observed along with a TL value of 3.1±1.2 (%Max).

Consideration was given regarding the phase of each participant's menstrual cycle during the hot yoga intervention and can been seen in Table 4.5. One participant was removed from the comparisons between groups as the duration of the intervention spanned her transition from late Follicular phase to the Luteal phase. This transitional period typically accompanies a rapid and large physiological change in resting core temperature due to hormonal fluctuations (95).The rest of the participants completed their six consecutive days within the same phase of their cycle. A distinguishing variation between the two groups prior to commencing the intervention was a significant reduction in hematocrit observed in participants residing in the Luteal phase ($p <$ 0.05). When accounting for menstrual cycle phase we observed a higher resting core temperature ($p < 0.05$) in participants who were currently in the Luteal phase with no differences observed in peak core temperature during hot yoga as seen in Figure 4.3. When examining the magnitude of change in PV% after the intervention we identified no significant difference between menstrual cycle phases (Table 4.6). However, when examining the within-group change, we observed a possibly large reduction in PV% in the Luteal group [ES = -1.2 CI 90% (-4.1;1.7), % chance 8/40/52] and a very likely large and reduction in PV% in the Follicular group [ES = -2.3 CI 90% (-4.1;-0.5), % chance 2/1/97].

Day-to-day change in PV% during the intervention period is presented in Figure 4.2. We identified a possibly moderate increase [2.3% CI 90% (-0.7;5.3), ES = 0.7 CI 90% (-0.3;1.7), % chance 47/52/1, Odds Benefit (88:1)] 24 hours after the pre-intervention maximal exercise test. This moderate expansion in PV was followed by a gradual reduction throughout the hot yoga intervention where a loss greater than the smallest worthwhile change was observed prior to completing the post- exercise test [-3.5% CI 90% (-6.9;-0.1), ES = -1.2 CI 90% (-2.3;-0.1), % chance 0/25/75] as seen in Table 2.7. An unclear relationship was observed between change in PV% and TL (%Max) achieved throughout the hot yoga intervention as seen in Figure 4.4 [r = 0.41 CI 90% (-0.2;0.8)]. No significant relationship was observed between alterations in PV% and change in core temperature during hot yoga (r = 0.01), core temperature and sweat loss (%kg) (r = 0.003) or between PV% and the total thermal load developed over the intervention as expressed through (i.e. ambient temperature + exercise intensity) (r = 0.05). A very large inverse relationship [r = -0.76 CI 90% (-0.4;-0.9), $p < 0.05$] was observed during the intervention between body fat % and change in PV% (Figure 4.5). A significant inverse relationship between body surface area and change in PV% was also observed [r = -0.57 CI 90% (-0.8;0].

Table 4-1 Environmental characteristics during laboratory testing, hot yoga and on-field competition

	Laboratory	Yoga Studio	On-field
T_A (^OC)	23.2 ±0	30.0 ±1.8	11.8 ±0.5
WBGT	15.6 ±0.8	24.4 ±1.7	9.8 ±0.8
RH %	27.3 ±9.4	30.0 ±1.8	83 ±4.2

Values represented as mean ± SD. Values shown are ambient temperature (TA) in degrees Celsius, wet bulb globe temperature (WBGT) and relative humidity (RH%).

Table 4-2 Hot yoga participant characteristics

Age (years)	Total Fat Free Mass (kg)	Body Fat %	Height (cm)	Body Surface Area (m^2)	*Pre-Intervention* Weight (kg)	*Post-Intervention* Weight (kg)
25.5 ±3	42.8 ±3.7	25.4 ±3.8	169.7 ±3.5	1.8 ±0.08	65.9 ±5.4	66.0 ±5.1

Fat free mass and body fat % was taken prior to the intervention using DEXA. Body surface area calculated using Dubois & Dubois (107). Values are represented as mean ±SD. (n=10)

Table 4-3 Daily physiological responses from six 60-minute hot yoga sessions

	Intensity	Δ Change	Change (CI 90%)	Standardized Differences (CI 90%)	ES	% Chance the True ES is Positive / Trivial / Negative
Weight (kg)	[redacted]	-0.37 ±0.1	-0.37 (-0.33;-0.42)	-0.08 (-0.08-0.79)	Trivial	0 / 100 / 0
T_c (^{O}C)	[redacted]	0.28 ±0.4	0.28 (0.03;0.55)	0.84 (0.48;1.2)	Moderate	*22 / 78 / 0*
% HR	47 ±4					
Training Load (Au)	24.1 ±9.4					
Training Load (% Max)	3.1 ±1.2					

The mean change (i.e. throughout a yoga class) from day one to day six for each measure is provided. Values are represented as mean ±SD. Mean change (CI 90%), standardized differences (CI 90%) and effect size (ES) ratings are provided. To enhance the clarity for each ES the chances that the true ES is positive, trivial or negative are expressed as a %. Core temperature (T_C). (n=10)

Table 4-4 Day to day change in plasma volume (PV%) throughout the hot yoga intervention

	Hot Yoga						Post-Test
	Day #1	Day #2	Day #3	Day #4	Day #5	Day #6	
ΔPV%	2.3 ±5.16	-0.94 ±5.7	0.79 ±5.77	-1.6 ±4.5	-0.53 ±7.2	-1.4 ±5.7	-3.5 ±5.8
% Change (CI 90%)	(-0.7;5.3)	(-4.3;2.4)	(-2.6;4.1)	(-4.23;1.0)	(-4.7;3.7)	(-4.7;1.9)	(-6.85; -0.1)
Standardized Differences (CI 90%)	0.72 (-0.3;1.7)	-0.33 (-1.4;0.7)	0.23 (-0.9;1.3)	-0.55 (-1.4;0.3)	-0.22 (-1.5;1.1)	-0.49 (-1.6;0.6)	-1.2 (-2.3;-0.1)
ES	Moderate	Small	Small	Small	Unclear	Small	Large
% Chances of Beneficial / Trivial / Harmful	47/52/1	5/71/24	20/73/7	1/66/33	10/66/23	3/64/33	0/25/75
Odds Benefit: Harm	88:1		3:1				

Mean change in PV% ±SD also expressed as % change (CI 90%). Standardized differences (CI 90%) and effect size (ES) ratings are provided. To enhance the clarity for each ES the chance for a beneficial, trivial or harmful effect are expressed as a % along with the calculated odds for a benefit: harm ratio. (n=10)

Table 4-5 Participant menstrual cycle characteristics during the hot yoga intervention

(n=9)	Menstrual Cycle	
	Follicular Phase	Luteal Phase
Participants	5	4

Table 4-6 Change in plasma volume (PV%) between menstrual cycle phases after six days of hot yoga

(n=9)	ΔPV% Post-Test (24 hrs)
Luteal Phase (*n=4*)	-3.4 (-12.0;5.3)
Follicular Phase (*n=5*)	-5.1 (-9.1; -1.1)

Values represented as mean % change (CI 90%)

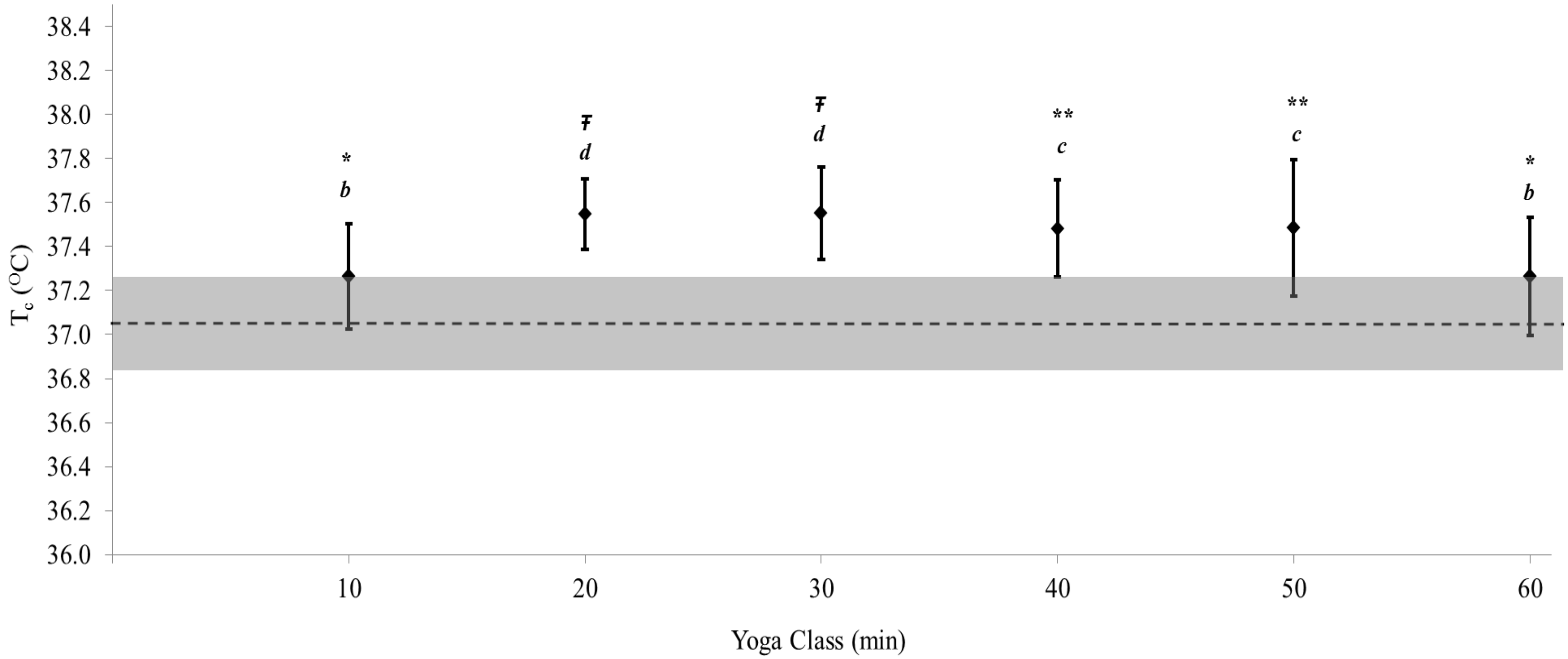


Figure 4-1 Change in core temperature (TC) over a 60-minute hot yoga session Values represented as a mean with error bars representing (CI 90%). The grey area represents the smallest worthwhile change (i.e. coefficient of variation = 0.9%,) the dotted line represents the mean resting value. Standardized differences: *a* trivial, *b* small, *c* moderate, *d* large, *e* very large. Likelihood of effect:* trivial, ** possibly higher or lower, *** likely high or lower, **** very likely higher or lower, Ŧ almost certain. (n=10)

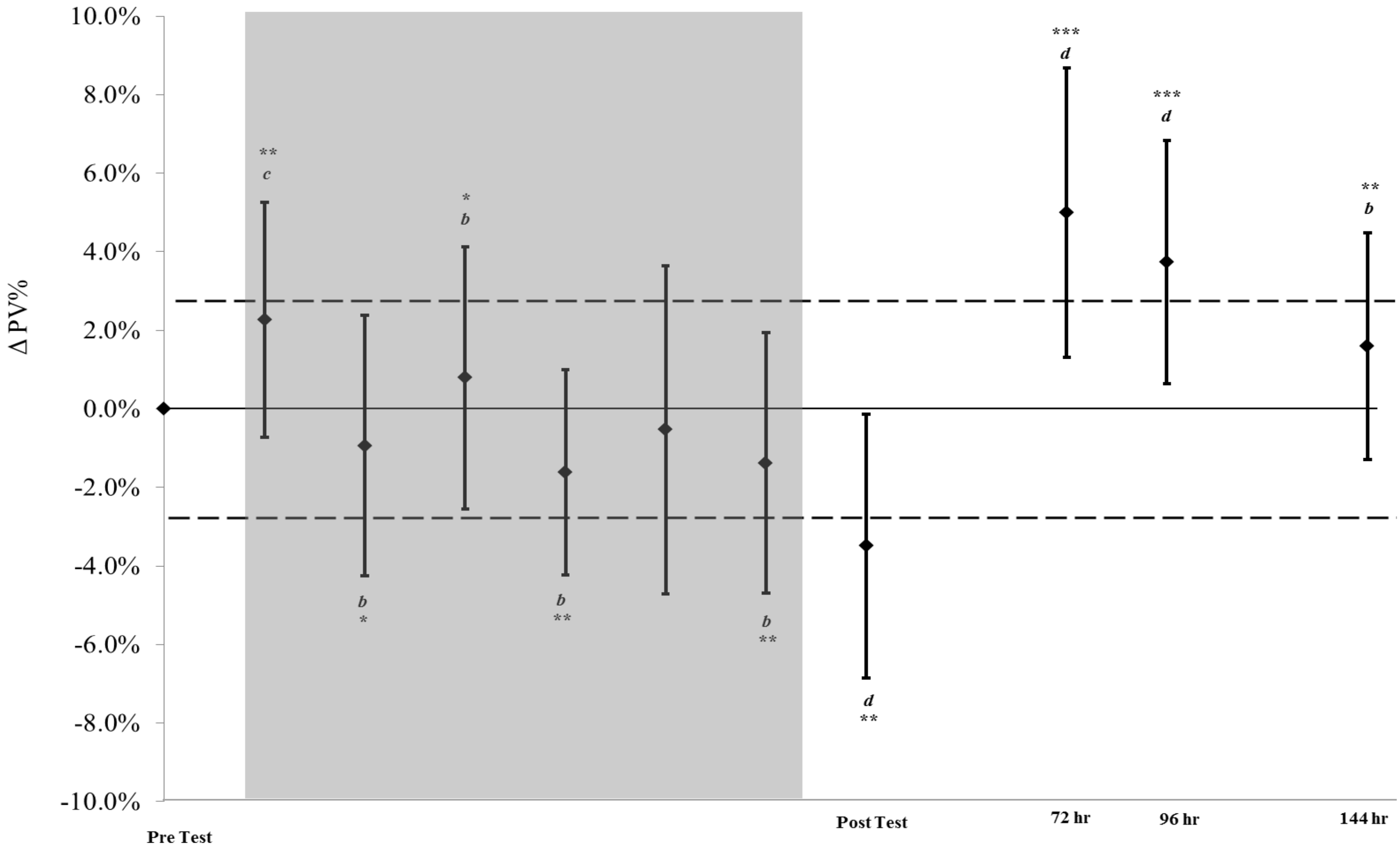


Figure 4-2 Change in plasma volume (PV%) during and post-hot yoga intervention

Values shown are means with error bars representing (CI 90%) for identifying the uncertainty in the true mean change. The grey area represents the hot yoga intervention period. Negative and positive dotted lines represent the smallest worthwhile change expressed as the coefficient of variation (coefficient of variation = 2.3%) calculated from the day to day change in PV prior to commencing hot yoga. Standardized differences: *a* trivial, *b* small, *c* moderate, *d* large, *e* very large. Likelihood of effect: * trivial, ** possibly higher or lower, *** likely high or lower, **** very likely higher or lower. (n=10)

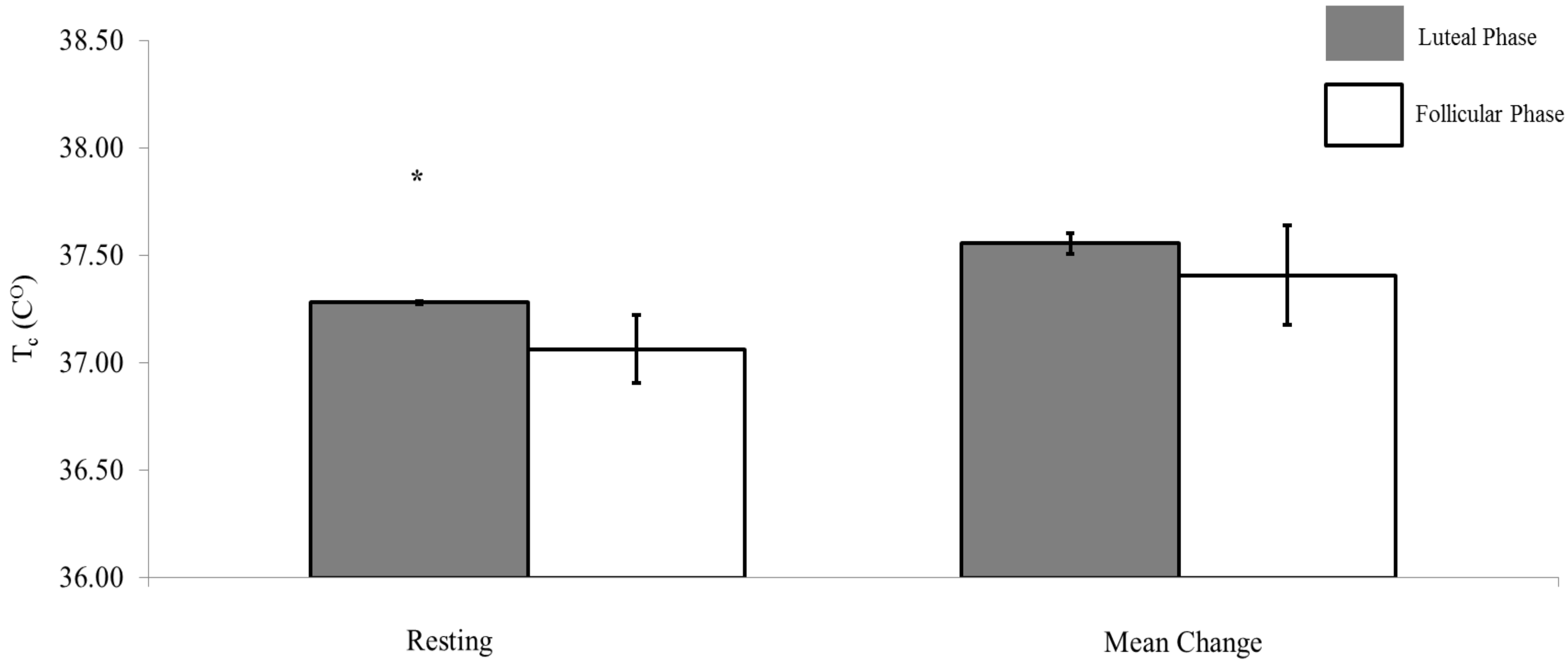


Figure 4-3 Core temperature (T_C) response in relation to menstrual cycle phase over a 60 minute hot yoga class Values represent the mean with errors representing the SD. * $p < 0.05$ between Luteal and Follicular Phase. (n=10)

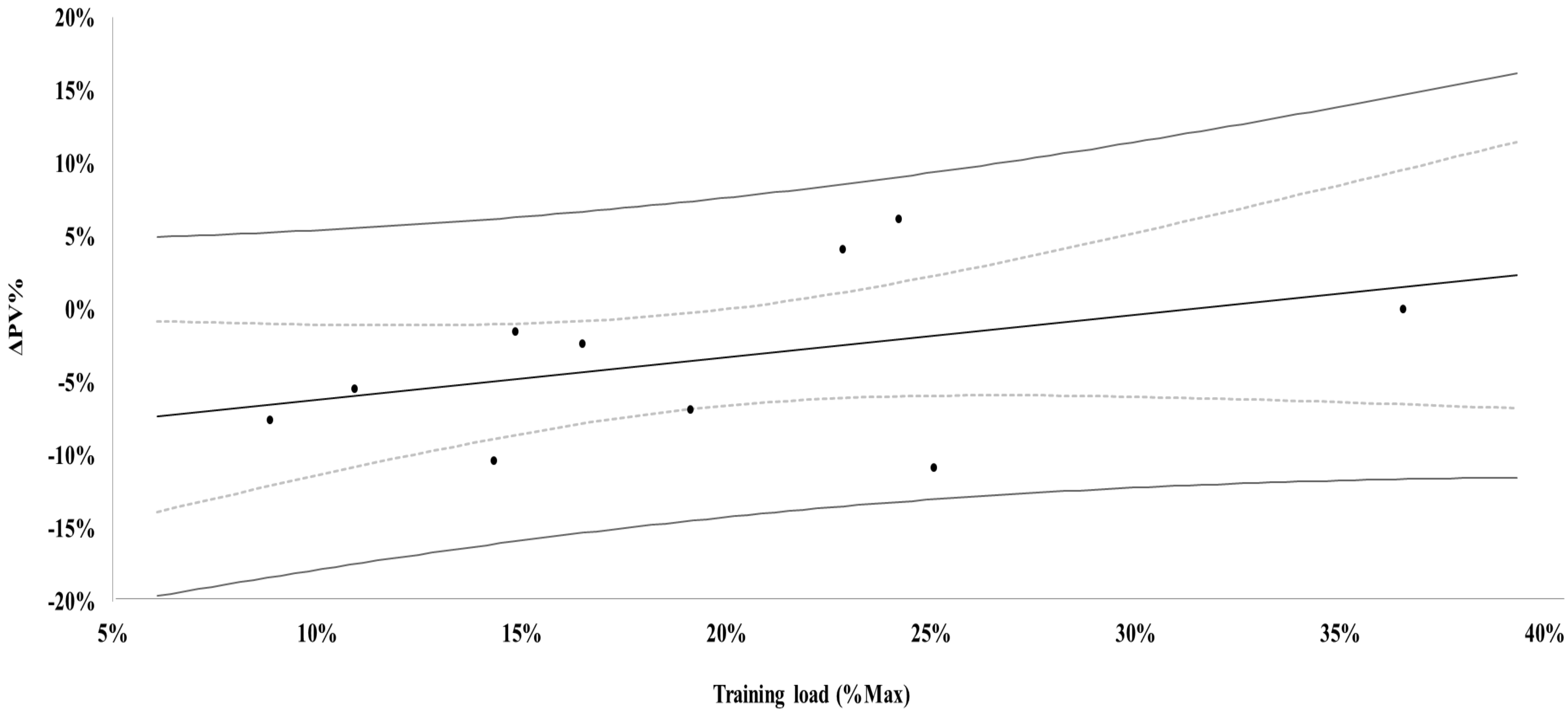


Figure 4-4 Relationship between the change in plasma volume (PV%) and the relative internal training load (%Max) accumulated over six hot yoga sessions

Pearson Product Moment Correlation (CI 90%), *r* = 0.41 (-0.2;0.8). (n=10)

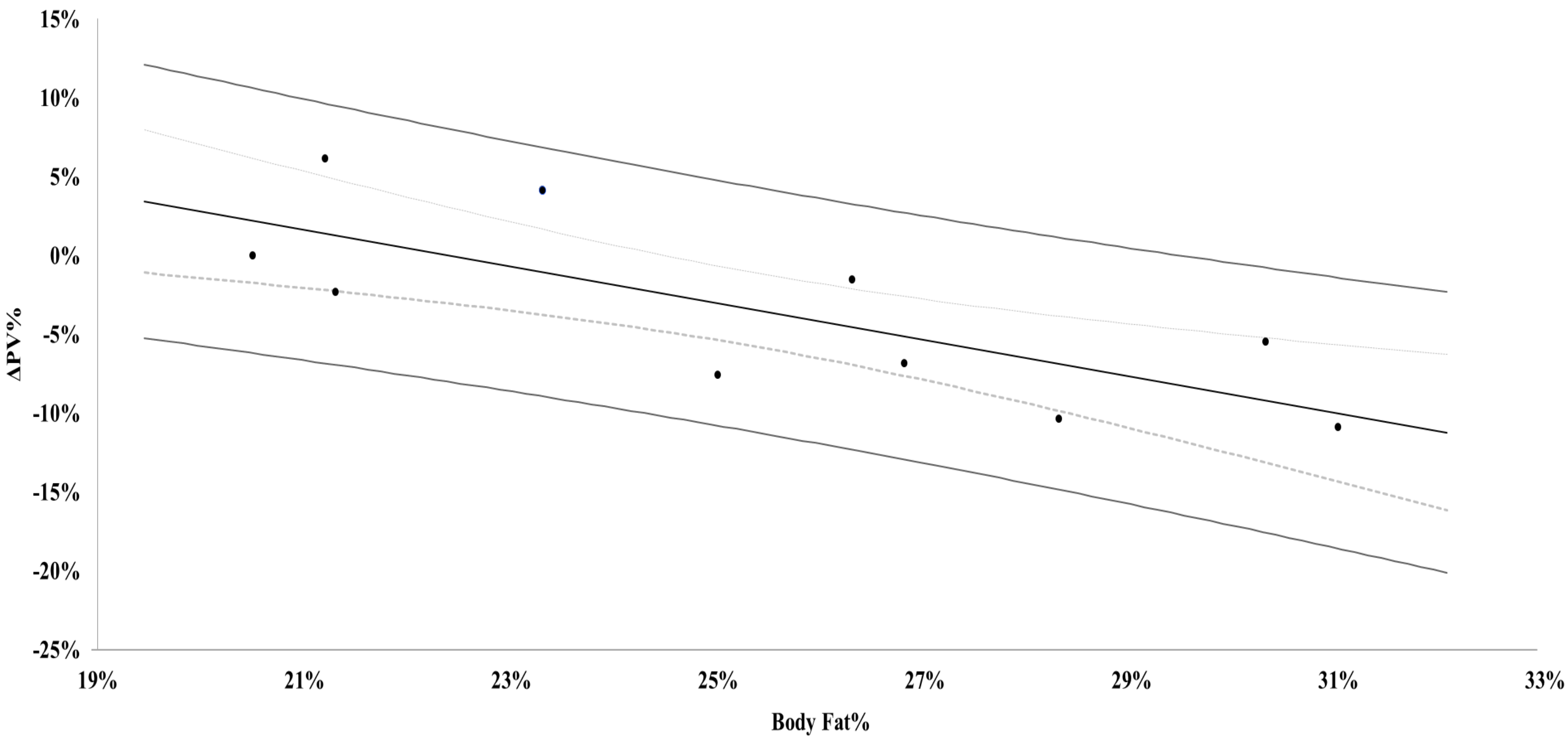


Figure 4-5 Relationship between body fat % (DEXA) and change in plasma volume (PV%) after six hot yoga sessions Pearson Product Moment Correlation (CI 90%), $r = -0.76$ (-0.4;-0.9), $p < 0.05$. (n=10)

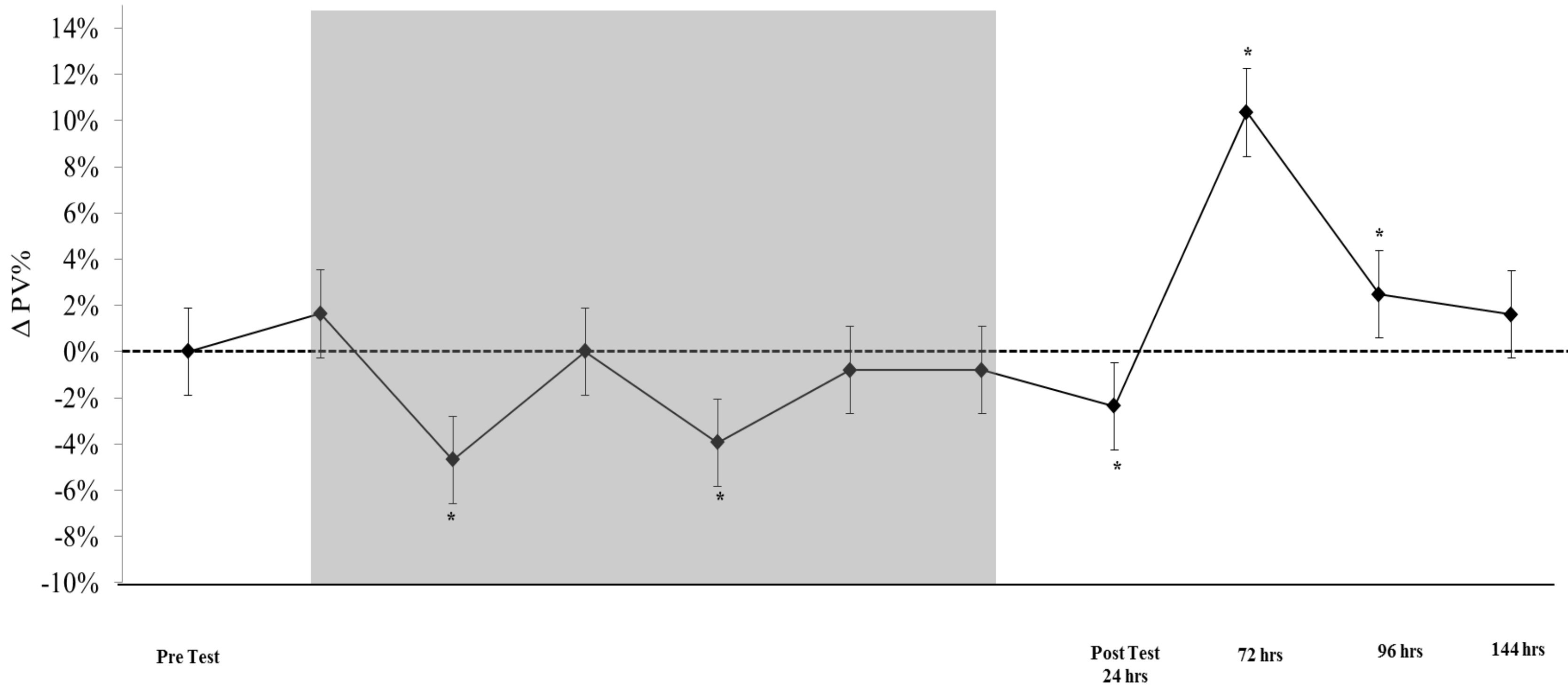


Figure 4-6 Change in plasma volume (PV%) observed in Participant[#]1 Grey area represents hot yoga intervention (i.e. Day[#]1-6). Error bars = 1.9% (*i.e.*1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

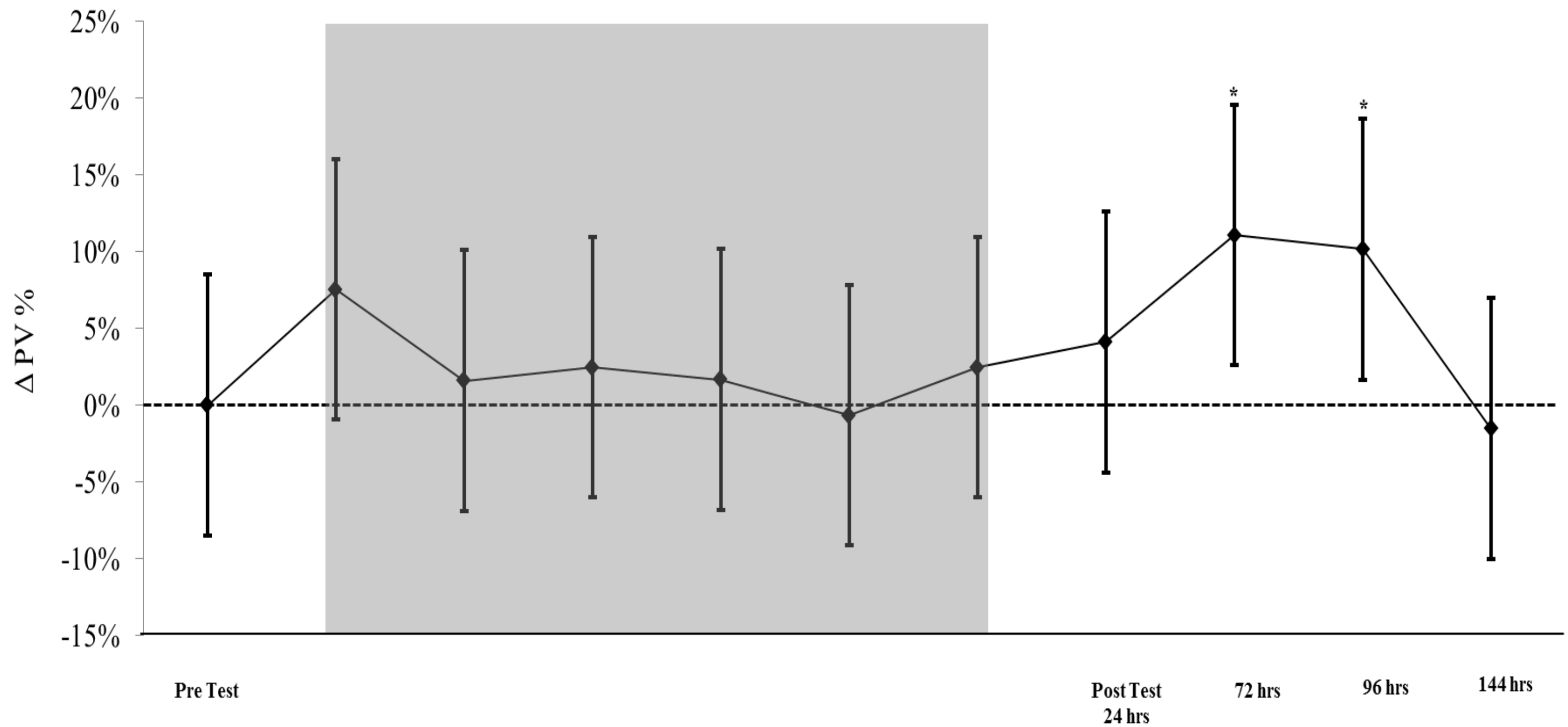


Figure 4-7 Change in plasma volume (PV%) observed in Participant#2 Grey area represents hot yoga intervention (i.e. Day#1-6). Error bars = 8.5% (*i.e.* 1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

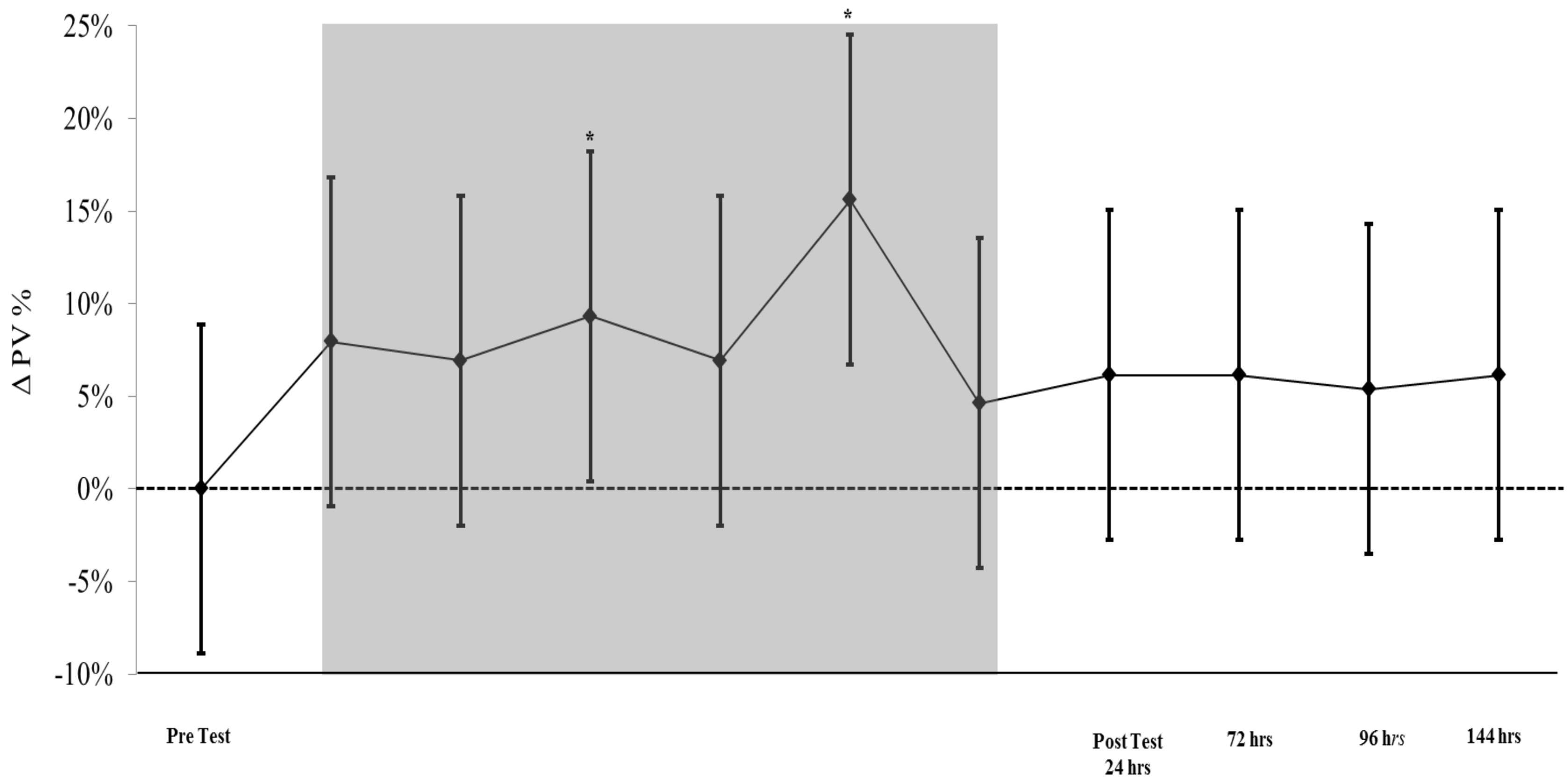


Figure 4-8 Change in plasma volume (PV%) observed in Participant#3 Grey area represents hot yoga intervention (i.e. Day#1-6). Error bars = 8.9% (*i.e.*1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

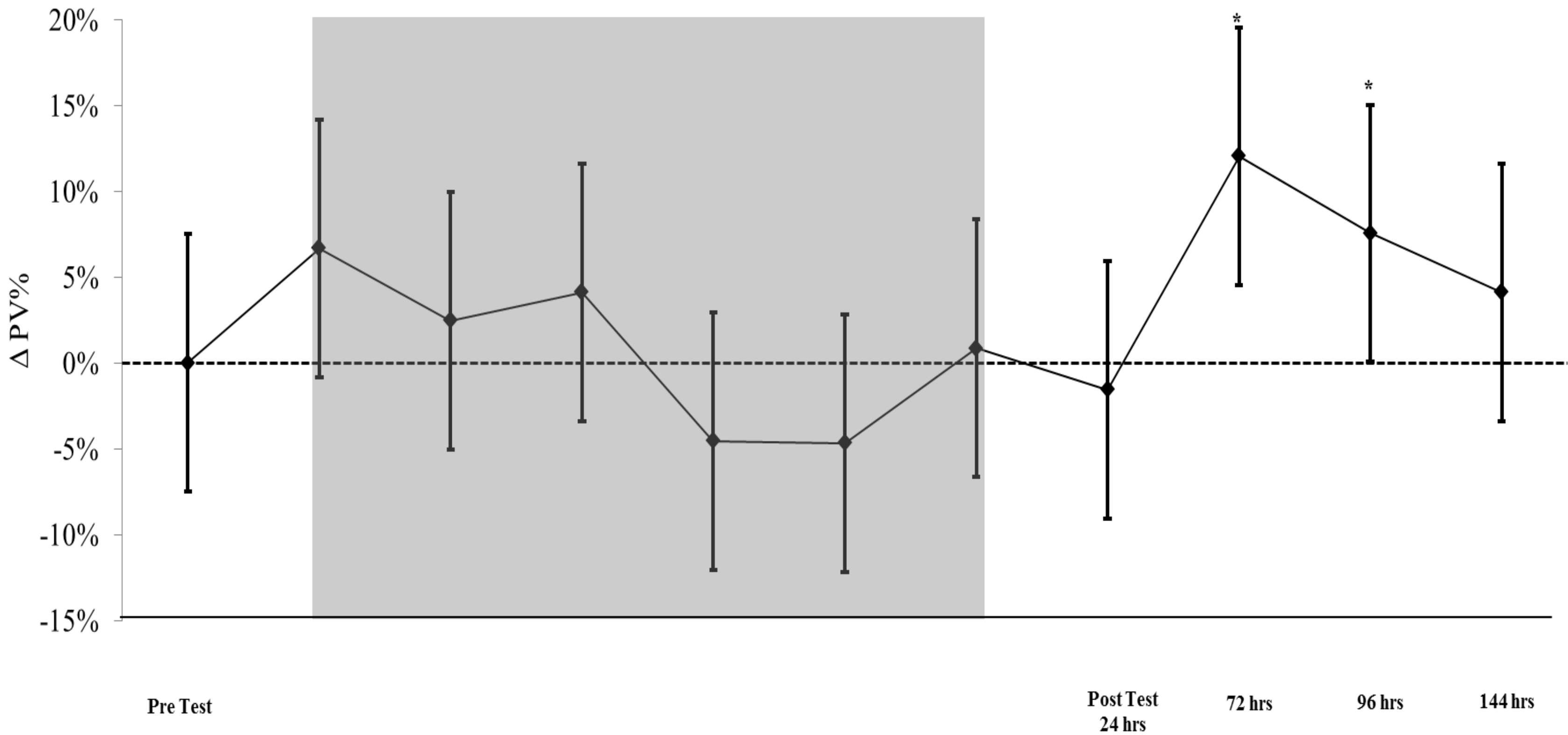


Figure 4-9 Change in plasma volume (PV%) observed in Participant#4 Grey area represents hot yoga intervention (i.e. Day#1-6). Error bars = 7.5% (i.e.1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

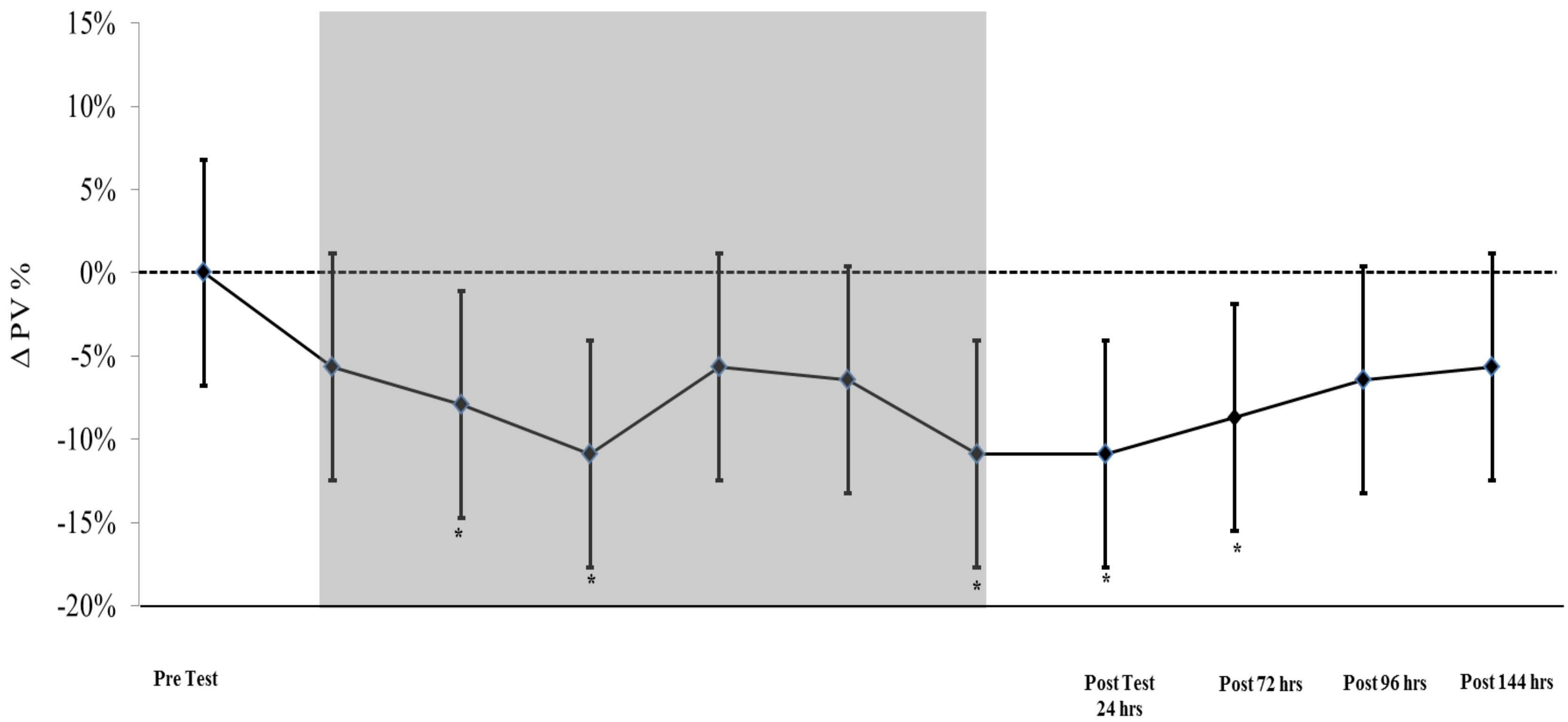


Figure 4-10 Change in plasma volume (PV%) observed in Participant#5 Grey area represents hot yoga intervention (i.e. Day#1-6). Error bars = 6.8% (*i.e.*1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

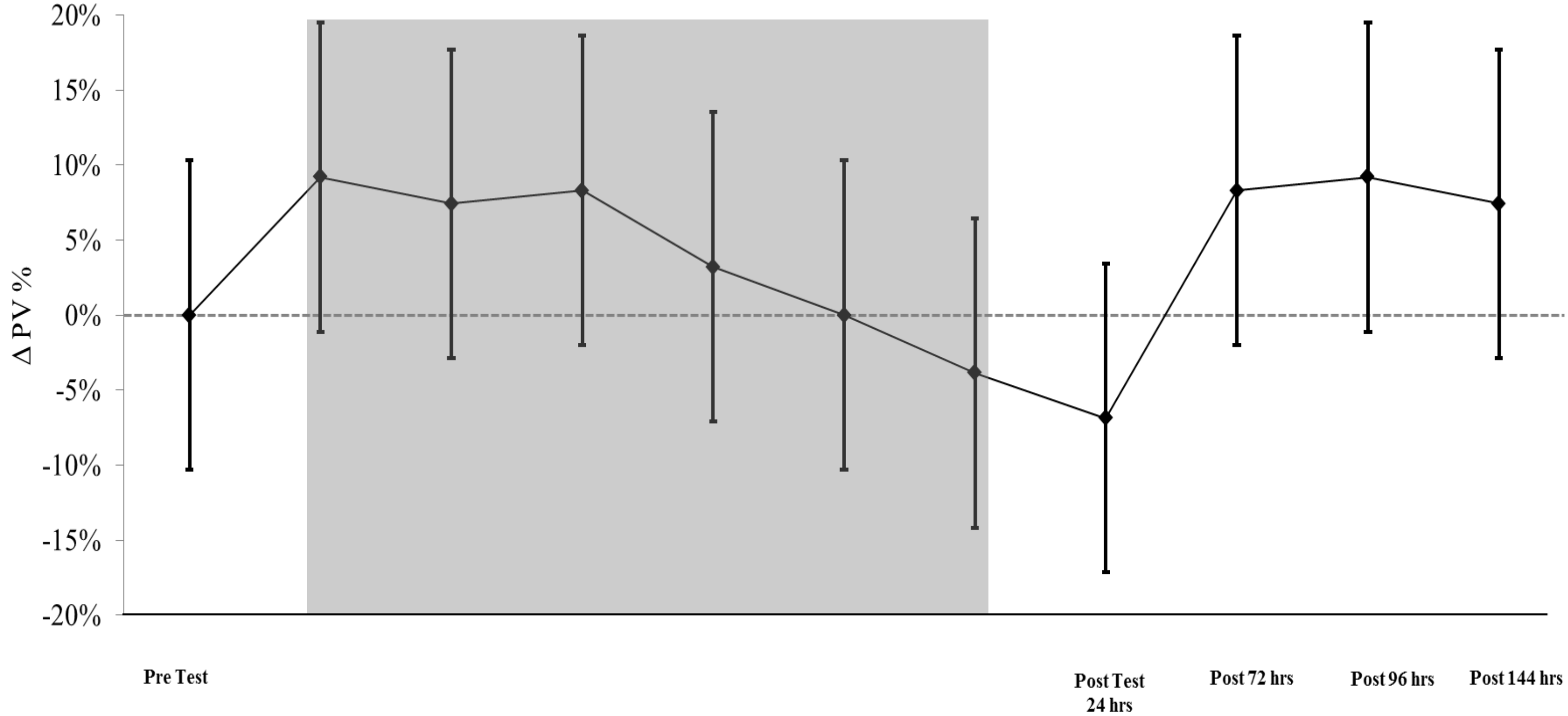


Figure 4-11 Change in plasma volume (PV%) observed in Participant#6 Grey area represents hot yoga intervention (i.e. Day[#]1-6). Error bars = 10.3% (*i.e.*1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

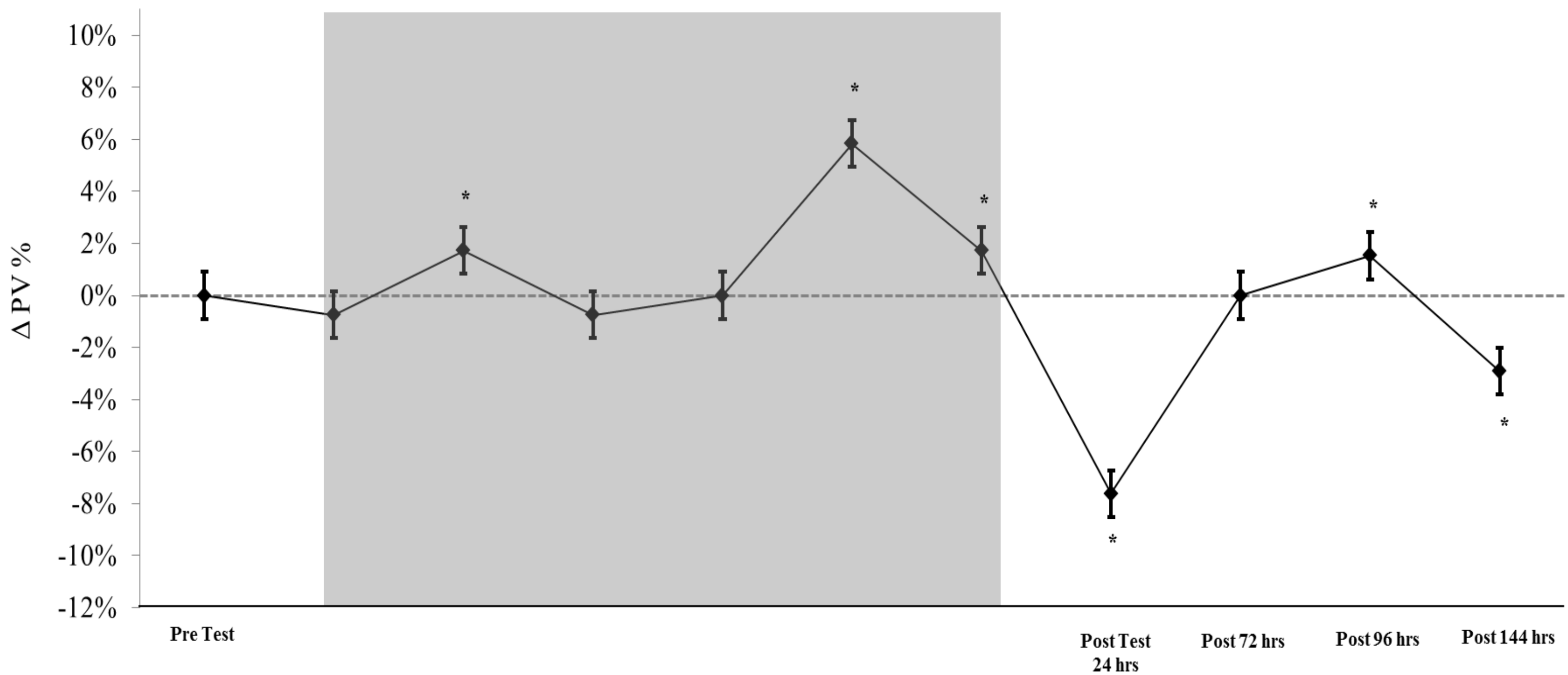


Figure 4-12 Change in plasma volume (PV%) observed in Participant#7 Grey area represents hot yoga intervention (i.e. Day#1-6). Error bars = 0.9% (i.e.1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

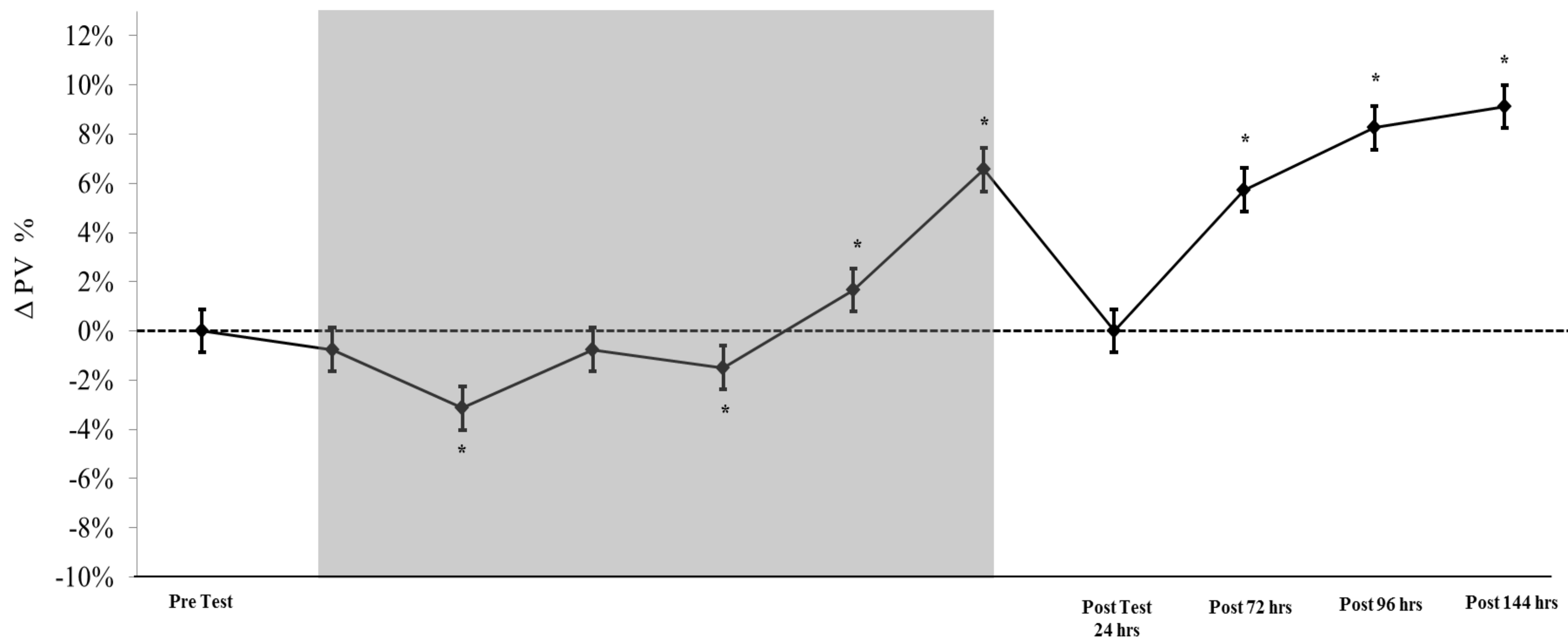


Figure 4-13 Change in plasma volume (PV%) observed in Participant#8 Grey area represents hot yoga intervention (i.e. Day#1-6). Error bars = 0.9% (*i.e.*1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

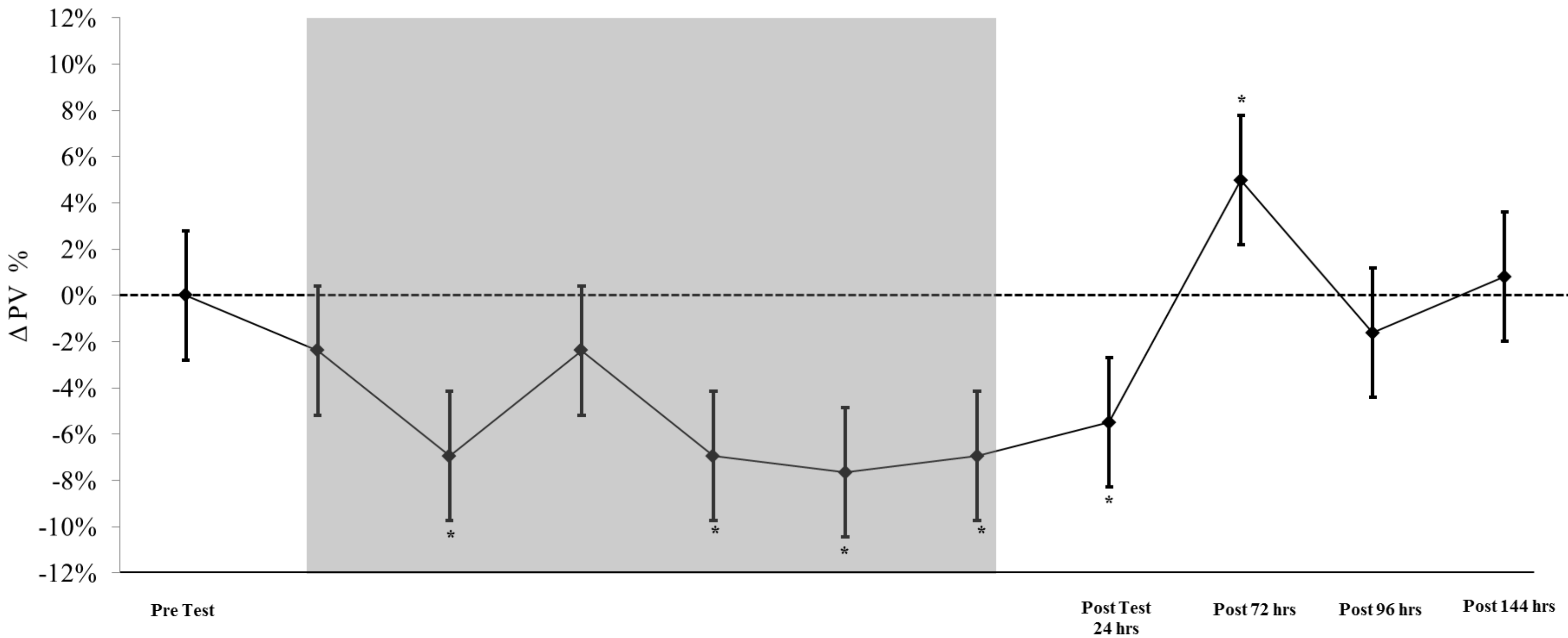


Figure 4-14 Change in plasma volume (PV%) observed in Participant#9. Grey area represents hot yoga intervention (i.e. Day#1-6). Error bars = 2.8% (*i.e.*1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

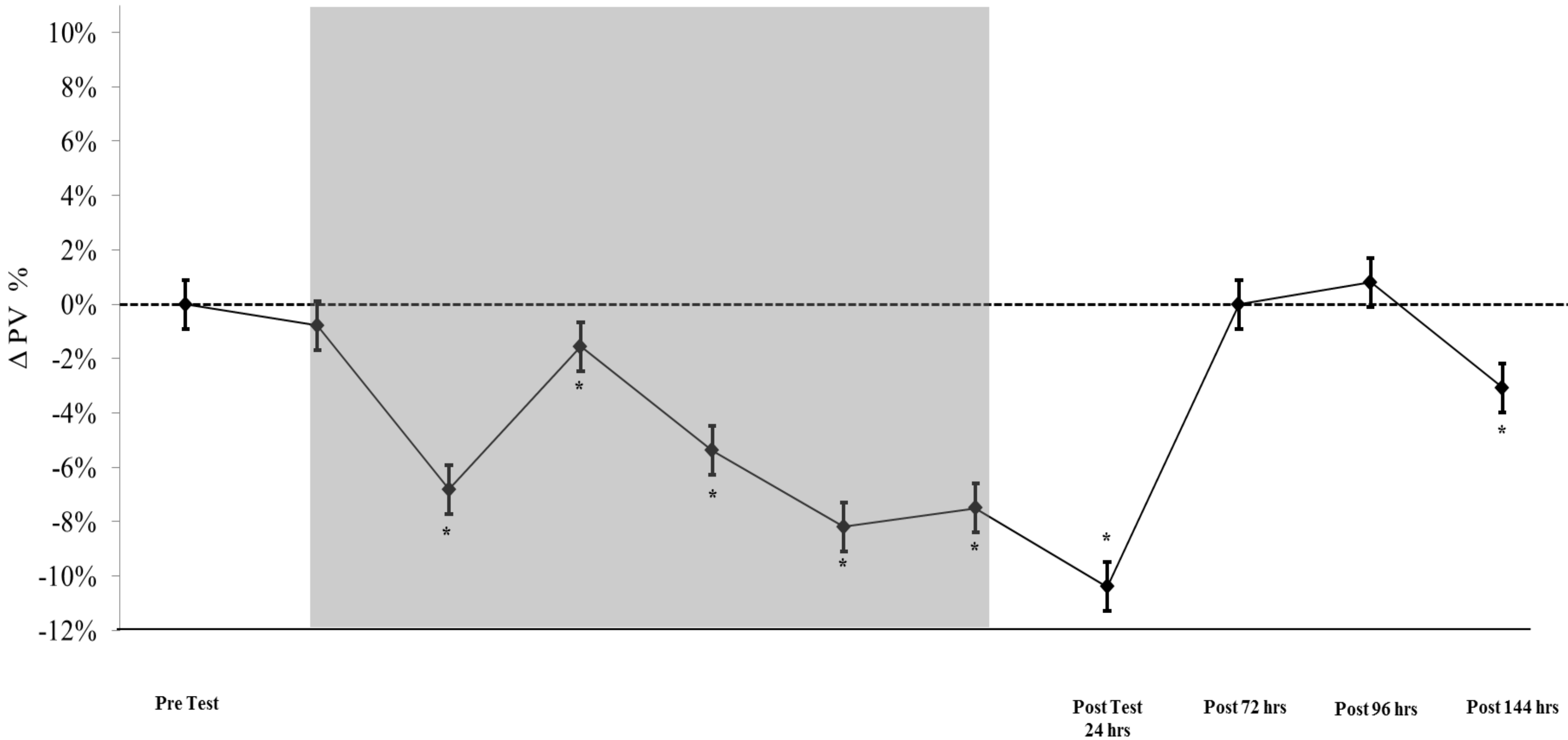


Figure 4-15 Change in plasma volume (PV%) observed in Participant#10
Grey area represents hot yoga intervention (i.e. Day#1-6). Error bars equal 0.9% (*i.e.*1.65 x typical error) as expressed as the coefficient of variation and represents a CI 90%. The coefficient of variation was developed from the day to day change in PV prior to hot yoga. Significant change = *

4.4.1.2 Cardiovascular and Aerobic Performance Measures

The assessment of resting cardiac output and maximum cardiac output was completed during the pre- and post-graded exercise test. The coefficient of variation was identified prior to testing as 2.5%. Due to uncontrollable circumstances, all cardiac output measures were deemed invalid when reassessed post intervention. As such all cardiac output measures were disregarded from this data analysis.

Change in cardiovascular and aerobic performance measures are represented as a percentage (%) in relation to the smallest worthwhile change (i.e. ES = 0.2) and are displayed in Figure 4.16. Of the 18 graded exercise test's completed; 17 reached a plateau in oxygen consumption as demonstrated by a change of no more than 150 mL•min^{-1} between the last two completed stages. One participant's post-intervention graded exercise test had a difference of 157 mL•min^{-1}, however secondary criteria demonstrated a maximal test. VO_{2max} revealed a likely trivial increase when represented as an absolute (L•min^{-1}) [0.4% CI 90% (0.0;0.8), ES = 0.02 CI 90% (-0.2;0.2), 14/83/3] or relative (mL•kg^{-1}•min^{-1}) [0.5% CI 90% 0.0;1.0), ES = 0.06 (-0.2;0.3), 5/93/3]. A possibly beneficial increase in VT_1 (mph) was observed [2.0% CI 90%(-0.3;4.3), ES = 0.2 CI 90% 0.2 (0.0;0.4), 50/49/0.8] with a likely beneficial increase in VT_2 (mph) [3.4% CI 90% (-0.8;7.6), ES = 0.5 CI 90% (-0.1;1.1), 82/15/2.5] while RT_{ex} demonstrated a likely trivial improvement [1.6% CI 90% (-1.0;4.2), ES = 0.1 CI 90% (-0.1;0.3), 19/90/0.6]. maximum heart rate displayed a likely trivial increase [0.5% CI 90% (-0.1;1.1), ES = 0.09 CI 90% (0.0, 0.2), 4/96/0]. Table 4.7 summarizes all post-test performance measures examined. Changes in high-intensity substrate utilization as expressed through RER during the last completed stage displayed small improvement [-0.8% CI 90% (0.4; -2.1), ES = 0.3 CI 90% (-0.1;0.6), 60/38/3].

When examining the within participant change in performance measures (Table 4.9) four participants were identified with a marked improvement in VO_{2max} (mL•kg-1•min^{-1}) along with a substantial increase in RT_{ex} (min-1• sec-1).

A secondary perspective involving the exclusion of participants #2 & #7 (*n=7*) for examining mean performance measures was adopted. This perspective was implemented to allow for ascertaining possible outcomes without the influence of outliers (Figure 4.17). This perspective demonstrated a likely beneficial improvement in VO_{2max} (mL•kg^{-1}•min^{-1}) [1.6% CI 90% (0.7;2.5) ES = 0.2 CI 90% (0.1;0.4), 55/45/0.1] and RT_{ex} [3.0% CI 90% (0.4;4.6), ES = 0.2 CI 90% (0.0;0.4), 58/42/0.1] as highlighted in Table 4.8.

Table 4-7 Change in cardiovascular and aerobic performance measures from pre- to post-hot yoga intervention

(n=9)	Pre-Intervention	Post-Intervention	% Change (CI 90%)	Standardized Differences (CI 90%)	ES	% Chance of Beneficial / Trivial / Harmful	Odds (Benefit : Harm)
$VO_{2\,max}$ ($L{\bullet}min^{-1}$)	3.05 ±0.42	3.06 ±0.36	0.4 (0.0;0.8)	0.02 (-0.2;0.2)	Trivial	14/83/3	2:1
$VO_{2\,max}$ ($mL{\bullet}kg^{-1}{\bullet}min^{-1}$)	46.2 ±3.48	46.4 ±3.11	0.5 (0.0;1.0)	0.06 (-0.2;0.3)	Trivial	5/93/3	5:1
VT_1 (mph)	5.4 ±0.58	5.6 ±0.63	2.0 (-0.3;4.3)	0.2 (0.0;0.4)	Small	50/49/0.8	120:1
VT_2 (mph)	7.3 ±0.57	7.6 ±0.63	3.4 (-0.8;7.6)	0.5 (-0.1;1.1)	Small	82/15/2.5	180:1
RT_{ex} ($min^{-1}{\bullet}sec^{-1}$)	24.27 ±3.26	24.50 ±3.21	1.6 (-1.0;4.2)	0.1 (-0.1;0.3)	Trivial	19/80/0.6	37:1
maximum heart rate (beats$\bullet min^{-1}$)	190 ±12	191 ±11	0.5 (-0.1;1.1)	0.09 (0.0;0.2)	Trivial	4/96/0	117:1
RER	1.10 ±0.04	1.09 ±0.02	-0.8 (0.4;-2.1)	0.3 (-0.1;0.6)	Small	60/38/3	56:1

Values are expressed as a mean ±SD for measures such as aerobic power (VO_{2max}), ventilatory thresholds one (VT_1) and two (VT_2), run time to exhaustion (RT_{ex}) max heart rate (maximum heart rate), respiratory exchange ratio of last completed stage (RER). Mean % change (CI 90%), standardized differences (CI 90%) and effect size (ES) ratings are provided. To enhance the clarity for each ES the chance for a beneficial, trivial or harmful effect are expressed as a % along with the calculated odds for a benefit: harm ratio.

Table 4-8 Change (*n=7*) in cardiovascular and aerobic performance measures from pre- to post-hot yoga intervention

(n=7)	Pre-Intervention	Post-Intervention	% Change (CI 90%)	Standardized Differences (CI 90%)	ES	% Chances of Beneficial / Trivial / Harmful	Odds (Benefit : Harm)
$VO_{2\ max}$ ($L \cdot min^{-1}$)	3.05 ±0.42	3.06 ±0.36	1.9 (0.7;3.1)	0.2 (0.1;0.3)	Small	79/21/0.1	2275:1
$VO_{2\ max}$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	46.2 ±3.48	46.4 ±3.11	1.6 (0.7;2.5)	0.2 (0.1;0.4)	Small	55/45/0.1	7047:1
RT_{ex} ($min^{-1} \cdot sec^{-1}$)	24.27 ±3.26	24.50 ±3.21	3.0 (0.4;5.6)	0.2 (0..0;0.4)	Small	58/42/0.1	819:1

Values are expressed as a mean ±SD for measures such as aerobic power (VO_{2max}) and run time to exhaustion (RT_{ex}) . Mean % change (CI 90%), standardized differences (CI 90%) and effect size (ES) ratings are provided. To enhance the clarity for each ES the chance for a beneficial, trivial or harmful effect are expressed as a % along with the calculated odds for a benefit: harm ratio.

Table 4-9 Individual changes in cardiovascular and aerobic performance measures from pre- to post-hot yoga intervention

(n=9)	VT_1 (mph)		VT_2 (mph)		VO_{2max} ($mL•kg^{-1}•min^{-1}$)		smallest worthwhile change	VO_{2max} ($L•min^{-1}$)		smallest worthwhile change	maximum heart rate ($beats•min^{-1}$)		RT_{ex} ($min^{-1}•sec^{-1}$)		smallest worthwhile change
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*(0.2 *SD_{pre})*	*Post*	*Pre*	*(0.2 *SD_{pre})*	*Pre*	*Post*	*Pre*	*Post*	*(0.2 *SD_{pre})*
1	5.5	5.5	7.5	7.5	47.6	48.4	(+)	2.92	2.97	T	191	191	27:00	27:48	(+)
2	5	5	6	7	42.3	42.3	T	2.58	2.62	T	202	204	18:00	19:07	(+)
3	5	5	7.5	8	49.5	50.7	(+)	3.08	3.21	(+)	201	198	26:02	27:47	(+)
4	6	6	7.5	8.5	46.4	47.9	(+)	2.96	3.06	(+)	186	189	27:00	27:39	T
5	6	6.5	7.5	8	45.9	44.9	(-)	3.17	3.04	(-)	191	193	27:00	25:37	(-)
6	5	5	7	7	43.0	44.2	(+)	2.68	2.76	(+)	188	188	21:36	22:04	T
7	5	5	7.5	7.5	52.9	50.5	(-)	3.96	3.76	(-)	200	201	28:17	27:56	T
8	6.5	6.5	8	8	45.9	46.0	T	3.38	3.39	T	186	188	23:04	24:22	(+)
9	5	5.5	7	6.5	42.5	42.9	T	2.76	2.75	T	164	166	22:00	21:11	(-)

Performance measures provided are ventilatory threshold one (VT_1), ventilatory threshold two (VT_2), relative and absolute maximum aerobic power (VO_{2max}), heart rate max (maximum heart rate), and run time to exhaustion (RT_{ex}). The smallest worthwhile change is represented as ($0.2 \times SD_{pre}$) and was stated as (+) beneficial, (-) harmful or (T) trivial.

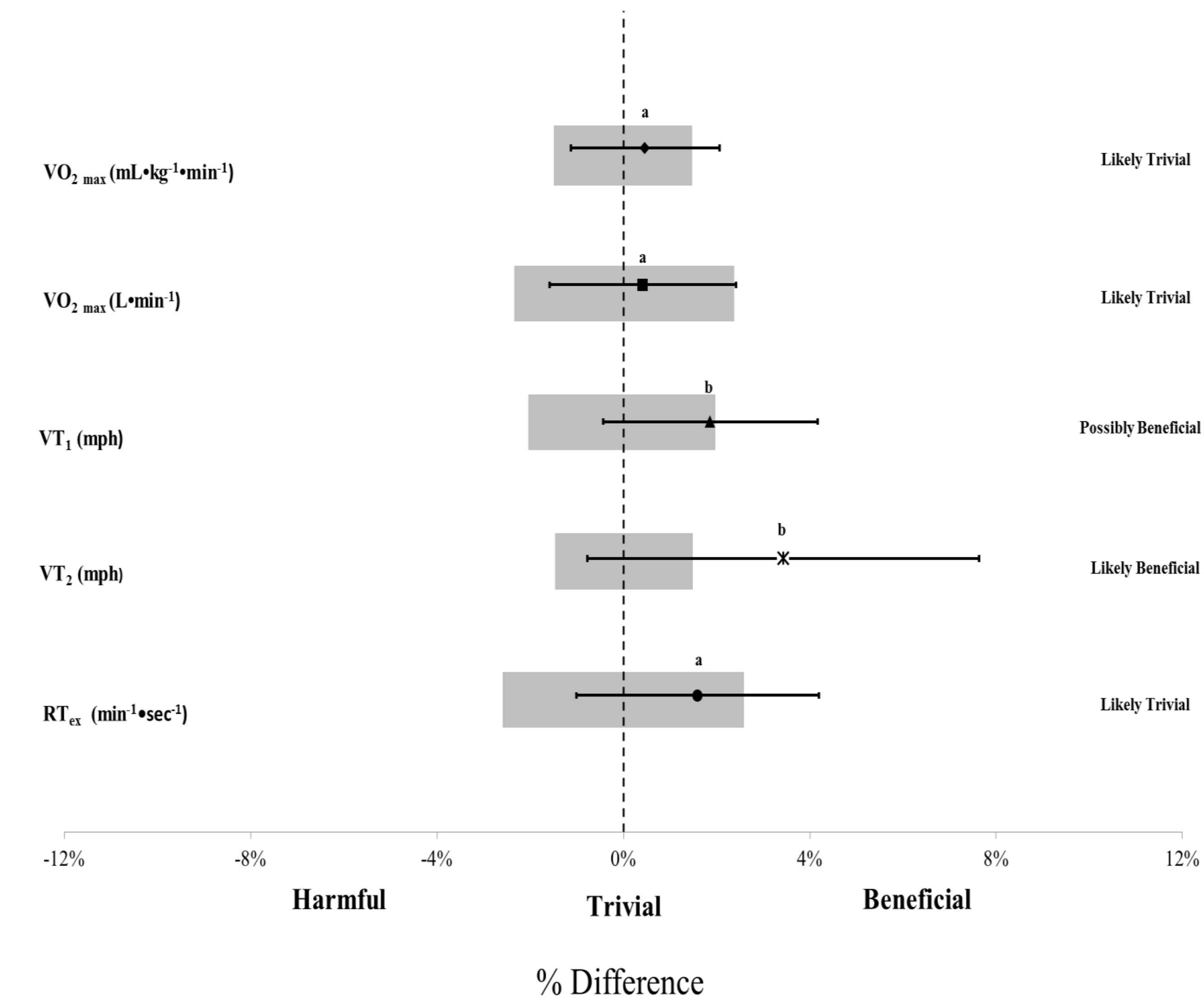


Figure 4-16 Mean % change (n=9) in cardiovascular and aerobic performance measures
Relative and absolute aerobic power (VO_{2max}), ventilatory thresholds one (VT_1) and two (VT_2) and run time to exhaustion (RT_{ex}). Error bars represent (CI 90%) for identifying uncertainty in the true mean change. Grey boxes represent the trivial area and were determined from the smallest worthwhile change (i.e. ES = 0.2) in each measure using standardized differences in the means. Standardized differences: *a* trivial, *b* small, *c* moderate, *d* large, *e* very large.

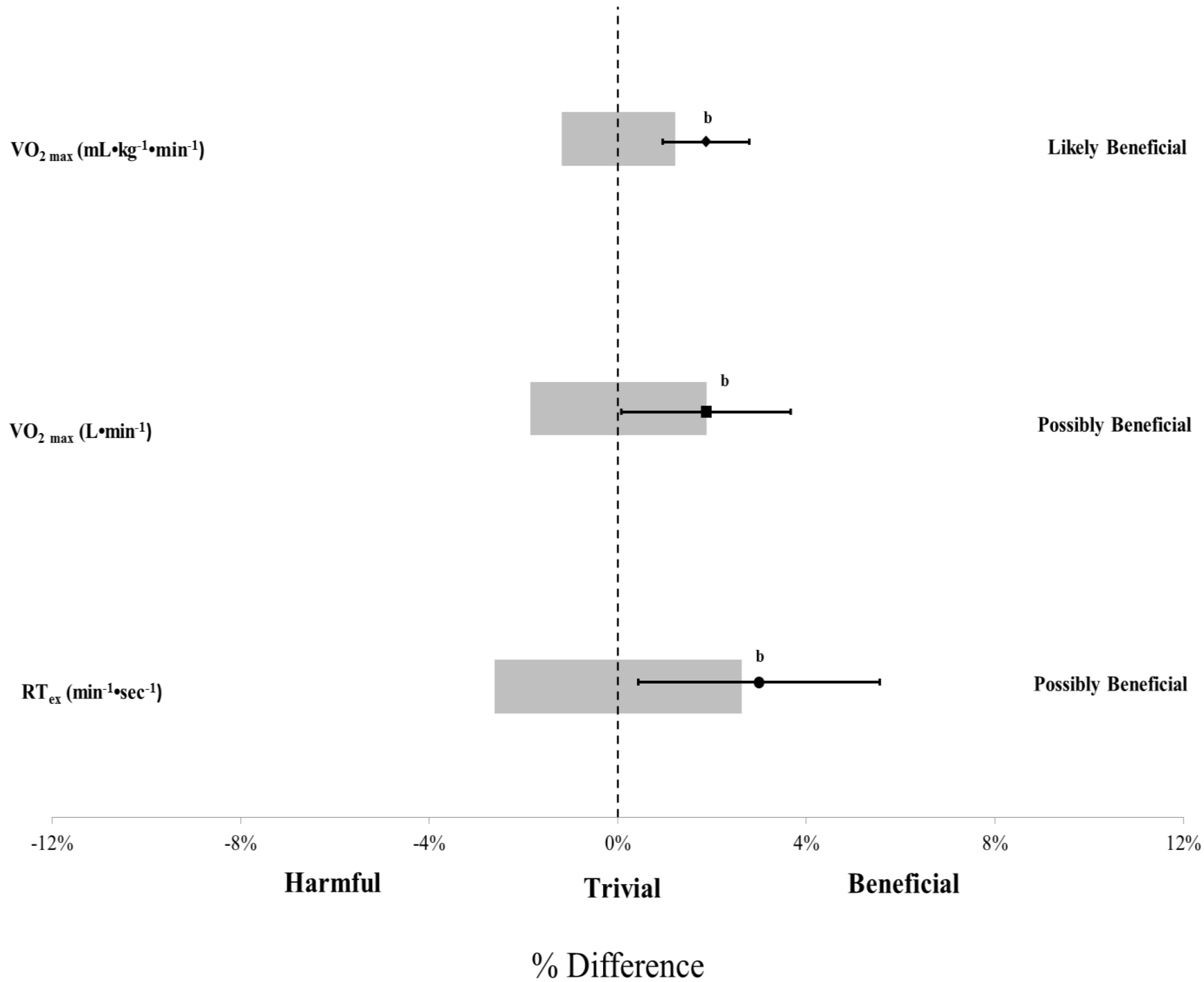


Figure 4-17 Mean % change (*n=7*) in cardiovascular and aerobic performance measures
Relative and absolute aerobic power (VO_{2max}) and run time to exhaustion (RT_{ex}). Error bars represent (CI 90%) for identifying uncertainty in the true mean change. Grey boxes represent the trivial area and were determined from the smallest worthwhile change (i.e. ES = 0.2) for each measure using standardized differences in the means. Standardized differences: *a* trivial, *b* small, *c* moderate, *d* large, *e* very large.

4.4.2 Post Acclimation: Rate of Decay in Hypervolemia

This section of the investigation was designed to examine the response in PV% after the removal of repeated heat stress (i.e. hot yoga) during a period of field competition in a cold and temperate environment. Figure 4.18 displays our observed alterations in PV% over a 144-hour period post-intervention. A super compensatory effect was observed during the post-intervention period as PV% demonstrated a likely large expansion at both 72 and 96 hours (Table 4.10). A change in PV% at 144 hours post-intervention demonstrated a possibly small expansion yet remained within the smallest worthwhile change [1.6% CI 90% (-1.3;4.5), ES = 0.5 CI 90% (-0.4;1.5), % chance 32/66/2, Odds Benefit (26:1)]. Individual adaptations in PV% during and post-intervention are presented in Figures 4.6 - 4.15. A non-significant difference in PV% between menstrual cycle stages were observed during the complete post-intervention period (Table 4.11).When examining the within group alterations in PV% a possibly moderate expansion was observed at 144 hours in the Follicular group demonstrating [3.0% CI 90% (-2.9;8.3), ES = 1.1 CI 90% (-1.3;3.5), % chance 53/40/7, Odds Benefit (16:1)] when compared to a possibly trivial expansion in the Luteal group [1.0% CI 90% (-7.0;9.1), ES = 0.4 CI 90% (-1.5,2.2), % chance 24/67/9, Odds Benefit (3:1)].

A secondary perspective was adopted for examining change in PV% during the post-intervention period to illustrate the substantial rebound upon commencing exercise. Figure 4.19 displays changes in PV% when calculated using the blood volume% recorded after the intervention (i.e. PV -2.2% CI 90% (-0.1; -4.3). We observed a very large and almost certain expansion at 72 hours [PV 9.9% CI 90% (7.2;12.6), ES = 2.9 CI 90%(2.2;5.0), 99.9/0.1/0], a very large and almost certain expansion at 96 hours [PV 8.6% 9 CI 90% (6.0;11.2), ES = 2.6 CI

90% (2.1;4.7), 99.9/0.1/0] and a very likely and very large expansion at 144 hours [PV 6.1% CI 90% (2.8;9.4), ES = 2.1 CI 90% (1.2;4.4), 98.8/1.0/0.2].

A likely large effect between accumulated on-field % of maximum training load and change in PV% was observed at 72 hours post [r = 0.64 CI 90% (0.1;0.9)] (Figure 4.20). This relationship diminished to an unclear effect [r = -0.10 CI 90% (-0.7;0.5)] by 144 hours. We observed a likely large relationship between body fat% and change in PV% recorded at 144 hours t [r = -0.50 CI 90% (-0.8;0.1)] as seen in Figure 4.21.

Table 4-10 Day to day change in plasma volume (PV%) post-hot yoga intervention

(*n=9*)		Post-Yoga		
	Post-Test	(72 Hrs)	(96 Hrs)	(144 Hrs)
ΔPV%	-3.5 ±5.8	4.9 ±6.4	3.7 ±5.3	1.6 ±4.9
% Change (CI 90%)	(-6.85;-0.1)	(1.3;8.7)	(0.6;6.8)	(-1.3;4.5)
Standardized Differences (CI 90%)	-1.2 (-2.3;-0.1)	1.6 (0.40;2.8)	1.2 (0.20;2.2)	0.51 (-0.40;1.5)
ES	Large	Large	Large	Small
% Chances of Beneficial / Trivial / Harmful	0.5/25/74	88/11/0.3	77/23/0.3	32/66/2
Odds (Benefit : Harm)		2428:1	1006:1	26:1

Mean change in PV% ±SD also expressed as % change (CI 90%). Standardized differences (CI 90%) and effect size (ES) ratings are provided. To enhance the clarity for each ES the chance for a beneficial, trivial or harmful effect are expressed as a % along with the calculated odds for a benefit: harm ratio.

Table 4-11 Change in plasma volume (PV%) between menstrual cycle phase post-hot yoga

(*n=9*)	ΔPV%		
	72 Hrs	96 Hrs	144 Hrs
Luteal Phase (*n=4*)	4.5 (-2.0;11.3)	3.7 (-1.4;8.8)	1.1 (-6.8;9.1)
Follicular Phase (*n=5*)	4.0 (-3.1;11.1)	2.0 (-4.1;6.1)	3.0 (-2.6;8.6)

Values represented as mean % change (CI 90%)

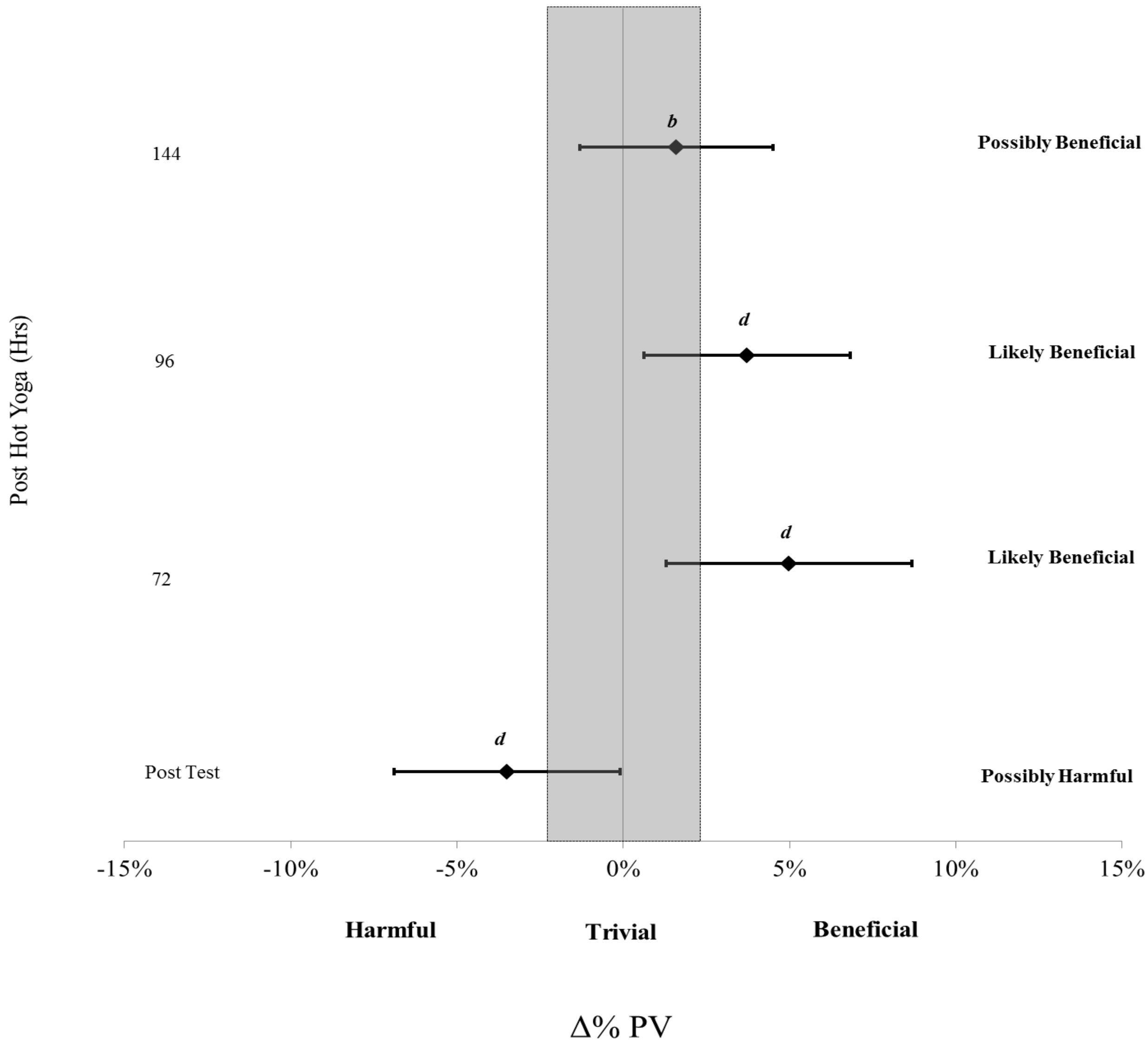
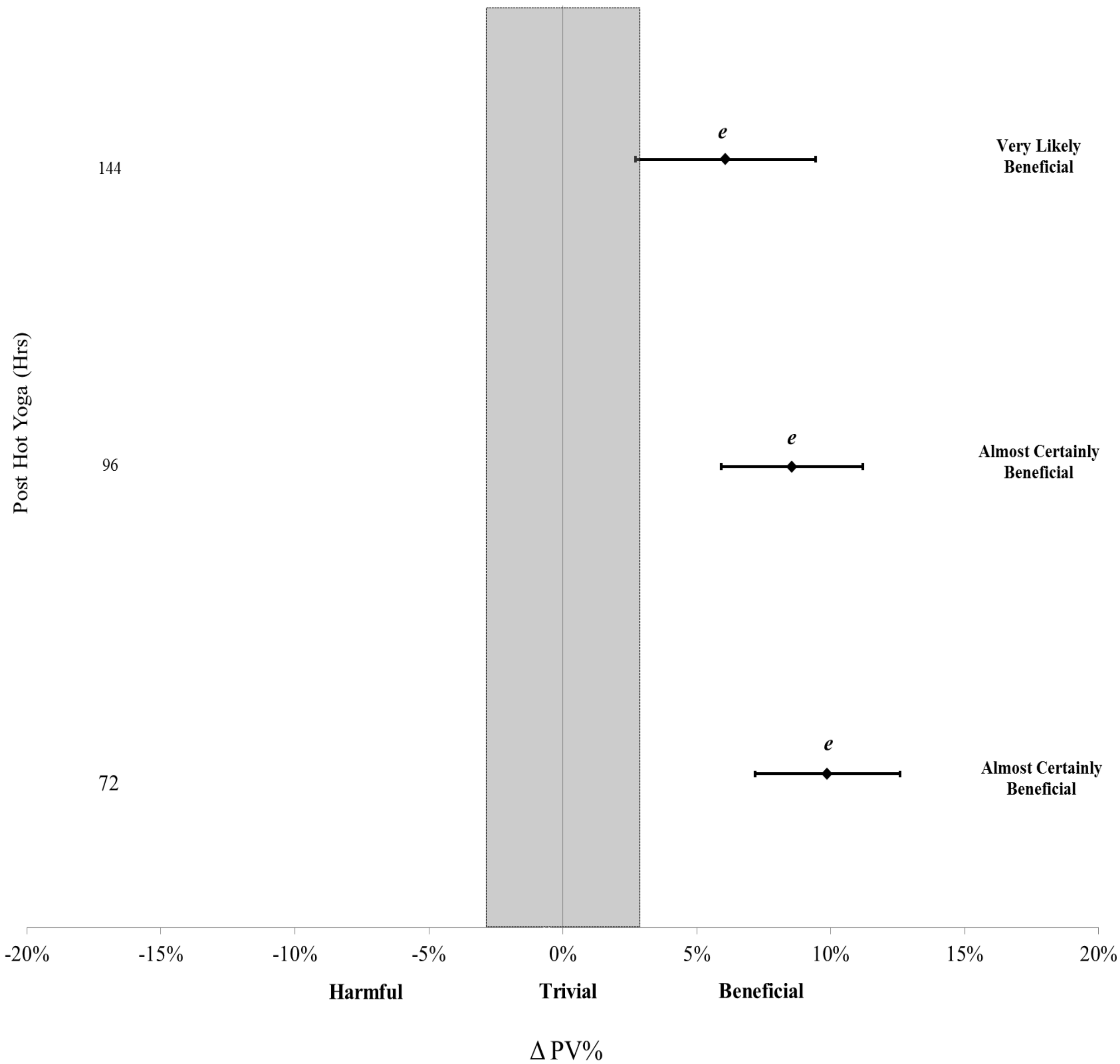


Figure 4-18 Rate of decay (n=9) in plasma volume (PV%) post-hot yoga intervention
Values shown are means with error bars representing (CI 90%) for identifying uncertainty in the true mean change. The grey area represents the smallest worthwhile change expressed as the coefficient of variation calculated from the day to day change in PV prior to commencing hot yoga. Standardized differences: *a* trivial, *b* small, *c* moderate, *d* large, *e* very large.



4-19 Change (n=9) in plasma volume (PV%) derived from changes in blood volume (blood volume%) post-intervention. (i.e. Post-blood volume% = -2.2%, CI 90% (-0.1;-4.3) Values shown are means with error bars representing (CI 90%) for identifying uncertainty in the true mean change. The grey box represents the smallest worthwhile change expressed as the coefficient of variation calculated from the day to day change in PV prior to commencing hot yoga. Standardized differences: *a* trivial, *b* small, *c* moderate, *d* large, *e* very large.

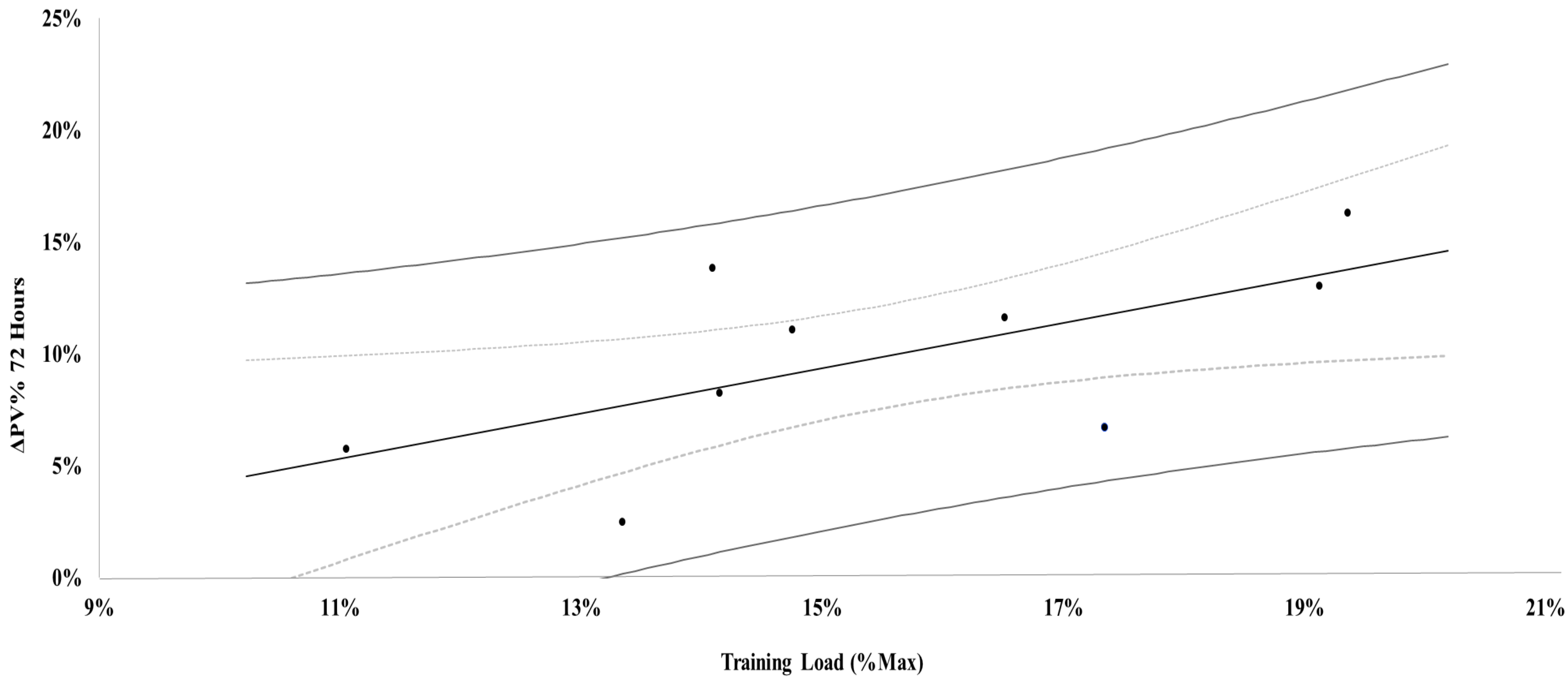


Figure 4-20 Relationship between the change in plasma volume (PV%) at post-72 hours and on-field training load (TL = % of maximum on-field training loading). Change in PV% was calculated using the diminished blood volume % recorded post-intervention. Pearson Product Moment Correlation (CI 90%), $r = 0.64$ (0.1;0.9) (n=9)

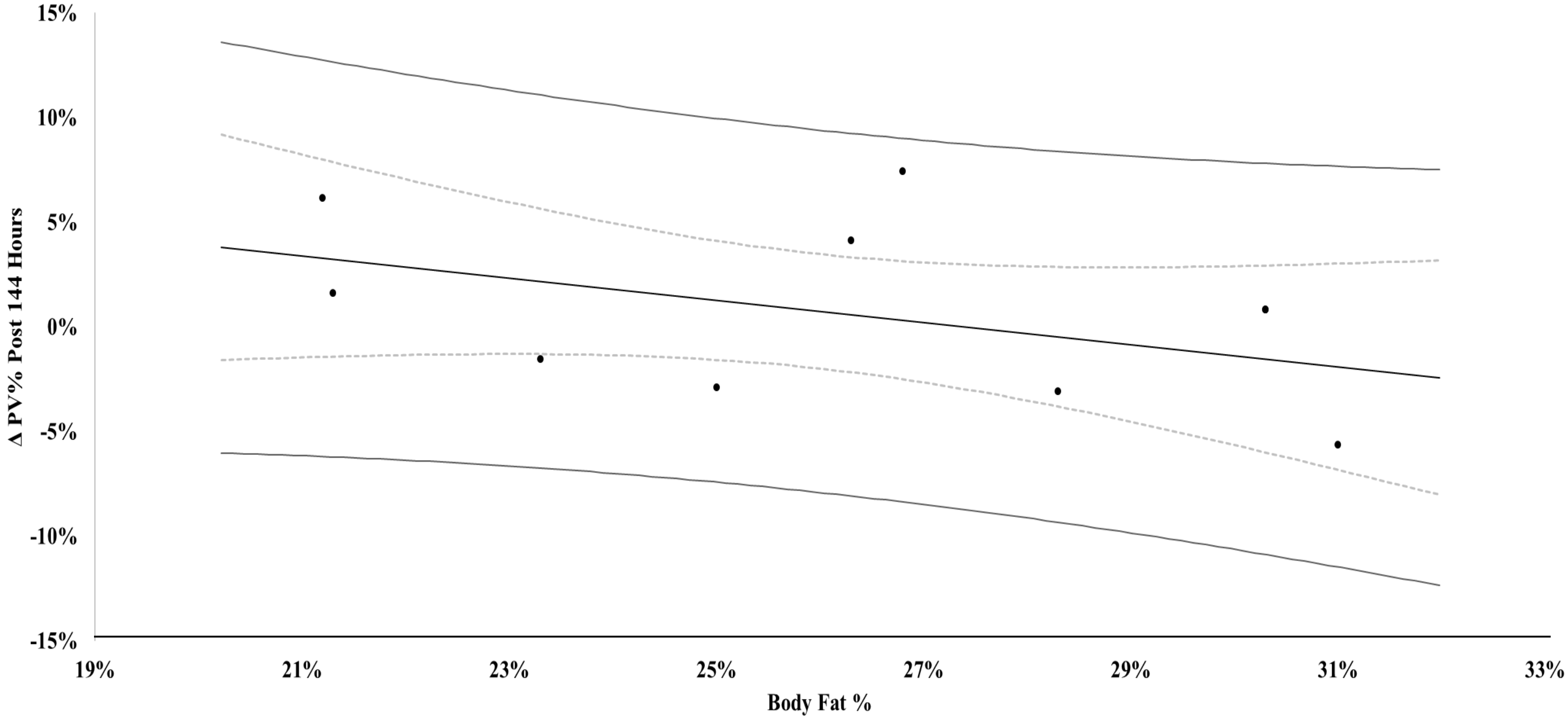


Figure 4-21 Relationship between body fat % (DEXA) and change in plasma volume (PV%) 144 hours post-intervention. Pearson Product Moment Correlation (90% CI), *r* = -0.50 (-0.8;0.1). (n=9)

4.5 Discussion

4.5.1 Induction of Heat Acclimation

4.5.1.1 Physiological Adaptations

Current literature has highlighted the necessity for directing future research towards identifying the minimal exercise intensity required for short term heat acclimation training to elicit positive physiological and performance adaptations (377). Additionally, the paucity of literature focusing on short term heat acclimation protocols comprising of female participants accentuates the need for further investigation to better understand their physiological response and subsequent performance alterations (71, 377). To our knowledge, only Sunderland et al. have focused on a cohort of female athletes and their subsequent response to four intermittent short term heat acclimation exposures over an eight-day period when using intermittent high-intensity training.

This investigation provides new evidence of the acute and daily physiological responses to repeated hot yoga exposures, its concomitant effect on cardiovascular and aerobic performance and the aptitude of hot yoga to act as a novel form of short term heat acclimation training applicable for team sport. As such, the findings in this investigation strengthen the support for the use of hot yoga as a novel form of short term heat acclimation training for enhancing cardiovascular and aerobic performance in national level female field hockey athletes.

The key findings of this investigation are that 1) hot yoga repeated over six days elicited a possible large reduction in PV% immediately post-intervention in the absence of additional exercise, 2) running speed (mph) at VT_1 and VT_2 was likely increased post-intervention, and 3) improved substrate utilization during high intensity running (i.e.RER) in a hypovolemic state.

We identified a very likely increase in core temperature throughout a 60-minute hot yoga session along with a peak increase occurring at the 30-minute mark. Peak change in core temperature was to be expected at the 30-minute period as each hot yoga class was structured to involve dynamic movement during the first 30 minutes followed by static stretching for the remaining 30-minute period. A possible reduction in metabolic heat in the later portion was probably reflected through the gradual reduction in core temperature that remained elevated yet trivially at 60 minutes. This investigation provides new evidence for changes in core temperature in athletes participating in hot yoga with the use of far infrared heating. Bikram Yoga has become a popular form of hot yoga involving environmental conditions of 40^{O}C and 60% RH. This practice of hot yoga was found to be more challenging than traditional hatha yoga due to the environmental conditions and its resulting influence on muscular and cardiovascular performance (463). Recently, far infrared sauna's (FIRS) have become a popular alternative to sauna heating when compared to mist or dry heat. Traditional sauna heating methods develop extreme ambient temperatures typically ranging from 70-100^{O}C in an effort change core temperature. FIRS has been demonstrated to be a more comfortable and relaxing environment for bathers as well as a heat source that may penetrate further in both adipose tissue and the neuromuscular system when compared to traditional saunas; furthermore FIRS has been shown to stimulate an exaggerated sweating response while at a reduced ambient temperature (29). This investigation demonstrated modest reductions in dry body weight (kg) from pre-to post-class and corresponds with previous studies examining far infrared heating and its ability to challenge the body's thermoregulatory system (237).

When examining the exercise intensity throughout a 60-minute hot yoga class, we observed a mean %maximum heart rate of 47%, indicating marginal demand on the cardiovascular system. This level of intensity when expressed through a % of maximum training load (%Max) was observed to be a nominal training stress. Our observations correspond with previous investigations examining the physiological demands of a 60-minute Bikram Yoga class (354), however we were able to demonstrate similar stress using a more comfortable ambient temperature using far infrared heating. Our results are encouraging for practitioners who wish to implement a form of short term heat acclimation training involving minimal training stress during a tapering period where training loads are typically suppressed leading to competition (315).

Preceding investigations have highlighted that oscillations in core temperature throughout a complete menstrual cycle can increase up to 0.3 to 0.5 C^{O} during the Luteal phase (95), with oral contraceptive use yielding similar fluctuations at rest and during exercise (181). Our results are consistent with previous investigations as we identified a marked increase in resting core temperature in participants recognized as in the Luteal phase when compared to the Follicular phase. Despite these observations, we detected no significant change in PV% between menstrual phases post-intervention. However, variations in PV% were observed when examining the within-group differences. Our results demonstrate participants in their Follicular phase had a very likely large reduction in PV% when compared to a possibly large yet unclear reduction in the Luteal group. Overall, the results of this investigation demonstrate how heat loss response and heat acclimation were largely unaffected by menstrual cycle stage or oral contraceptive usage. Additionally, we failed to replicate previous observations identifying larger increases in exercise core temperature with participants who were in the Luteal phase of their menstrual cycle (181). A possible explanation for this discrepancy could be the lack of a standardized intensity placed on each participant during each pose throughout a hot yoga class. A self-selected intensity would have allowed for the depth of pose and muscular contraction to be self-regulated by comfort level, potentially altering the metabolic heat production and its concomitant effect the core temperature and total thermal load. It should be emphasized that the primary objective of this investigation was not to examine the variations in physiological responses in females during a short term heat acclimation protocol, our interest was directed towards examining a novel form of short term heat acclimation when applied to a team sport of international caliber.

A secondary observation in this investigation highlighted a change in PV% of 2.3% (±5.2) 24 hours after the pre-intervention graded exercise test. The observed PV expansion from a single exercise session provides further support that short duration, high-intensity exercise, can stimulate secondary hypervolemia in trained female athletes as previously demonstrated in male athletes (386).

Contrary to our hypothesis we observed a gradual reduction in PV% throughout a six-day hot yoga intervention that gave rise to a state of hypovolemia during the post-intervention graded exercise test. The results from this investigation shed light on the potential development of a marked hypovolemic response during this form of short term heat acclimation when exercise intensity is minimal, and suggest the commonly developed PV expansion often observed during the immediate introduction of a heat stress to promote cardiovascular stability may be depended on thermal load (451, 489). Recent investigations involving HA protocols utilizing exercise in the heat (61, 151), passive heat exposure post-exercise (446) or a total passive HA protocol (84), have all demonstrated the immediate induction of hypervolemia within 4 days. Convertino et al., established the importance of exercise while undergoing a HA protocol for its concomitant effect on elevated plasma albumin content. When compared to passive heat exposure, exercising in the heat has been shown to elicit an increase in plasma albumin content that was recorded to be five times greater (84). A flux in plasma albumin content is thought to be partially responsible for the induction of hypervolemia as 1g of albumin has been shown to adhere to 14-15mL of water inducing a temporary expansion on total vascular fluid (424). This increase in plasma albumin from exercise during a HA protocol may be due to increased capillary filtration rates and the ensuing flushing of the interstitum, whereby albumin is returned to the intra-vasculature compartment via the lymphatic return (421).

We propose that the exercise intensity observed during this hot yoga intervention was inadequate to significantly increase the capillary pressure required to cause a flushing of the interstitium. Furthermore, we must acknowledge that the temporary PV expansion recorded 24 hours after the pre-intervention graded exercise test failed to remain elevated throughout the intervention. As such we additionally propose that the exercise intensity observed from repeated hot yoga sessions failed to preclude the transcapillary escape of plasma albumin. These findings may be explained by an imbalance in the convective and diffusive gradients between the plasma and interstital albumin content within the cutaneous and musculature compartment which has been demonstrated to be regulated through exercise (199).

To control for additional independent variables arising from day to day on-field training that may have influenced alterations in blood volume, we conducted our intervention during a rest and recovery week previously determined in the yearly training plan of the Canadian Women's National Field Hockey Team. The gradual reduction in PV% observed in this investigation followed a similar response to previous literature examining alterations in blood volume in responses to cessation of exercise in athletes. Cullinane et al., demonstrated a rapid and marked reduction in PV% recorded at 5% at 72 hours post-cessation of exercise, a reduction that remain stagnant for a further seven-day period. It is possible the results from this investigation suggest a mitigated response to PV% reduction during cessation of exercise when implanting a short term heat acclimation protocol involving minimal exercise stress.

A supplementary protocol in this investigation involved a permissive dehydration technique during all hot yoga sessions. This additive heat stress technique has previously been demonstrated to independently challenge thermoregulation and the fluid regulatory response such that the rate of acclimation and magnitude of PV expansion has been shown to be enhanced rather than diminished during a short term heat acclimation protocol (153). Our results contradict previous findings as an observed hypovolemic response was recorded in most participants possibly suggesting poor re-hydration or amino acid and electrolyte consumptions following each hot yoga class and throughout the remaining 24-hour recovery periods (340). As such, a major observation from this investigation was the inability of repeated hot yoga session to stimulate or maintain PV during a period where exercise training was absent.

The magnitude of change observed in PV% during the hot yoga intervention had a small and unclear relationship to the exercise intensity recorded when expressed as either a % of maximum training load or the total thermal load (i.e. TL+core temperature). This was inconsistent with our hypothesis that % of maximum training load would demonstrate a strong correlation to changes in PV%. Unanticipatedly our observations highlighted the impact that anthropometric characteristics may have on thermoregulation and its concomitant alterations in blood volume. A large negative relationship between change in PV% and high levels of body fat % or a large body surface ratio (A_D/M) was observed during the intervention. Previous inquiry has highlighted anthropometric characteristics to significantly influence evaporative heat loss during metabolic heat production or heat accumulation when challenging the thermoregulatory system (8, 204). Our results demonstrated a small relationship between participants with smaller

A_D/M resulting in larger core temperature change throughout each hot yoga session, consistent with previous findings. These observations suggest an alternative physiological response in smaller athletes for improving evaporative sweat loss in the absence of an enlarged surface area (203). The relationship between A_D/M and thermoregulation has suggested to be beneficial for individuals with a large A_D/M when working in compensable heat as their large surface area promotes greater evaporative heat loss capacity, however this relationship becomes inverse when working in a uncompensable heat stress (390). In accordance with current evidence stating HA training must invoke a marked increase in core temperature and of no more than $39.5^{O}C$ for health purposes (456), we propose that the far infrared heating utilized in this investigation failed to elicit a substantial heat stress in participants with larger A_D/M, unsuccessfully challenging their thermoregulatory capacity whereby possibly inhibiting a hypervolemic response.

4.5.1.2 Cardiovascular and Aerobic Performance Adaptations

The purpose of this investigation was to examine a novel form of short term heat acclimation training utilizing hot yoga to induce hypervolemia and augment cardiovascular and aerobic performance in a temperate environment. Prior research investigating short term heat acclimation training and its effects on team sport performanc e have demonstrated marked improvements in indirect aerobic performance measures (61, 452). Contrary to our hypothesis we failed to observe a marked improvement in VO_{2max} or RT_{ex}, however we did identify an small improvement in running speed (mph) at VT_1, a likely increase in speed seen at VT_2 and a possible improvement in substrate utilization (i.e. RER) at high intensities during the last completed stage of a graded exercise test.

Enhancement in cardiovascular performance from short term heat acclimation training has been suggested to be the result of a PV expansion typically observed within the first six days of repeated heat exposure (153). The onset of hypervolemia has been demonstrated to augment cardiac output as a consequence of the Frank Starling effect through an increase in stroke volume (260). This investigation deliberately utilized a short term heat acclimation protocol to expand on previous research displaying enhanced cardiovascular and aerobic function in hot environments to further investigate the potential for improved performance in a temperate environment. Contrary to our hypothesis, we observed a hypovolemic response during the intervention and post-performance assessment suggesting a possible negated effect on stroke volume during the post-intervention graded exercise test.

It is well recognized that current examining the thermoregulatory response during exercise when comparing sexes have suggested females present an altered sudomotor sensitivity response (144, 146), possibly explaining the discrepancy between sweat rate and evaporative heat loss capacity above certain exercise intensities (145). Recent evidence has demonstrated an identical onset threshold between sexes for cutaneous dilation and sweat rate suggesting that the female sweat glands capacity to produce sweat at higher exercise intensities may be the difference between sexes during maximal exercise (145). It was further suggested that thermoregulatory adaptations during HA in females may be in large due to alterations in sudomotor response, largely in principle to peripheral afferent feedback (145). Previous investigations have demonstrated females to possess a lower thermosensitivity when compared to males resulting in a diminished sudomotor response to heat stress (146). However, limited evidence suggests possible peripheral modulations in the size of sweat gland (403), the concentration of cholinergic neurotransmitters discharged in the sudomotor junction (427) or the upregulation of cholinergic receptors may be early adaptions in females when experiencing repeated heat exposures (427).

We propose that our observed trivial to small improvements in VO_{2max} and RT_{ex} in the existence of a hypovolemic state parallels recent discoveries demonstrating enhanced sudomotor response and a concomitant improvement in substrate utilization (i.e. RER) in females during a short term heat acclimation protocol while in absence of a PV expansion, and that the early development of hypervolemia when starting a short term heat acclimation protocol in men may be a delayed secondary response requiring longer HA periods in females (302).

The observations in this investigation support previous research (406) demonstrating a possible improvement in substrate utilization as expressed through a small reduction in RER during the last completed stage of the post-intervention graded exercise test. Recent literature has supported this discovery when implementing short term heat acclimation protocols that fail to induce hypervolemia that still lead to improvements in cycling efficiency in temperate conditions (323). A reduction for a given exercise intensity when examining RER, blood lactate accumulation or glycogen depletion in type I muscle fibres have been reported in earlier short term heat acclimation investigations (47, 122, 359, 452). It has been proposed that alterations in muscle metabolism may be due to changes in motor recruitment patterns through modified proprioceptive afferent neural activity (180). Sawka expanded on this idea suggesting repeated exposure to heat stress may improve proprioceptive afferent activity causing a larger recruitment of type 1 motor units (406).

Lastly we found it prudent to isolate the performance response of a reduced sample ($n=7$) as two participants were potentially negatively and unenviably effected during the post-intervention graded exercise test. During the pre-intervention graded exercise test one participant tripped and fell on the treadmill upon completion of the test which possibly established an altered motivation to challenge herself, a negative psychological effect during her post-graded exercise test, while a second participant terminated her post-intervention graded exercise test due to muscle soreness in her abdominals and shoulders, a consequence of a specific hot yoga pose. Contrary to the decrease in both participant's VO_{2max} and RT_{ex}, improvements in their running speed (mph) at $VT_1$and VT_2 along with a reduction in RER during their last completed stage were observed. As such, we propose that the improvements in substrate utilization (i.e. RER) in the absence of muscle soreness and possibly an affected psychological drive may have masked a potential improvement in RT_{ex} and VO_{2max} in both participants. When examining the mean response ($n=7$) upon the removal of unforeseen circumstances, we found a likely beneficial improvement in VO_{2max} and a possible improved RT_{ex}. In accordance with previous literature examining the effects of detraining on physiological and performance measures, we observed similar alterations in PV% and VO_{2max} (316). Therefore we propose the following, 1) the observed performance alterations in the altered sample size ($n=7$) while in the state of hypovolemia, may have been induced through an enhanced sudomotor response potentially improving evaporative cooling capabilities and subsequent thermal strain, a result that may have enhanced physiological comfort (323), and 2) the observed improvement in substrate utilization (i.e. RER) may have been elicited through greater recruitment of type I motor units due to altered proprioceptive afferent feedback and diminished psychological strain, a consequence of improved thermosensitivity from an altered sudomotor response (180).

4.5.2 Post Acclimation: Rate of Decay in Hypervolemia

This component of the investigation was designed to examine the rate of decay in the expected development of hypervolemia from a six day short term heat acclimation protocol involving hot yoga. Contrary to our hypothesis we observed the development of hypervolemia during the post-intervention period after the removal of a heat stress.

A likely moderate expansion in PV% at 72 hours post-intervention demonstrated a moderate yet unclear relationship to accumulated % of maximum training load. The TL experienced was developed from the post-intervention graded exercise test at 24 hours post-and the end of year Canadian Women's National Field Hockey Team fitness assessment, involving the YoYo Level#1 test completed at 48 hours post-intervention. The substantial rebound observed in PV% at 72 hours is further accentuated when calculating the change using the post-intervention blood volume%. This hypervolemic response was induced through high-intensity; low volume exercise accumulated over a 48-hour period of exercise testing.

The hypervolemic response demonstrated in this investigation at 72 hours post-intervention was twofold compared to the acute PV% expansion observed after the pre-intervention graded exercise test. This observation is supported by the established TL value over the 72 hour post-intervention period which was twice as large as the pre-intervention graded exercise test TL. Previous investigations have demonstrated the effects of a high-intensity exercise regime and its ability to rapidly stimulate secondary hypervolemia within three days in trained participants (83). In contrast to the development of secondary hypervolemia with exercise, detraining has demonstrating an inverse relationship with blood volume% that elicits large increases in plasma aldosterone and plasma renin levels in response to the absence of exercise (429). In consonance with earlier literature focusing on the renin angiotensin systems response to detraining, recent evidence for short term heat acclimation training to upregulate resting plasma aldosterone levels have been observed over a five day period (151). A possible explanation for the likely increase in PV% in this investigation observed at both 72 and 96 hours post intervention, after the development of hypovolemia, may have been in part to a large surge in resting plasma aldosterone and renin levels (331), accompanied with the introduction of an independent stimulus such as exercise. The possible additive effects of these independent variables regulating blood volume may have been responsible for the significant rebound in PV% during the post-intervention and competition period even when competing in a cool environment.

We observed a likely moderate level of hypervolemia at 96 hours that subsided to a possibly trivial increase at 144 hours after removal from of a repeated heat stress. The PV expansion at 144 hours resided within the smallest worthwhile change, however the range of individual responses at this time point suggest other possible independent variables may have accounted for the variance observed. A similar inverse relationship between body fat % and PV% was observed during the post-intervention period during on-field competition. This observation possibly highlights the enhanced capability for evaporative heat loss due to the increase in surface area as expressed through the A_D/M. Previous investigations have suggested that when exercising in a hot environment an increase in core temperature is largely due to the development of heat stress which stimulates physiological mechanisms for the purpose of evaporative heat loss, while exercising in the cold typically elicits a rise in core temperature where heat loss can occur with diminished magnitudes of physiological stress (399). Although the physiological response when possessing a larger A_D/M is conducive for on-field performance in a cold and temperate environment, this anthropometric characteristic may have mitigated increases in core temperature required to challenge thermoregulation for the maintenance of such hematological adaptations. The results observed from this investigation are in contrast with Saat et al., who previously demonstrated exercising athletes in a cold environment after a HA protocol can enhance the rate of decay in PV%. A possible discrepancy in the observations observed between this investigation and Saat et al., was the already developed state of hypervolemia during the post-intervention period in the earlier investigation. As such, the physiological response of the renin angiotensin aldosterone system and its concomitant effect on water conservation upon commencing exercise in a cool environment may have led to distinct outcomes.

4.6 Limitations

This investigation examined a novel form of short term heat acclimation involving hot yoga during a complete rest period in the yearly training plan of the Canadian Women's National Field Hockey Team. Additionally, this inquiry occurred during the coldest period of the 2015 calendar year. As such, we must acknowledge previous evidence suggesting seasonal effects towards HA and the degree of adaptation in blood volume observed (426). Further research should examine the physiological response to hot yoga as form of short term heat acclimation during warmer months of the calendar year to expand on the possible hematological responses.

We chose to limit the number of independent stimuli on blood volume expansion during the intervention period; as such our investigation occurred during a period of complete rest within the Women's National Team training schedule. Previous evidence supports exercise as an independent stimulus for PV expansion even within trained athletes (83, 386). Therefore, we must acknowledge the need for further research examining the introduction of hot yoga during concurrent daily on-field training to better interpret the influence of this form of heat stress on blood volume. It was the intention of this investigation to examine stroke volume and cardiac output during each graded exercise test to assess the influence and strength of effect on alterations in PV towards cardiovascular performance. Although the open circuit acetylene washin method technique was administered during each graded exercise test, computer software malfunctioning prevented any confidence in the values collected. Therefore, we are unable to assess the cardiovascular performance alterations in response to a marked reduction in PV%.

The physical stress of each yoga session was solely displayed through cardiovascular stress as represented through HR% and a TL value. This design was to provide practical insight for coaches and sport practitioners who use predetermined TL values and HR% when monitoring their athletes. Recent evidence demonstrating the prevalence of delayed on set muscle soreness when implementing yoga has offered a position stance on when and how to implement this form of exercise into a training regime for athletes, especially if the athletes are unaccustomed to this mode of exercise (43). The potential muscle breakdown accumulated over six consecutive sessions prior to completing the post-intervention graded exercise test was not accounted for and may have influenced our performance measures.

Additionally the sample size when examining the effect of menstrual cycle stage on core temperature and PV% alterations was low (i.e. $n=4$ Luteal ; $n=5$ Follicular). Although this area was not the focus of our investigation, and our results comparing resting core temperature between phases supports previous evidence (181), we must acknowledge this limitation when making inferences towards the physiological responses during phase of the menstrual cycle when experiencing heat stress.

Throughout the post-intervention period we did not examine hormonal fluctuations which may have identified alterations in the renin angiotensin aldosterone system as previously demonstrated to accompany exercise (429) and short term heat acclimation training (151). Therefore, the proposed explanation stating a possibly elevated presence of aldosterone and renin during the on-field competition period lacks conclusive support.

4.7 Conclusions

We identified a novel form of short term heat acclimation training involving hot yoga that when accompanied with permissive dehydration demonstrated trivial improvements in VO_{2max} and RT_{ex}, a trivial increase in maximum heart rate, marked improvements in running speed (mph) at VT_1 and VT_2 and a small improvement in RER during high intensity exercise while in a hypovolemic state. The observed improvement in running speed at VT_2 in this investigation may suggest an advantage in international level female field hockey athletes as this running intensity is the average playing intensity during competition for the Canadian Women's National Team.

We also demonstrated a possible small improvement in VO_{2max} and RT_{ex} that may transpire when accounting for unexpected delayed onset muscle soreness and an accidental fall during a graded exercise test. The observations provided from this investigation suggest possible differences in the female athlete's response to a short-term heat acclimation protocol and further supports recent evidence for improved sudomotor responses during exercise and enhanced thermosensitivity that may augment aerobic performance.

The results of this investigation suggest that a short-term heat acclimation protocol utilizing hot yoga, accompanied with permissive dehydration, and when performed in the absence of supplemental exercise fails to induce hypervolemia after six sessions. Furthermore, we found a non-existent relationship between TL experienced during hot yoga and alterations in PV%. In contrast to our hypothesis, we failed to observe a significant relationship between the accumulated % of maximum training load over 144 hours and alterations in PV% after cessation of hot yoga. In particular, these results highlight a possible ergogenic protocol involving the induction of purposeful hypovolemia through a short-term heat acclimation protocol to stimulate a delayed super compensatory effect in PV% when recommencing exercise which may augment a delayed improvement in cardiovascular and aerobic performance.

Our results support the combination of implementing high-intensity exercise during a hypovolemic state to elicit a significant rebound in PV% that was accompanied with a small training load after the cessation of repeated heat stress. Further research is warranted to examine the typical response in PV% when re-introducing exercise in a hot environment.

Chapter 5: Innovative Approaches to Monitoring Internal Training Load in Team Sport Athletes

5.1 Introduction

Measuring the internal exercise stress imposed on an athlete involves quantifying both the magnitude and duration to which the training stress was applied for (235), and as such can be regarded as the athlete's physiological response to experiencing a training load (TL) (417). Establishing the appropriate balance between the application of a TL and its subsequent recovery period has shown to be imperative for the development and demonstration of optimal sport performance (23, 435). This approach to modelling TL throughout a mesocycle is viewed as the dose (TL), response (adaptations) relationship (39). Developing an understanding of an athlete's response to a TL and how best to provide optimal recovery periods allow sport practitioners to build undulating training blocks in the effort to enhance peak performance when exiting one mesocycle and entering a competition phase. However, minimal exploration examining the congruency between the planned and achieved on-field TL in team sport and its influence on the cardiovascular and autonomic nervous systems is available.

To date, various forms of TL's are available for monitoring team sport. Global positioning systems which measures total distance covered, accelerations/decelerations and time spent in speed zones have become popular methods to assess work completed during on-field training or competition (139, 455). A possible limitation in the validity of assessing this form of a TL lies with each variable often being measured independently to the athlete's physiological characteristics (473). Although coaches often utilize external TL's for planning on-field sessions, current consensus states the stimulus required for performance adaptations are elicited from the relative physiological stresses experienced (i.e. internal TL), thus monitoring the acute or chronic fatigue through internal TL's may be considered a more valid and appropriate method for understanding the injury risk and development of NFOR (304).

Recent reviews focusing on the utilization of HRV for examining the cause and effect relationship to accumulated training load have highlighted the necessity for examining R-R intervals in combination with parasympathetic modulation (50, 370). Further examination into the HRV response in endurance athletes have suggested a prevailing misunderstanding into the belief that a linear relationship exists between vagal related HRV indices and its parasympathetic impact on heart rate (370). Contrary to this collective perception, previous literature has demonstrated this relationship to be quadratic in nature (164, 165). For this reason, it may be imperative for sport practitioners to examine the ratio of Ln rMSSD:R-R(ms) to fully understand the implications of experiencing large training loads, its resulting fatigue, and what is the optimal state of readiness in the autonomic nervous system prior to competition.

As such the purpose of this investigation was to: 1) examine an individually periodized mesocycle and the congruency between the planned and achieved on-field TL in a team sport environment, and 2) to examine the relationship between two markers of exercise stress (i.e Training Load & Time (min) $> LT_2$) and alterations in the Ln rMSSD:RR ratio. In conducting this investigation we hypothesized the following, 1) on-field communication of real time accumulated TL between the sport practitioner and coaching staff would promote a strong relationship between the planned and achieved TL, and 2) a comprehensive marker of exercise stress when expressed as a training load value would demonstrate a stronger relationship with alterations in the Ln rMSSD : R-R ratio than time spent above LT_2.

5.2 Methods

A total of 24 athletes from the Canadian Women's National Field Hockey Team were available to act as participants for examining training load. Our sample size was restricted to athletes who were residing in Vancouver, who were not limited by U-Sport, NCAA or professional playing contracts overseas during the time of the study. A letter of support from Field Hockey Canada's Assistant Coach can be found in the Appendix (Field Hockey Canada Letter of Support #2). Every athlete belonging to the Canadian Women's National Field Hockey program was assigned a POLAR Team^2 heart rate monitor (Polar, Electro, Oy, Kempele, Finland) programed to record at one second intervals for both on and off field monitoring purposes. All heart rate monitors were designated to correspond to the athlete's jersey number to reduce potential confusion and misinterpretation of data. Each heart rate monitor provided a live recording of heart rate and TL (AU's) during on-field training sessions via Bluetooth to the sport practitioner's laptop. The Polar Team^2 system provides TL values that are derived from an intermittent sport algorithm based of each individual's unique changes in energy metabolism as exercise intensity shifts above or below aerobic and anaerobic threshold and the time held in specific sport zone (327). The Polar Team^2 TL value has previously demonstrated to possess a strong relationship with the five heart rate sport zones calculation method commonly used (111) along with subjective measures such as exercise session ratings of perceived exertion (131) when examined in team sport (78).

All transmitters were collected after each training session in an effort to export and secure TL data to a laptop computer for further analysis. A five-week mesocycle leading to an FIH World League#3 Olympic Qualifying tournament was designed with TL values (% Max) in the order of 60%, 80%, ≥100%, 80% and 30% unique to each athlete's own maximum TL as seen in

Appendix (Olympic Preparation Mesocycle). TL's (% Max) were based on the most recent maximum TL value accumulated over a single week of on-field training during the 2015 yearly training plan.

All on-field training sessions were two hours in length and were conducted every Monday, Wednesday, and Friday morning from 10am to 12pm at the University of British Columbia's Wright Field. Every on-field training session throughout the week was predesignated with a specific TL value that modelled to the weekly loading structure as seen in Appendix (Olympic Preparation Microcycle) and the loading structure for the mesocycle (Appendix – Olympic Preparation Mesocycle). An excel spread sheet with individually predetermined daily TL values was used to monitor on-field training sessions throughout the mesocycle in the effort to facilitate communication between the sport practitioner and the head coach and to improve the congruency between the actual and planned training load. Communication was upheld between coaches and the sport practitioner throughout each training session to inform the coaching staff when the team as an average reached 50% of their TL limit. Any alterations to the planned TL values for each session was made by the head coach after being informed of the achieved TL from the sport practitioner periodically and was determined based on the technical, tactical and physiological objectives of the designed session.

It was expected that athlete adherence would be the limiting factor for data collection and the analysis of HRV (52, 369). As such, if one of the two R-R sampling periods over a weekend was not collected that participant was not included in the weekly dataset. Only participants who captured the required HRV recordings for a minimum of three weeks were included in the examination of NFOR. Participants who did not complete a training session or if a TL value was not captured for a single session throughout the training week were excluded from analysis when examining both team and individual results for that given training week.

Ten minutes of R-R reordering were collected immediately upon awakening in the supine position throughout each weekend (i.e. Saturday & Sunday) during the mesocycle. Participants were instructed to lie perfectly still and breathe at a normal rate without any audio instruction or guidance. The importance of standardizing this routine for data collection was stressed prior to and repeatedly during the mesocycle. All R-R collections were recorded using the POLAR Team^2 System. Each POLAR Team^2 heart rate monitor utilizes a 1000Hz sampling frequency when collecting R-R intervals and can record up to 48 hours of data. Weekend R-R collections were exported from every heart rate monitor to the sport practitioner's computer every Monday for the analysis of HRV using a Kubios HRV 2.2 computer software program. A 10-minute R-R recording period was selected in an effort to improve the opportunity to manually select a five-minute period free of artifact or noise that would allow for the analysis of rMSSD.

A time domain analysis as represented through rMSSD was preferred for its ability to represent vagal modulation (470) and provide enhanced reliability when compared to other power spectral density indices (7). Both breathing rate and depth were left uncontrolled for and participants were instructed to relax and breathe at a natural rate. The statistical properties that rMSSD possess have demonstrated strong resilience against the effects of respiratory sinus arrhythmia during R-R internal recording when not controlling for breathing rate and depth (358).

Each rMSSD value was log transformed (Ln rMSSD) using the natural log rhythm to help reduce any bias through possible non-uniformity in error. A medium level of artifact correction that was already pre-programmed into Kubios HRV 2.2 was applied to every five-minute R-R recording sample. This level of artifact correction interpolates any artifact in R-R intervals that differ by more the 0.25 seconds when compared to the mean R-R intervals sampled. A medium level of correction was selected to preserve the R-R variability without compromising the validity and reliability of each sample. A spline interpolation method involving cubic interpolation was used for removal of ectopic beats or artifact. This filtering method utilizes a third degree polynomial to smooth out any ectopic beats or artifacts and is recommended when examining time domain HRV indices such as rMSSD (357). It is acknowledged that errors may still exist after utilizing an automatic artifact correction method however, when standardizing a correction method for repeated measures in athletes this difference has been deemed non-significant (50).

5.3 Statistical Analysis

All data in text, figures and tables are represented as a mean with a confidence interval (CI) of 90% unless otherwise stated. A CI of 90% was chosen as it has been suggested to be an appropriate default level as the probability of the true value residing below or above these limits are 5% each and interpret as unlikely (219). All data collected was analyzed employing a practical significance standpoint using magnitude based inferences. Current literature focusing on athletic performance have demonstrated traditional statistical approaches commonly fail to identify the size and importance of an effect and its implication to physical performance (217). Furthermore, a qualitative approach becomes increasingly important when working with reduced sample sizes commonly employed in high performance research (215, 365). For this reason a qualitative approach was chosen focusing on the magnitude of effect size (ES) (80), using a customized excel spreadsheet (216). The following ES threshold values were followed: <0.2 trivial, >0.2 small, >0.6 moderate, >1.2 large, > 2.0 very large, and > 4.0 extremely large (215).

A spreadsheet was used to calculate probabilities to identify if the true unknown difference was higher, trivial or lower than the smallest worthwhile change as calculated using an excel spreadsheet for practical significance and insight (28, 216). The qualitative likelihood of a change being either higher or lower, or harmful or beneficial were as follows; 1% almost certainly not, 1-5% very unlikely, 5-25% unlikely, 25-75% possible, 75-95% likely, 95-99% very likely, >99% almost certainly. A Pearson Product Moment Correlation (*r*) analysis was used to examine, 1) the relationship between the planned and achieved on field training load (AU), 2) the relationship between TL and Ln rMSSD : R-R and time spent >LT_2 (min) and Ln rMSSD : R-R. The magnitude of the correlation between each measurement used the following scale of strength of effect; <0.1 trivial, 0.1-0.3 small, 0.3-0.5, 0.5-0.7 large, 0.7-0.9 very large and 0.9-1.0 almost perfect (215). Fishers Z statistic transformation was used for developing CI 90% for all regression analysis (125). Throughout the complete analysis, if the CI 90% overlapped both a negative (harmful) and positive (beneficial) range the ES was declared unclear, otherwise the ES was declared the detected value (215).

5.4 Results

A total of 24 athletes in the Canadian Women's National Field Hockey Program trained in Vancouver during a five-week mesocycle and were able to act as participants when examining the congruency between the planned and achieved on field training load. This investigation was conducted during the Olympic preparation period held in April and May of 2015. Participant characteristics are found in Table 5.1.

5.4.1 The Examination of the Planned vs. Achieved On-field Training Load

When examining the planned vs. achieved on-field training load (AU) we observed an extremely large and significant relationship [$r = 0.92$ CI 90% (0.84;0.96), $p < 0.01$] as demonstrated in Figure 5.2. This investigation revealed minimal deviation from the planned load as demonstrated by an effect size remaining small or trivial throughout the five week mesocycle as displayed in Figure 5.1. Largest deviations in the actual TL's were observed when the target load was set at 80% as presented during week#2 [-5.4% CI 90% (-10.1; -0.7), ES = - 0.41 CI 90% (-0.7;-0.1), % chance 0/15/85], and week#4 [7.1% CI 90% (2.1;12.2), ES = 0.46 CI 90% (0.1;0.8), % chance 91/9/0]. We identified a favorable percent chance for the true ES to be trivial in the remaining weeks indicating a strong congruency between the planned and achieved on-field training load with the largest planned training load (i.e. ≥100% Max) demonstrating the smallest deviation as seen in Table 5.2.

5.4.2 The Relationship Between Markers of Internal Training Load and the Ln rMSSD : R-R Response

A total of 12 out of 20 athletes captured a complete data set involving on field training load and HRV to be involved in this investigation. This investigation demonstrated a moderate relationship [r = 0.33 CI 90% (-0.1;0.5), $p < 0.05$] between TL (AU) and the Ln rMSSD : R-R ratio (Figure 5.3). When examining the time spent above anaerobic threshold (> LT_2) we identified a slightly stronger moderate relationship [r = 0.48 CI 90% (0.2;0.7), $p < 0.01$] as represented in Figure 5.4.

Table 5-1 Participant Characteristics

(*n=24*)			Indirect Aerobic Power	
Age (yrs)	Height (cm)	Weight (kg)	YoYo Level#1 (m)	Est. VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)
22.6 ±3.0	169.7 ±3.5	61.3 ±5.7	2020 ±325	53.5 ±7.9

Values are represented as mean ± SD.

Table 5-2 A comparison of the planned to actual on-field training load achieved during a five week mesocycle

(n=24)	Planned Training Load (AU)	Actual Training Load (AU)	% Difference (CI 90%)	Effect Size (CI 90%)	ES Rating	% Chance the True Value is Positive / Trivial / Negative
Week #1	446.1 ±74.9	455 ± 97.2	2.0 (-5.6;9.6)	0.10 (-0.2;0.4)	Trivial	30 / 65 /5
Week #2	606.3 ±84.2	573.2 ±75.4	-5.4 (-10.1;-0.7)	-0.41 (-0.7;-0.1)	Small	0 / 15 / 85
Week #3	732.9 ±137.7	721.6 ±125.2	-1.5 (-8.2;5.2)	-0.09 (-0.4;0.2)	Trivial	5 / 68 / 27
Week #4	596.0 ± 96.8	638.5 ±86.2	7.1 (2.1;12.2)	0.46 (0.1;0.8)	Small	91 / 9 / 0
Week #5	223.4 ±37.6	231.3 ±48.3	3.5 (-4.4;11.5)	0.18 (-0.2;0.5)	Trivial	8 / 40 / 52

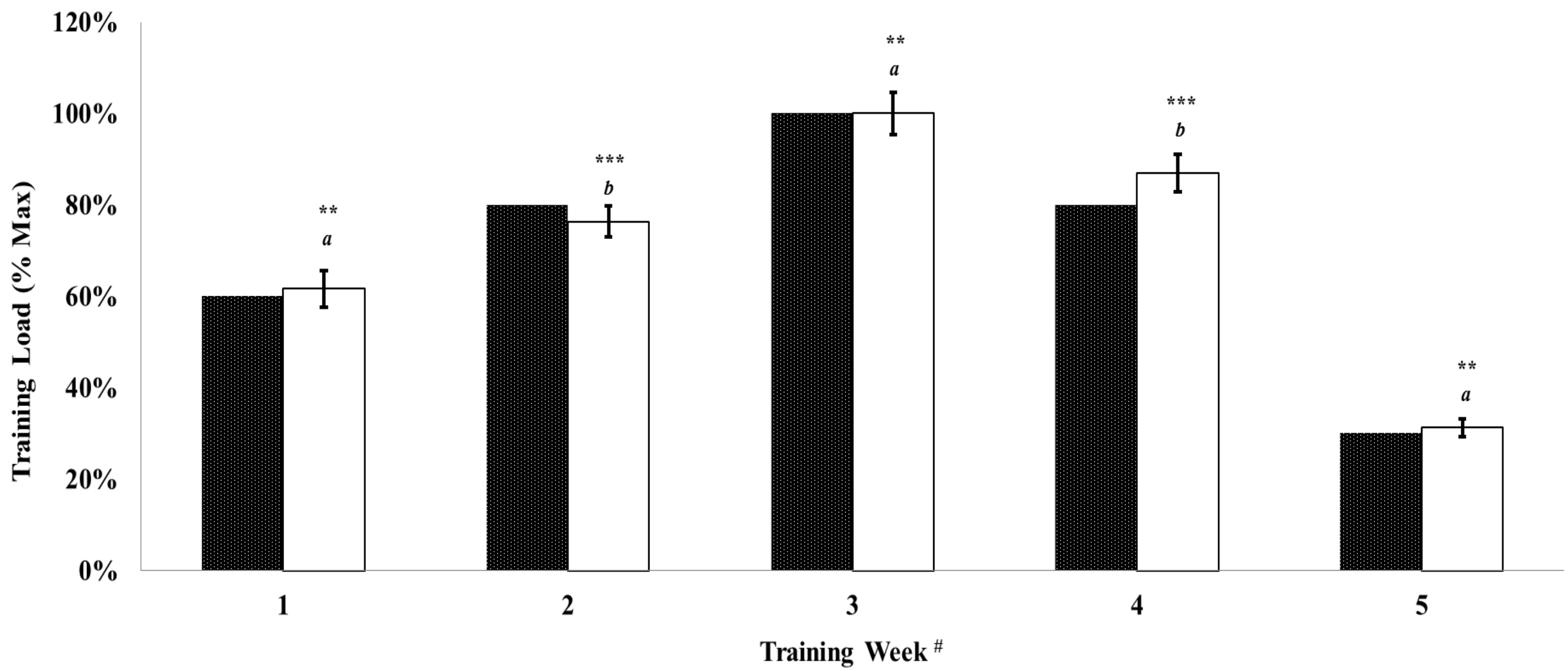


Figure 5-1 The comparison between achieved training load (%Max) to the planned training load
Values shown are means with error bars representing (CI 90%) for identifying uncertainty in the true mean difference. Dark bars represent the planned training load with open bars representing achieved training load. Effect Size: *a* trivial, *b* small, *c* moderate, *d* large, e very large. Likelihood of effect: * trivial, ** possibly, *** likely, **** very likely. (n=24)

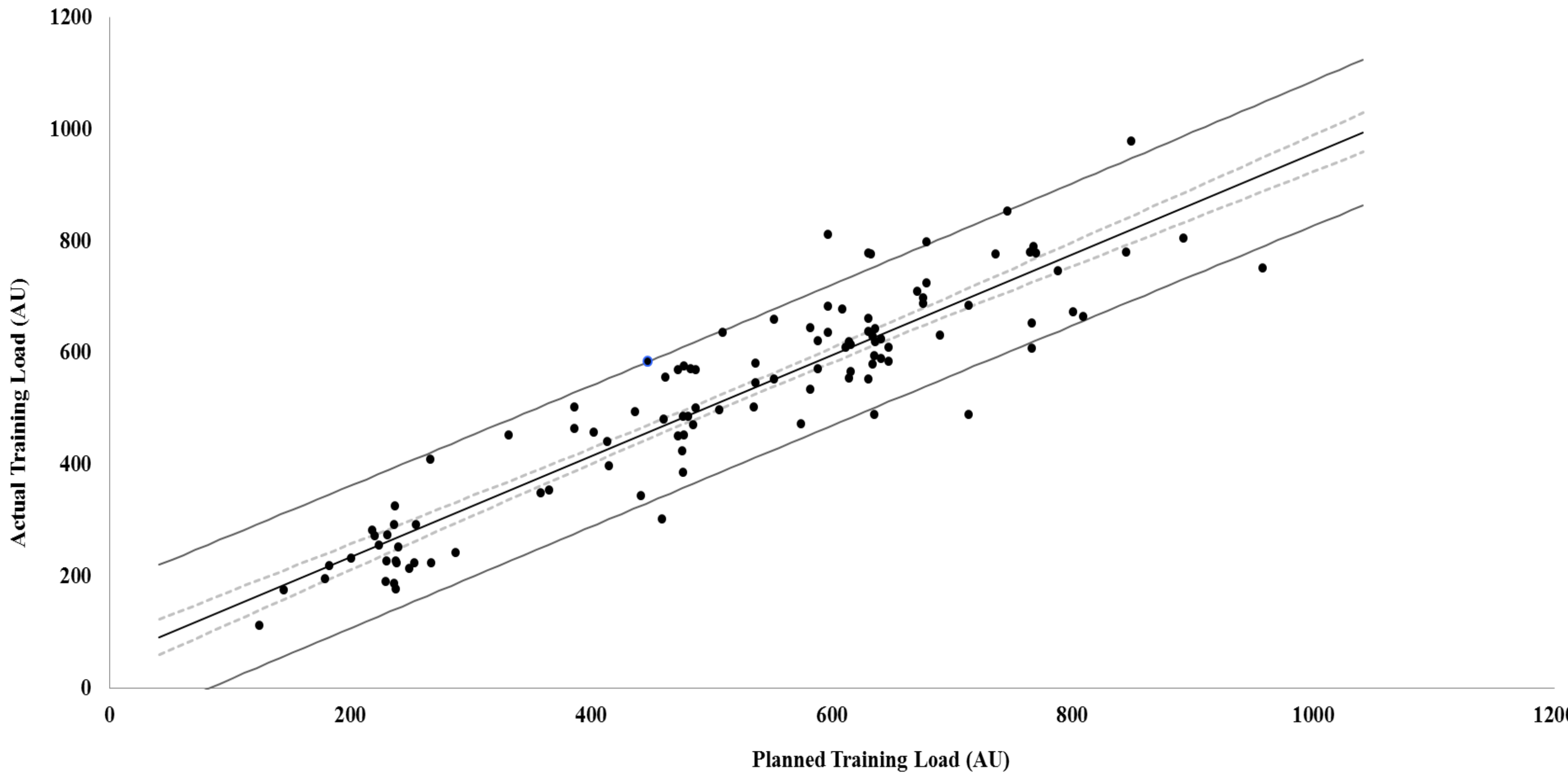


Figure 5-2 Relationship between the planned training load (AU) and the actual training load (AU) during a five week mesocycle

Pearson Product Moment Correlation (CI 90%), $r = 0.92$ (0.84;0.96), $p < 0.01$. (n=24)

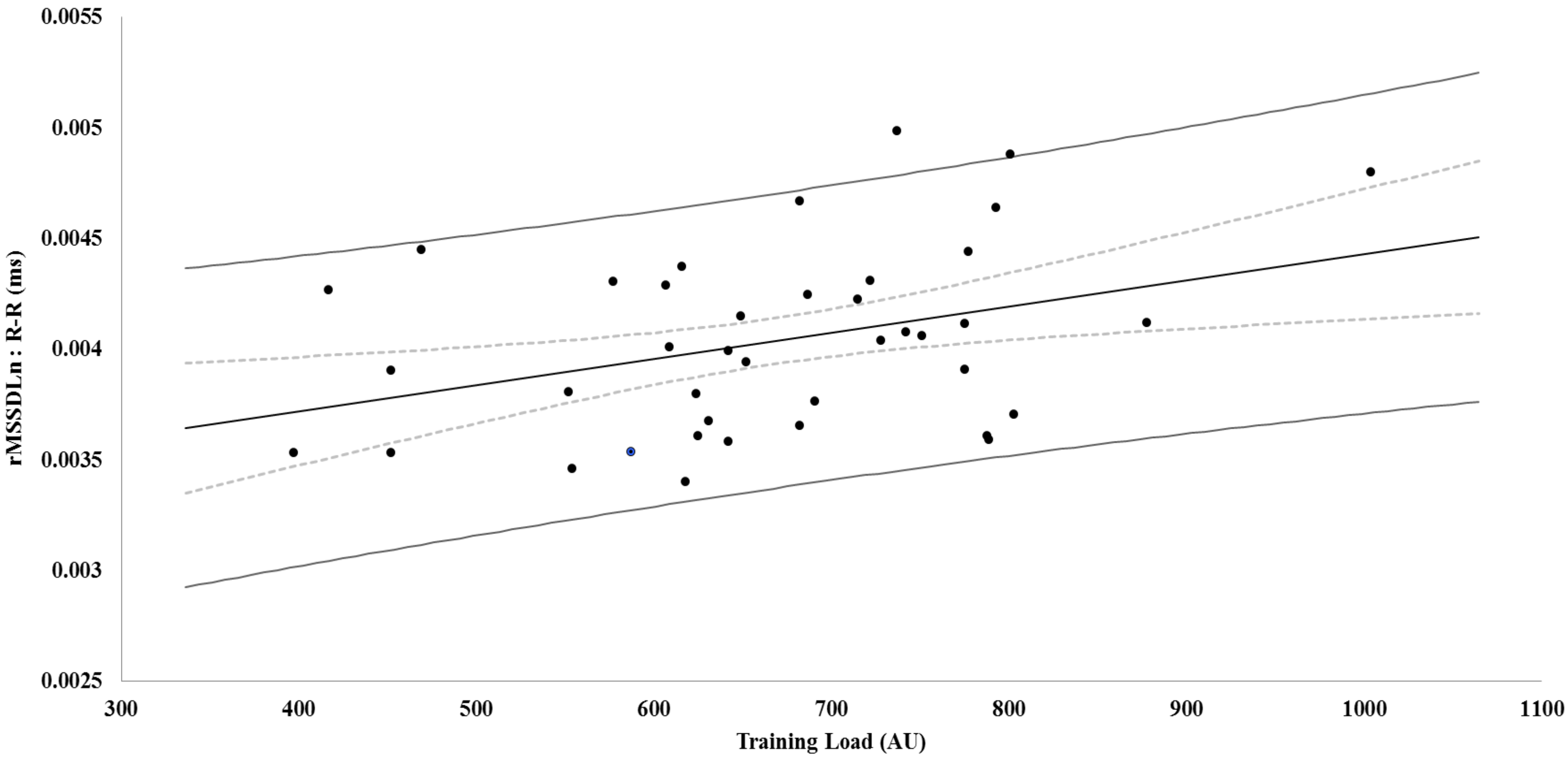


Figure 5-3 Relationship between training load (AU) and the Ln rMSSD : R-R ratio during a four week mesocycle
Pearson Product Moment Correlation (CI 90%), $r = 0.33$ (-0.1;0.5), $p < 0.05$ (n=12)

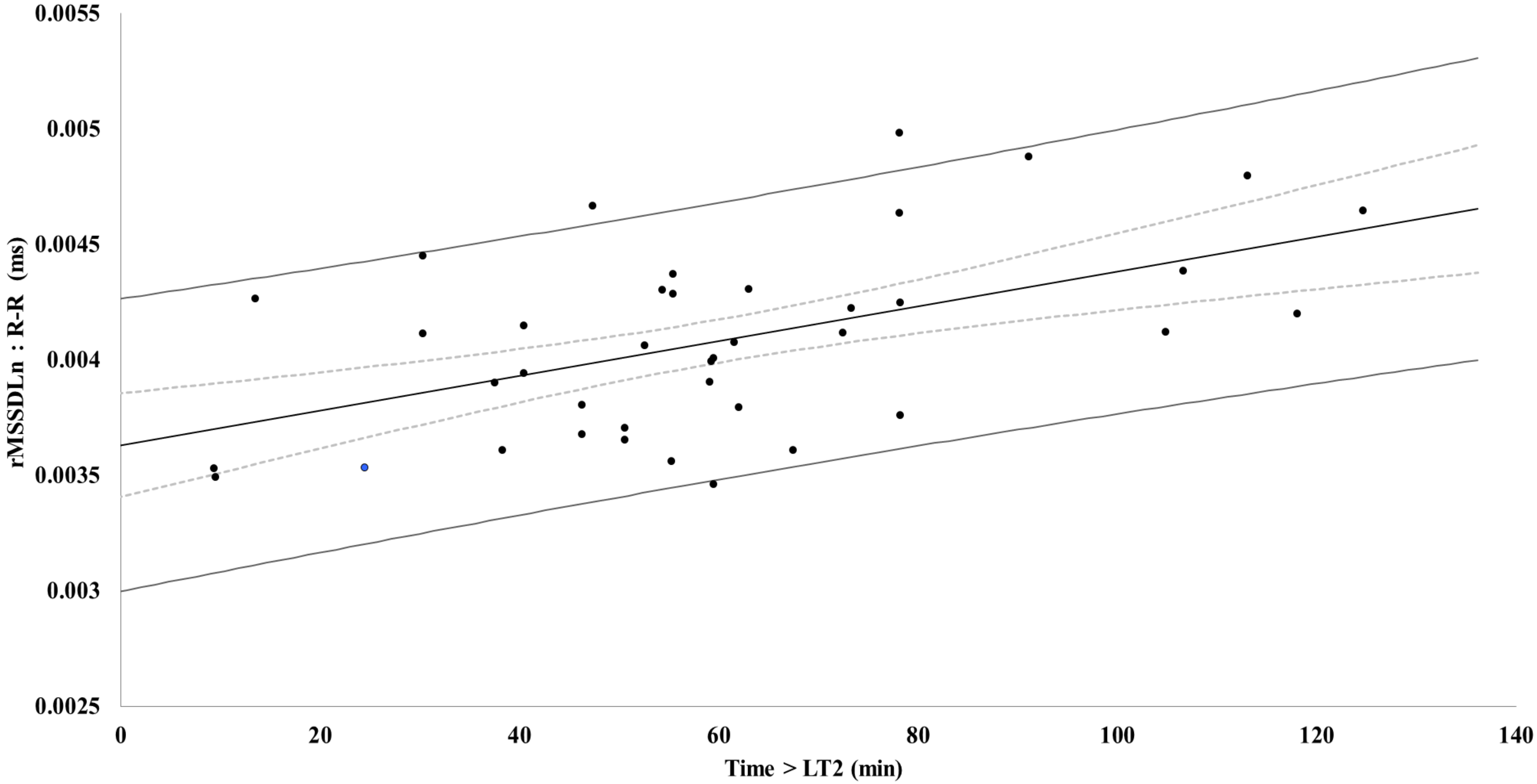


Figure 5-4 Relationship between time spent above LT_2 (min) and Ln rMSSD : R-R ratio during a four week mesocycle
Pearson Product Moment Correlation (CI 90%), $r = 0.48$ (0.2;0.7), $p < 0.01$ (n=12)

5.5 Discussion

5.5.1 Congruency between the Planned & Achieved On-Field Training Load

Increasing amounts of evidence supporting the management of TL and its resulting effect on injury occurrence (81, 228, 392) and athletic performance (142) has recently emerged when examining team sport. It is commonly believed that athlete monitoring in a team sport environment delivers increased challenges due to its multifaceted approach and the sheer volume of athletes. Previous literature focusing on endurance athletes have demonstrated a natural tendency for coaches to underestimate the achieved TL compared to the planned TL, a consequence that often leads to larger TL values experienced (473). Furthermore when comparing the coach's perception of the TL delivered for a single session, an underestimation in the amount of stress experienced by the athlete was revealed (473).

A major focus of this investigation was to examine the effectiveness of developing normative TL data specific to a national sporting organization for the proactive approach of modelling future individualized mesocycles consisting of a standardized exercise stress for each athlete. This investigation sheds new light on the capability to achieve a large relationship (Figure 5.2) between the planned and the experienced on-field TL in national level team sport athletes. Our observations demonstrated a strong congruency between the planned and achieved on-field load TL as indicated by a trivial or small difference throughout the complete mesocycle. Undeniably the real-time communication between the sport practitioner and coaching staff at 50% and 80% of the allocation training time throughout each training session largely contributed to the congruency observed. Although the purpose of each on-field session involved multiple training objectives, it can be hypothesized that the feedback the coaching staff received provided a quick assessment of the direction of training in relation to its planned structure and the desired focus areas. This opportunity for coaches to reflect on the achieved exercise stress at certain periods throughout a training session may provide the necessary reinforcement to continue with the session's direction; or change course in light of the technical, tactical and desired physical conditioning objectives prematurely achieved.

Recent reviews (106) have suggested the assessment of an internal TL become the principal variable examined when monitoring athletes due to its enhanced sensitive to injury prediction when compared to external training loads (227). Current literature examining internal TL's have revealed an acute to chronic work load paradigm, demonstrating how the weekly tracking of TL in relation to the previous mesocycle's total TL may help predict (i.e. positive prediction = 62.3%) non-contact soft tissue injuries in team sport (140). Furthermore, strong evidence supporting the use of controlled, acute (i.e. weekly) increases in weekly TL (%Max) have indicated reductions in injury susceptibility when TL's remain at 10% fluctuations from week to week (141). When modelling the loading structure throughout a mesocycle the comparison of the achieved to the planned TL must be examined in effort to adapt future training sessions to remain within the desired loading parameters. Previous investigations have highlighted athletes who experience greater TL's compared to the planned load demonstrated a 68% increase in non-contact soft tissue injuries when averaged throughout the entire playing season (140). Our results support the use of an athlete monitoring system that provides an internal TL (i.e. heart rate) value in real time, allowing for rapid decision making amongst integrative support staff and coaches in the effort to prevent excessive TL's that may elicit exacerbated levels of fatigue or decrements in sport performance.

5.5.2 Markers of Internal Training Load and their Relationship with Parasympathetic Modulation

Previous literature investigating HRV response to a TL over a periodized mesocycle have demonstrated a cause and effect relationship whereby an HRV response is dependent upon on the magnitude of training stress experienced (52, 360, 361). When examining autonomic modulation over consecutive training blocks, previous evidence suggests moderate TL's augment parasympathetic activity while larger TL's act to suppress this activity (360, 361). However, recent reviews have highlighted that the majority of investigations have focused on endurance athletes and their HRV response to heart rate derived or blood lactate intensity zones (50). Minimal research focusing on team sport where energy systems are being stressed concurrently have identified similar relationships between HRV and TL's derived through heart rate (128) or exercise sessional ratings of perceived exertion (321).

The undulating pattern in TL's experienced throughout a typical microcycle in team sport have demonstrated large (i.e. 10-20%) daily variations in parasympathetic (i.e. Ln rMSSD) modulation when using cardiac measures such HRV (56, 59). High-intensity exercise such as repeated sprinting (55) and aerobic exercise above the second ventilatory threshold (i.e. VT_2) (418) have shown reductions in parasympathetic activity establishing exercise intensity as a significant contributor in the 24 – 48 hour suppression in vagal related HRV indices (447). Indeed, both sprinting and prolonged high-intensity actions are common demands in field hockey (139, 285) and provide support for our observations in the cause and effect relationship between both TL and time spent $\geq LT_2$ and reductions in parasympathetic activity (Figure 6.4 & 6.5). This investigation demonstrated a similar linear response to previous investigations (366, 368, 370) in the Ln rMSSD : R-R ratio after experiencing increasing amounts of TL's (AU) or time $\geq LT_2$, with the latter demonstrating a stronger relationship. However, we failed to identify a quadratic response or a plateau in the ratio after experiencing larger TL's during this mesocycle. A probable explanation for this absence was the lack of a large enough or sustained exercise stress. The emphasis of the mesocycle examined in this investigation was to prepare the Canadian Women's National Field Hockey Team for a 2016 Olympic Qualifying tournament, as such prolonged periods of high loading were not conducive to the object of the mesocycle and may have negated the development of a quadratic response. Future research is warranted to examine the probability of this quadratic response in a team sport setting throughout a yearly training plan for where purposefully periods of sustained high TL's are more common.

Our observation of a high intensity exercise marker (i.e. time spent $\geq LT_2$) and the resulting HRV response are in support of previous investigations examining endurance athletes (367), and supports the utilization of heart rate monitoring systems such as the Polar Team^2 for team sports where time spent $\geq LT_2$ are calculated and preprogrammed variables. Furthermore, recent reviews (238) focusing on team sport have highlighted the importance of monitoring this level of exercise stress for its relationship towards enhancing aerobic fitness (68, 69), its inverse relationship to injury (293, 345), and enhanced susceptibility to illness (346).

5.6 Limitations

One of the purposes of this investigation was to examine the cause and effect relationship between markers of exercise stress and alterations in parasympathetic indices in high performance athletes. This investigation was conducted at a period in the yearly training plan where the degree of psychological, emotional and mental stress were potentially at their highest in preparation for a 2015 FIH World League #3 Olympic Qualifying. As such further investigations are warranted to examine similar training load values and the concomitant HRV response when additional stressors may not be present.

Additionally, a possible limitation of this investigation may have been the seasonal effect (i.e. ambient temperature) on both exercise heart rate and HRV and its relationship to changes in PV% (61). As such future research directed towards examining the cause and effect relationship between TL and HRV when experiencing equal seasonal effects may reinforce the observations provided in this investigation.

5.7 Conclusions

This investigation demonstrated a strong congruency between the planned and achieved on-field TL during an individually periodized mesocycle in the Canadian Women's National Field Hockey team. Contrary to our hypothesis, the results presented in this investigation suggest that the magnitude of training stress when expressed as time spent $\geq LT_2$ may provide greater insight into parasympathetic alterations when compared to a more comprehensive exercise marker (i.e. TL).

Chapter 6: Heart Rate Variability in Team Sport Athletes for Identifying Non-Functional Overreaching

6.1 Introduction

Athletes commonly undergo physical training directed towards improving sport performance and experience increased levels of stress stimulating perturbations in physiological and psychological homeostasis, a disturbance that can shift along a fatigue continuum eventually developing from a state of overreaching to non-functional overreaching (NFOR) and finally over training syndrome (137). Upon cessation of an exercise session, the body initiates an immediate response to multiple perturbations to homeostasis which can begin with the removal of muscular degradation and metabolites (195), a gradual reduction in body temperature (335), and the increased activity of a neuroendocrine immune response (133) to restore physiological functioning back to a pre-exercise state. The significant contribution of the autonomic nervous system during this recovery period whereby adjusting physiological progressions and responses through the upregulation of hormonal glands, the regulation of the vasculature muscle tone and excitement of the cardiac tissue, can be examined through cardiac variability using a non-invasive technique called heart rate variability (HRV) (470). These perturbations in cardiac autonomic modulation post-exercise have been associated with modifications in hemodynamics (317), and cardiac performance (103).

Such changes in the homeostatic regulation of the cardiovascular system can display a shift in the priority and redistribution of cardiac output throughout the body demonstrating a possibly increased demand for the regeneration of localized tissue (98). Consequently, this increased demand from various tissues throughout the body has been thought to initiate autonomic feedback altering both cardiac and smooth musculature response to promote localized tissues homeostasis (110). For this reason, examining the rate of recovery in cardiac autonomic restoration using HRV may demonstrate the time course to regain cardiovascular homeostasis (447), a possibly large and important component for future performance in field hockey athletes.

The TL an athlete experiences as derived through a function of exercise intensity and its duration (319, 418), or through exercise sessional ratings of perceived exertion (243), have demonstrated to powerfully influence the magnitude of parasympathetic modulation and its time course of recovery in the post-exercise state. Implementation of sufficient recovery periods can promote similar pre-exercise parasympathetic activity levels within 24-72 hours (6, 54, 314) with a possible supercompensation above pre-exercise values (54, 200).

Microcycle's commonly utilized in team sport often involve single or multiple high-intensity sessions per day throughout the week. Previous literature has suggested the application of a large TL on consecutive days may elicit a cumulative effect whereby delaying the recovery of parasympathetic activity over a complete microcycle (256). The use of the coefficient of variation established from the day to day variation in HRV may provide greater insight into the recovery process and has recently been proposed as a new viewpoint for monitoring HRV (368). A current consensus towards HRV alterations demonstrating small or larger alterations during an over training state remains to be developed (230, 231, 361). It has been postulated when examining physiological variables that reside on the extreme ends of a continuum, further stimuli may only elicit minimal change (483). This proposed "law of initial values" may allow for the examination of Ln $rMSSD_{CV}$ to be used in context to the TL experienced. As such it is currently believed that athletes who experience a TL that causes minimal alterations (i.e. Ln $rMSSD_{CV}$)

demonstrate a large capacity for recovery and adaptability due to high fitness levels, as compared to larger alterations suggesting a diminished ability to adapt due to low fitness levels (56).

The modelling of TL's has been shown to be effective for session planning and the retrospective analysis of performance, however the development of NFOR is acknowledged to be accompanied with decrements in performance (376). For this reason, the monitoring of a TL alone cannot indicate a state of NFOR. Practitioners should be encouraged to identify a maximal test (i.e. athletic performance test) which stresses the desired energy systems called upon by their sport as an appropriate indicator for identifying NFOR. However great difficulty may lie with implementing such testing during a taper period or a training block as the test itself would elicit a TL and must be accounted for the in the weekly loading scheme (303). Recent attention has turned to non-invasive, non-performance tasks such as physiological assessments which may provide insight into the fatigue performance relationship. The weekly assessment of HRV as expressed through Ln rMSSD in relation to the smallest worthwhile (i.e. coefficient of variation) has shown promising results in endurance athletes for identifying NFOR when examined to their physical performance (366, 368, 370)

Therefore, the purpose of this investigation was to examine, 1) the relationship between Ln $rMSSD_{CV}$ and accumulated on-field TL, and 2) to examine the effectiveness of assessing alterations in Ln rMSSD in relation to the typical error (i.e. coefficient of variation) for identifying NFOR. This investigation was conducted during the last mesocycle of the Canadian Women's National Field Hockey Team prior to an Olympic qualifying tournament. Such a training block consisting of elevated emotional and psychological levels of stress can be viewed as an opportune period for examining a Basedowian style of overtraining. In conducting this investigation, we hypothesized that: 1) the Ln $rMSSD_{CV}$ would demonstrate a strong relationship to the weekly accumulated on-field training load, and 2) alterations in the Ln rMSSD when compared to the coefficient of vitiation would indicate the development of non-functional overreaching (NFOR).

6.2 Methods

A total of 20 athletes from the Canadian Women's National Field Hockey Team were available to act as participants for examining training load and its cause and effect relationship with the development of NFOR. Our sample size was restricted to athletes who were residing in Vancouver, who were not limited by U-Sport, NCAA or professional playing contracts overseas during the time of the study. A letter of support from Field Hockey Canada's Assistant Coach can be found in the Appendix (Field Hockey Letter of Support #2). Every athlete belonging to the Canadian Women's National Field Hockey program was designated a POLAR Team^2 heart rate monitor (Polar, Electro, Oy, Kempele, Finland) programed to record at one second intervals for both on and off field monitoring purposes. All heart rate monitors were designated to correspond to the athlete's jersey number to reduce potential confusion and misinterpretation of data. Each heart rate monitor provided a live recording of heart rate and TL (AU's) during on-field training sessions via Bluetooth to the sport practitioner's laptop. The Polar Team^2 system provides TL values that are derived from an intermittent sport algorithm based of each individual's unique changes in energy metabolism as exercise intensity shifts above or below aerobic and anaerobic threshold and time held in specific sport zones (327). The Polar Team^2 TL value has previously demonstrated to possess a strong relationship with the five heart rate sport zones calculation method commonly used (111) along with subjective measures such as sessional ratings of perceived exertion (131) when examined in team sport (78).

All transmitters were collected after each training session in an effort to export and secure exercise data to a laptop computer for further analysis. A five week mesocycle leading to an FIH World League#3 Olympic Qualifying tournament was designed with TL values in the order of 60%, 80%, ≥100%, 80% and 30% unique to each athlete's own maximum TL (%Max) and were predetermined for the entire mesocycle as seen in Appendix (Olympic Preparation Mesocycle). TL's (% Max) were based on the most recent maximum accumulated TL over a single week of on-field training during the 2015 yearly training plan. All on-field training sessions were two hours in length and were conducted every Monday, Wednesday, and Friday morning from 10am to 12pm at the University of British Columbia's Wright Field. Each on-field training session throughout the week was predesignated with a specific TL value that modelled to the weekly loading structure as seen in Appendix (Olympic Preparation Microcycle) along with the loading structure for the mesocycle.

It was expected that athlete adherence would likely be the limiting factor for data collection and the analysis of HRV (52, 369). As such, if one of the two R-R sampling periods over a weekend was not collected that participant was not included in the weekly data set. Participants who did not complete a training session or if a TL value was not captured for a single session throughout the training week were excluded from analysis when examining both team and individual results for that given training week. This aspect of the research project intended to not only shed light on the capability of a weekend rolling average to demonstrate changes in autonomic modulation in relation to TL, but to demonstrate the practicality of using HRV in a team sport environment without supervision.

10 minutes of R-R reordering was collected immediately upon awakening in the supine position throughout each weekend (i.e. Saturday & Sunday) during the mesocycle. Participants

were instructed to lie perfectly still and breathe at a normal rate without any audio instruction or guidance. The importance of standardizing this routine for data collection was stressed prior to and repeatedly during the mesocycle. All R-R collections were recorded using the POLAR Team^2 System. Each POLAR Team^2 heart rate monitor utilizes a 1000Hz sampling frequency when collecting R-R intervals and can record up to 48 hours of data. Weekend R-R collections were exported from every heart rate monitor to the sport practitioner's computer every Monday for the analysis of HRV using a Kubios HRV 2.2 computer software program. A 10 minute R-R recording period was selected in an effort to improve the opportunity to manually select a five minute period free of artifact or noise that would allow for the analysis of rMSSD and R-R (ms).

A time domain analysis as represented through rMSSD was selected for its ability to represent vagal modulation (470) and provide enhanced reliability when compared to other power spectral density indices (7). The statistical properties to which rMSSD possess have demonstrated strong resilience against the effects respiratory sinus arrhythmia during R-R internal recording when not controlling for breathing rate and depth (358). Both breathing rate and depth were left uncontrolled for and participants were instructed to relax and breathe at a natural rate.

Each rMSSD value was log transformed (Ln rMSSD) using the natural log rhythm to help reduce any bias through possible non-uniformity in error. A medium level of artifact correction that was already pre-programmed into Kubios HRV 2.2 was applied to every five-minute R-R recording sample. This level of artifact correction interpolates any artifact in R-R intervals that differ by more the 0.25 seconds when compared to the mean R-R intervals sampled. A medium level of correction was selected to preserve the R-R variability without compromising the validity and reliability of each sample. A spline interpolation method involving cubic interpolation was used for removal of ectopic beats or artifact. This filtering method utilizes a third degree polynomial to smooth out any ectopic beats or artifacts and is recommended when examining time domain HRV indices such as rMSSD (357). It is acknowledged that errors may still exist after utilizing an automatic artifact correction method however, when standardizing a correction method for repeated measures in athletes this difference has been deemed non-significant (50).

6.3 Statistical Analysis

All data in text, figures and tables are represented as a mean with a confidence interval (CI) of 90% unless otherwise stated. A CI of 90% was chosen as it has been suggested to be an appropriate default level as the probability of the true value residing below or above these limits are 5% each and interpret as unlikely (219). All data collected was analyzed employing a practical significance standpoint using magnitude based inferences. Current literature focusing on athletic performance have demonstrated traditional statistical approaches commonly fail to identify the size and importance of an effect and its implication to physical performance (217). Furthermore, a qualitative approach becomes increasingly important when working with reduced sample sizes commonly employed in high performance research (215, 365). For this reason a qualitative approach was chosen focusing on the within trial standardized mean differences to reveal the magnitude of effect size (ES) (80), using pre-designed excel spreadsheet (216). The following ES threshold values were followed: <0.2 trivial, >0.2 small, >0.6 moderate, >1.2 large, > 2.0 very large, and > 4.0 extremely large (215). The smallest worthwhile change in Ln $rMSSD_{CV}$ was derived from the weekend to weekend variation during the preceding mesocycle and is expressed as the coefficient of variation (218). Weekly alterations in Ln $rMSSD_{CV}$ were analyzed in relation to the preceding week. The smallest worthwhile change in Ln rMSSD for examining NFOR was derived from the weekend to weekend variation during the preceding mesocycle and is expressed as the coefficient of variation (218). When examining the within-participant change in physiological measures (i.e. non-performance measures), the establishment of a smallest worthwhile change equal to (1 x coefficient of variation), can be deemed as acceptable through providing an odds ratio of 2:1 for a real change to have occurred (218).

Supplementary to the derived ES values, a spreadsheet was used to calculate probabilities to identify if the true unknown difference was higher, trivial or lower than the smallest worthwhile change as calculated using an excel spreadsheet for practical significance and insight (28, 216). The qualitative likelihood of a change being either higher or lower, or harmful or beneficial were as follows; 1% almost certainly not, 1-5% very unlikely, 5-25% unlikely, 25-75% possible, 75-95% likely, 95-99% very likely, >99% almost certainly (215). A Multiple Regression (r^2) correlation using a second-degree polynomial was used to examine the relationship between TL and the Ln $rMSSD_{CV}$. The magnitude of the correlation between each measurement used the following scale of strength of effect; <0.1 trivial, 0.1-0.3 small, 0.3-0.5, 0.5-0.7 large, 0.7-0.9 very large and 0.9-1.0 almost perfect (215). Fishers Z statistic transformation was used for developing CI 90% for all regression analysis (125). Throughout the complete analysis, if the CI 90% overlapped both a negative (harmful) and positive (beneficial) range the ES was declared unclear, otherwise the ES was declared the detected value (215).

6.4 Results

A total of 20 Canadian Women's National Field Hockey Team athletes trained in Vancouver during a five-week mesocycle in preparation for an Olympic qualifying tournament during April and May of 2015. Participant characteristics are displayed in Table 6.1.

6.4.1 The Examination of Non-Functional Overreaching with the Use of Heart Rate Variability

Only 60% (n=12) of the total (*n*=20) athletes with enough normative HRV data to be involved in this examination provided the minimum requirements for inclusion in this investigation. Four weekends of the five week mesocycle was used for analysis as the last week (*i.e.* week#5) failed to capture a complete weekend data collection as the Women's National Team departed for Valencia Spain on the Saturday morning. The smallest worthwhile change as defined as (1 x coefficient of variation) for each athlete is provided in Table 6.4 along with each participants achieved on-field training load expressed as both an AU and as a % Max. The identification of a single participant (participant #10) whose Ln rMSSD resided outside of their smallest worthwhile change is displayed in Figure 6.4. This observed reduction in Ln rMSSD was correlated to the participant achieving a training load value of 1004 AU (i.e.115 %Max). Our observations displayed the remaining participants achieved variations in weekly Ln rMSSD values within their coefficient of variation throughout the complete mesocycle, with 67% of participants demonstrating vagal modulation that resided below baseline values (i.e. negative % change) at week#4.

6.4.2 Weekend Ln rMSSD$_{CV}$ in Response to Accumulated On-Field Internal Training Load

Both the preceding and rest week's mesocycle Ln rMSSD and Ln rMSSD$_{CV}$ means ±SD are found in Table 6.2 for comparative purposes. We identified a moderate increase in the Ln rMSSD$_{CV}$ during week#1 after experiencing a TL % (61.3 ±10.8). A trivial increase was observed during week#2 in response to a 12.6% increase in TL. Week#3 presented the largest %

of maximum training load (96.5± 10.8) during the mesocycle and was accompanied with a moderate yet possibly trivial decrease [Ln $rMSSD_{CV}$ = 12.4 ±6.0 CI 90 (9.1;15.7), ES = -0.7 CI 90% (-1.6;0.2), % Chance 0 / 71 / 29] . We observed the largest reduction in Ln rMSSD during week#4 that was accompanied with a very likely and very large increase in the Ln $rMSSD_{CV}$ [Ln rMSSD = 4.12 ±0.45, Ln $rMSSD_{CV}$ = 32.1 CI 90% (18.8;45.4), % Chance 96/4/0].

When examining the strength of relationship between TL as expressed through (% Max) and the Ln $rMSSD_{CV}$ throughout the mesocycle, we observed an unclear relationship [r^2 = 0.11 CI 90% (-0.15;0.36)] (Figure 6.2). When TL was expressed as (AU's) this relationship remained unclear as shown in Figure 6.1.

Participants (*n=7*) who achieved a weekly TL value above 100 (%Max) at any time throughout the mesocyclce demonstrated a marked increase in Ln rMSSD 24 hours post-exercise (i.e Saturday) when compared to their following 48 hour (i.e. Sunday) value as shown in Figure 6.3. A small increase [Ln rMSSD = 4.11±0.40 CI 90% (3.8;4.4), ES = 0.5 CI 90% (0.3;0.7), % Chance 100 / 0 / 0] was observed on Saturdays (i.e. 24 hours post) when compared to Sundays (i.e. 48 hours post) when experiencing a TL greater than 100 (%Max) (Table 6.3). Our observations demonstrated enhanced variation in the Ln $rMSSD_{CV}$ over 48 hours rest when TL's were greater than 100 (%Max). A possibly moderate increase was observed [Ln $rMSSD_{CV}$ = 17.4± 11.1 CI 90% (9.9;24.8) ES = 1.2 CI 90% (-0.6;3.0), % Chance 58 / 40 / 2] after experiencing a TL greater than 100% when compared to TL's between 90-100 (%Max).

Table 6-1 Participant Characteristics

(*n=12*)			Indirect Aerobic Fitness	
Age (yrs)	Height (cm)	Weight (kg)	YoYo (m)	Est. VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)
23.0 ±2.1	169.7 ±3.5	61.3 ±5.7	1852 ± 374	52.2 ±2.9

Values are represented as means ± standard deviation.

Table 6-2 Change (n=12) in weekly Ln $rMSSD_{CV}$ over a four week mesocycle

	Previous Mesocycle	Rest Week	Week#1	Week#2	Week#3	Week#4
TL (%Max)			61.3 ±10.8	73.9 ±10.8	96.5 ±17.5	86.6 ±13.7
Ln rMSSD	4.25 ±0.51	4.54 ±0.10	4.26 ±0.40	4.23 ±0.54	4.19 ±0.44	4.12 ±0.45
Ln $rMSSD_{CV}$	19.2 ±4.3	13.1 ±0.96	23.5 ±16.9	27.6 ±21.9	12.4 ±6.0	32.1 ±25.7
Ln $rMSSD_{CV}$ (CI 90%)	(17.0;21.4)	(8.1;18.1)	(14.3;32.7)	(14.1;41.2)	(9.1;15.7)	(18.8;45.4)
Standardized Differences (CI 90%)			1.1 (0.1;2.1)	0.2 (-0.8;1.3)	-0.7 (-1.6;0.2)	3.3 (1.1;5.5)
ES			Moderate	Unclear	Moderate	V. Large
% Chance the True ES is Positive / Trivial / Negative			57 / 43 / 0	11 / 87 / 3	0 / 71 / 29	96 / 4 / 0

Values are represented as means ±SD unless otherwise stated. Standardized differences (CI 90%) and effect size (ES) ratings are provided. To enhance the clarity for each ES the chances for a positive, trivial or negative effect are expressed as a %.

Table 6-3 Change in Ln rMSSD over 48 hours rest after achieving a weekly training load >100 (%Max)

	HRV	
(*n=7*)	24 Hrs	48 Hrs
Ln rMSSD	4.11 ±0.40	3.91 ±0.43
Ln rMSSD (CI 90%)	(3.8;4.4)	(3.6;4.2)
Standardized Differences (CI 90%)	0.5 (0.3;0.7)	
ES	Small	
% Chance the True ES is Positive / Trivial / Negative	100 / 0 / 0	

Values are represented as means ±SD unless otherwise stated. Standardized differences (CI 90%) and effect size (ES) ratings are provided. To enhance the clarity for ES the chances for a positive, trivial or negative effect are expressed as a percentage.

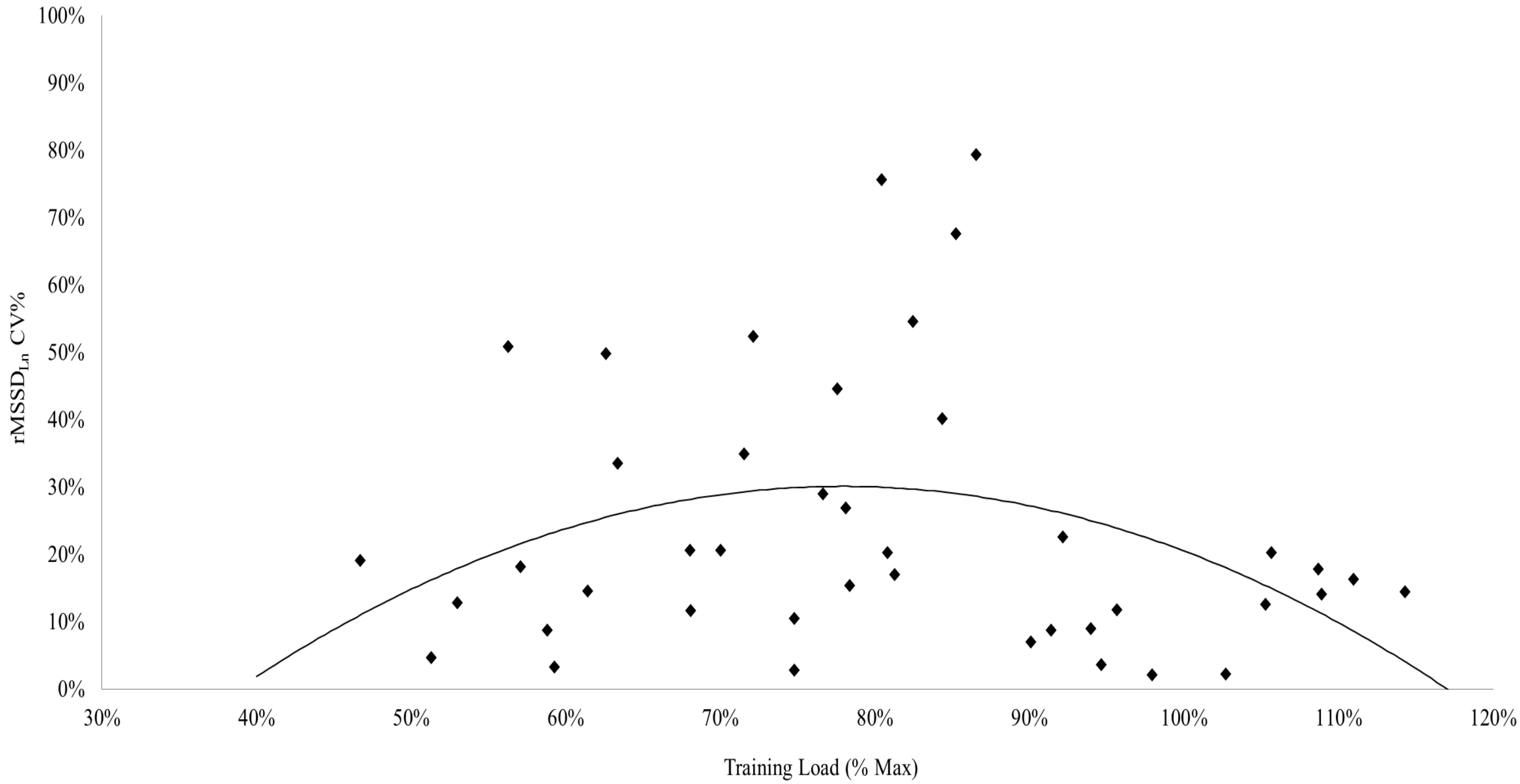


Figure 6-1 Relationship between training load (%Max) and Ln rMSSD$_{CV}$ during a four week mesocycle
Nonlinear regression coefficient (CI 90%), r^2= 0.11 (-0.15;0.36). (n=12)

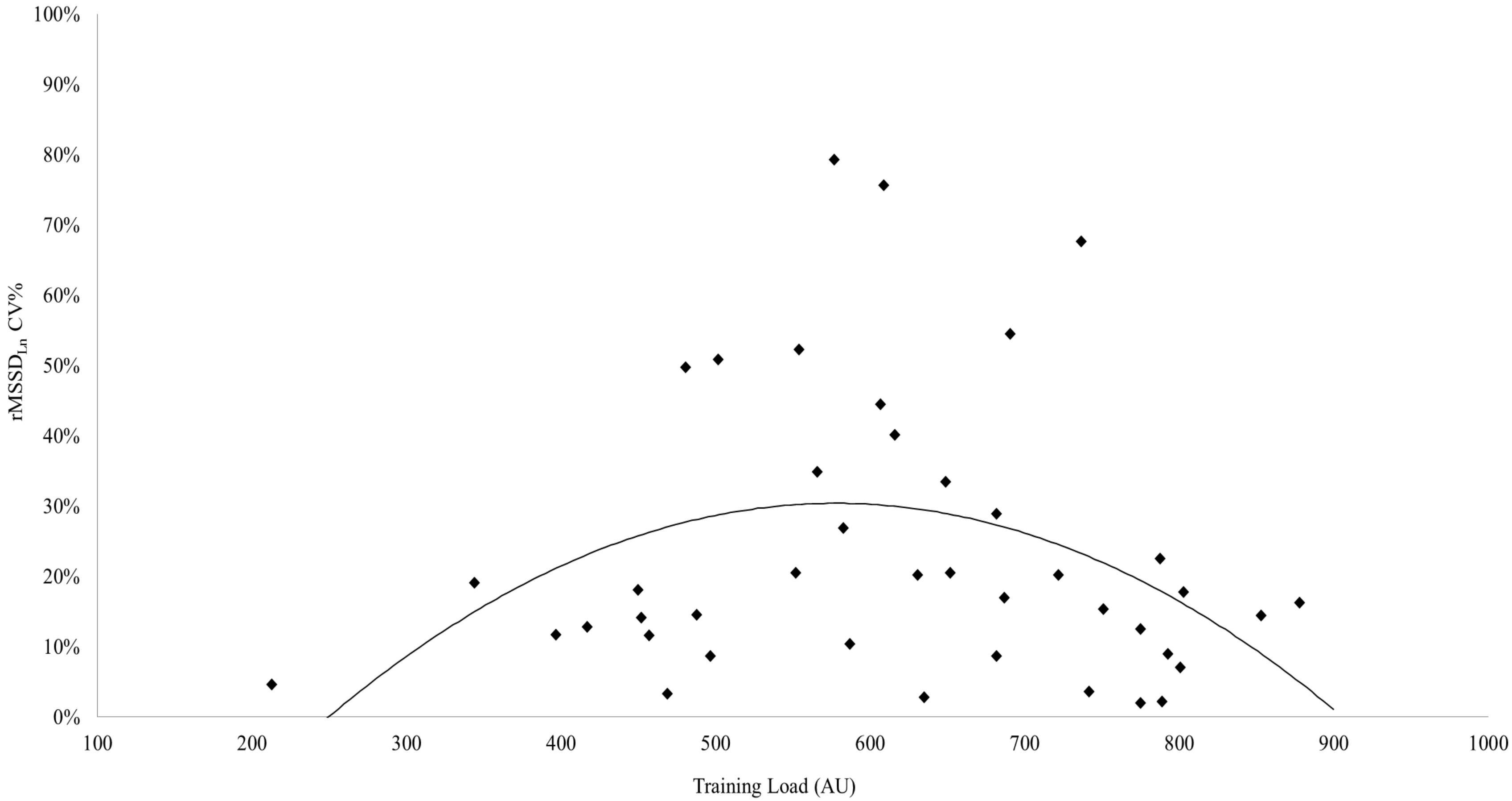


Figure 6-2 Relationship between training load (AU) and Ln rMSSD$_{CV}$ during a four week mesocycle
Nonlinear regression coefficient (CI 90%), r^2= 0.15 (-0.11;0.39). (n=12)

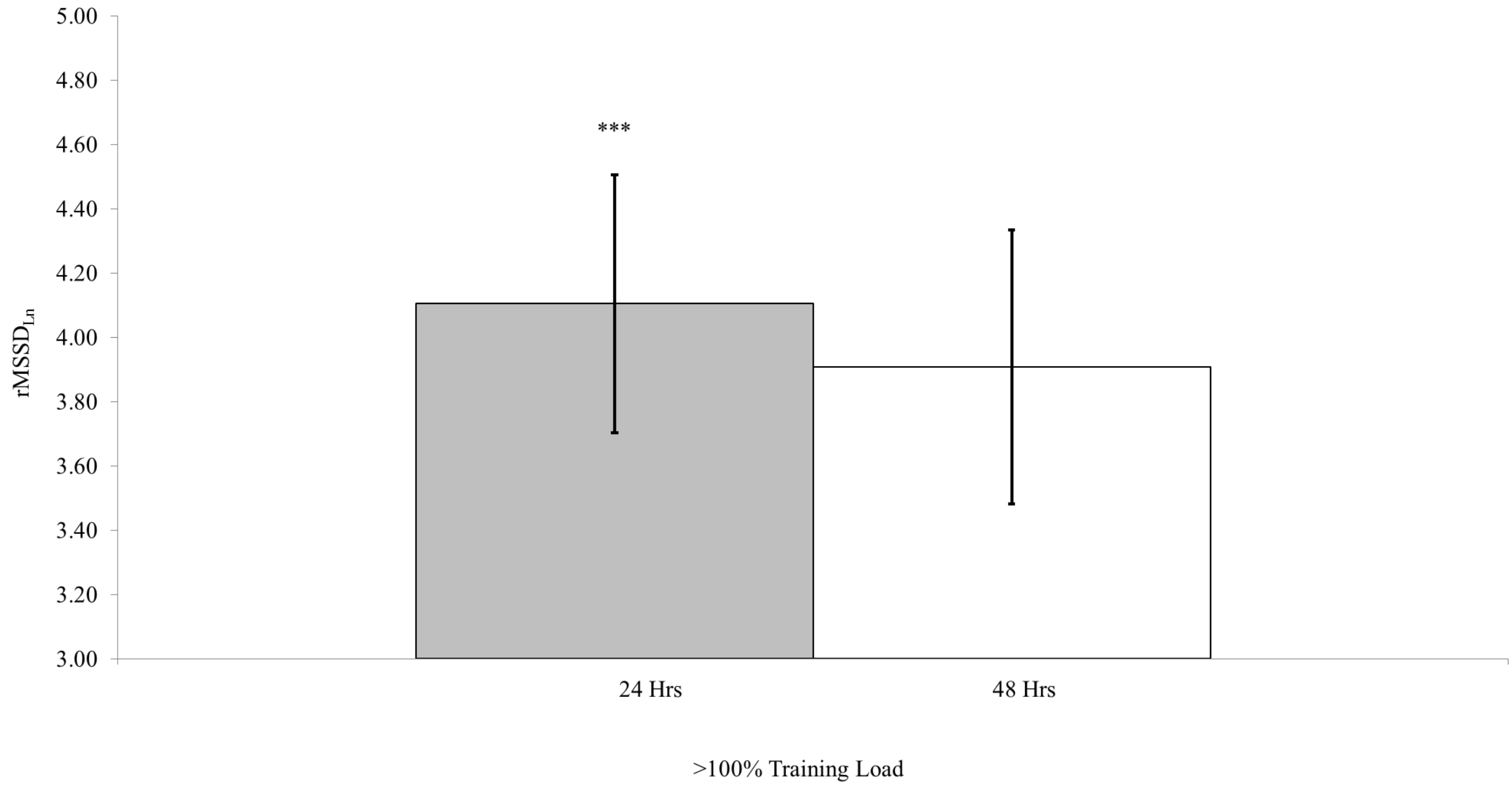


Figure 6-3 Ln rMSSD response (*n*=*7*) over 48 hours rest when achieving a weekly training load greater than 100 (%Max) Values represent the mean with error bars representing the SD of the mean. *** = $p < 0.001$.

Table 6-4 Achieved training loads and the associated HRV variation over a four week mesocycle

Participant (n=12)	HRV	Training Load							
	Coefficient Of Variation	Week[#]1		Week[#]2		Week[#]3		Week[#]4	
		(AU)	% Max	(AU)	% Max	(AU)	% Max	(AU)	% Max
1	7.8%	385	48%	488	61%	417	53%	587	75%
2	11.7%	450	57%	552	70%	742	95%	631	81%
3	6.8%	481	63%	554	72%	789	103%	609	80%
4	19.3%	497	59%	687	81%	788	92%	691	82%
5	15.7%			652	68%	751	78%	649	63%
6	24.6%	502	56%			801	90%	682	77%
7	15.0%	344	47%	607	78%	775	105%	616	84%
8	20.4%	566	72%	469	59%	878	111%	775	98%
9	10.4%	213	51%			387	96%	452	109%
10	11.8%	635	75%	737	85%	1004	115%	793	94%
11	20.0%	457	68%	546		722	106%	577	87%
12	10.2%	583	78%	682	91%	853	114%	803	109%
Mean ±SD	14.5% ±5.6	464.8 ±118.5	61.3% ±10.8	597.4 ±89.9	73.9% ±10.8	742.3 ±175.9	96.5% ±17.5	655.4 ±101.6	86.6% ±13.7

Individual training load values represented as (AU) and (%Max) are provided. The individual coefficient of variation representing the smallest worthwhile change in HRV is provided. Mean± SD is provided for all training load variations and the coefficient of variation for HRV.

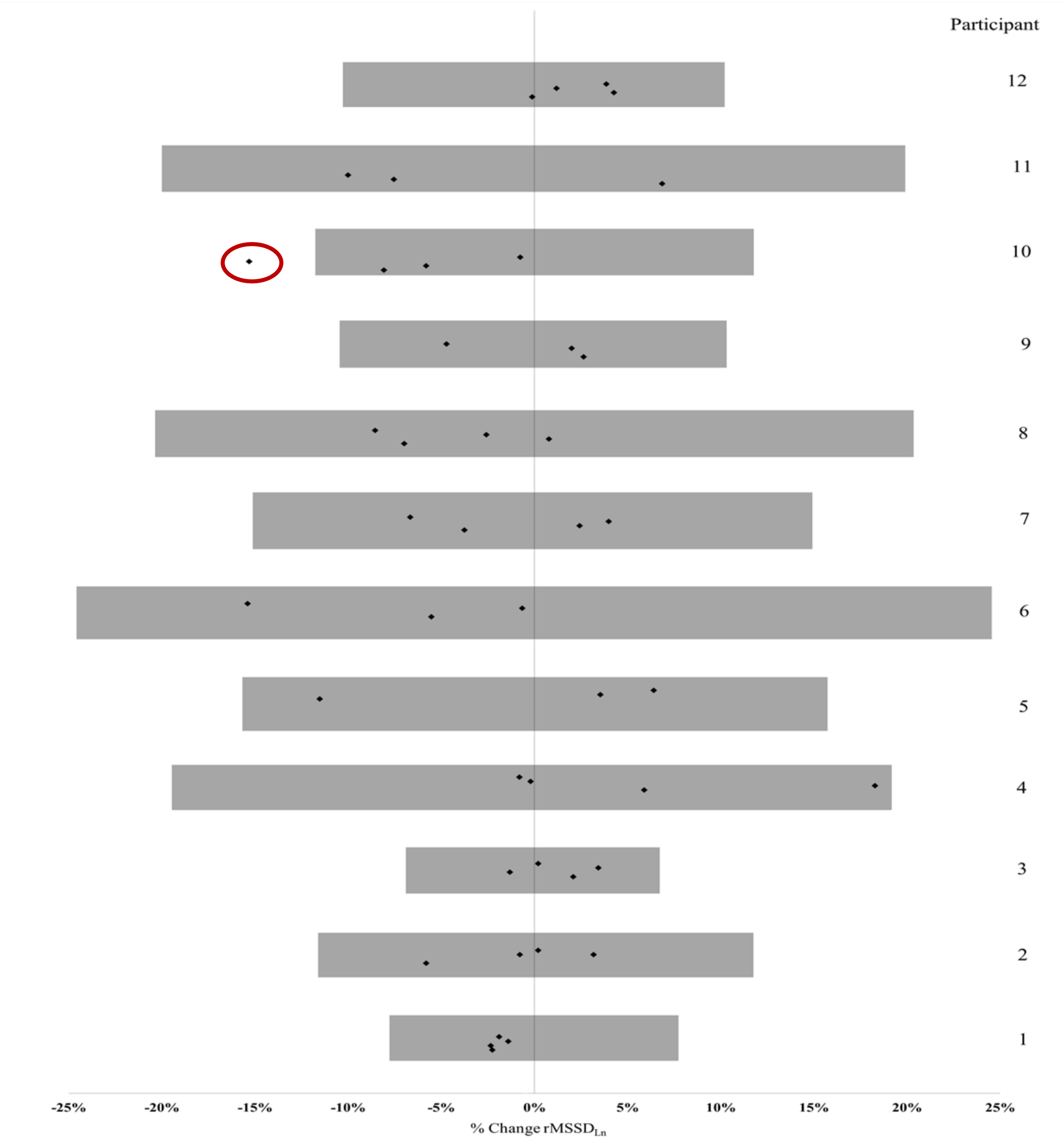


Figure 6-4 Individual (n=12) change (%) in Ln rMSSD during a four week mesocycle
Grey bars represent the smallest worthwhile change as expressed through the coefficient of variation for each participant

6.5 Discussion

6.5.1 The Relationship between Accumulated On-Field Training Load and Ln $rMSSD_{CV}$

When it comes to examining the cumulative effect of repeated training impulses throughout a microcycle, the consideration of a weekend rest period (i.e. 48 hour) and its Ln $rMSSD_{CV}$ may provide further insight into an athlete's recovery status prior to entering the proceeding mesocycle. The cumulative effect of repeated exercise bouts has been suggested to act as a compounding factor into the daily response of HRV potentially suppressing its escalation towards baseline or an eventual supercompensation (256). This investigation demonstrated an un clear nonlinear relationship between TL (AU) and alterations in weekend Ln $rMSSD_{CV}$ (Figure 6.2). When TL was expressed as a percentage this relationship demonstrated a similar result.

The magnitude of within athlete HRV variation has been suggested to be highly influenced by aerobic fitness, whereby athletes who possess a large VO_{2max} demonstrate lower daily parasympathetic variation (i.e. coefficient of variation) after exercise (56). This idea would suggest the physiological demands of competition and training may be achieved at a reduced relative intensity and as such elicit diminished perturbations to parasympathetic homeostasis post-exercise. However, this assumption along with previous investigations in team sport often examine TL as an arbitrary unit and not as a percentage based on within athlete normative data. As such, any assumption towards a relationship between fitness and HRV response to exercise should express exercise intensity as a relative TL (%Max), allowing for the within athlete variation to be equally accounted for. This investigation demonstrated a lack of relationship between the within participant fitness levels and HRV responses when experiencing a similar TL (%Max). Nonetheless, it must be acknowledged that non training stressors may have been unequally experienced outside of the training environment and may have influenced our observations possibly negating a cause and effect relationship between fitness and HRV as previously demonstrated (53, 329).

Our observations demonstrated an inverted U shape Ln $rMSSD_{CV}$ response in relation to an increase in TL and supports previous evidence suggesting minimal variation after experiencing both low and high TL's in endurance athletes (368). The differences in Ln $rMSSD_{CV}$ observed after experiencing a moderate TL during week#2 and week#3 (Table 6.2) in the presence of a diminished Ln rMSSD presents further insight beyond that of alterations in Ln rMSSD alone and suggests its usefulness in assessing adaptability along with the magnitude of parasympathetic activity. This viewpoint is further supported after observing a large Ln $rMSSD_{CV}$ recorded during week#4 in unison with the lowest rolling average in Ln rMSSD. Such observations may suggest TL's residing in the middle of an athlete's TL continuum elicit perturbations to physiological homeostasis that remain adaptable although in the presence of a possibly diminished Ln rMSSD. These responses in day to day variation may suggest mitigated decrements in aerobic performance in the presence of a diminished Ln rMSSD.

Additionally, a marked increase in Ln rMSSD 24 hours post-exercise was observed when compared to the following 48 hour response in participants who achieved a TL greater than 100 (%Max) at any time throughout the mesocycle (Figure 6.3). This physiological response lead to a significant increase in the Ln $rMSSD_{CV}$ between TL's ranging between 90-100 (%Max) and those greater than 100 (%Max). A possible explanation for the enhanced parasympathetic activity seen 24 hours' post-exercise may have been the result of a hypervolemic response to a substantial TL experienced the previous day (i.e. Friday). Research focusing on supramaximal exercise has demonstrated a rebound effect in Ln rMSSD during a 48 hour period, a response which also elicited larger increases in PV% 24 hours post-exercise when compared to a 48 hour response (54). This physiological response has been attributed to the development of hypervolemia and the possible increase in the afferent activity of the baroreflex loop providing an inhibitory response to sympathetic outflow and the resulting encouragement of parasympathetic activity from the medullary cardiovascular control center (82, 187). As such, our results suggest when examining the coefficient of variation in Ln rMSSD sport practitioners should account for the TL experienced and the context of where the team is in their mesocycle.

6.5.2 Identifying Non-Functional Overreaching when Examining Alterations in Parasympathetic Modulation

The examination of resting vagal-related HRV indices for monitoring training fatigue and performance capacity in endurance athletes is well explored (52, 201, 202, 226, 369). Earlier reviews discussing HRV and its practicality in team sport have suggested limited benefits stating increased difficulty in acquiring the necessary data collection for interpreting true change (50). However, recent literature has begun to support the implementation and effectiveness of HRV as an athlete monitoring tool in team sport (126, 320). Furthermore, these investigations have observed alterations and adaptions in vagal related HRV indices that have correlated to sport performance alterations (117) exhibiting its usefulness for practitioners and coaches.

Inquiry focusing on endurance athletes when examining correlations between the magnitude of modulation in vagal related HRV indices and athletic performance have suggested that alterations to the within-athlete measured typical error (i.e. coefficient of variation) are suitable for establishing the smallest worthwhile change and for identifying a possible state of NFOR (215, 368, 370). To our knowledge, this form of individual approach in team sport athletes has yet to be examined.

This study identified a single HRV measure from one participant that resided outside of their smallest worthwhile change during a complete mesocycle and that occurred after experiencing a TL of 115 %Max. The observed rebound in parasympathetic activity in this participant after a TL reduction (i.e. -20%) in the following week suggests the appropriate modeling of TL was established to negate further sympathetic dominance and the potential development of NFOR. As such, this significant reduction and eventual return in parasympathetic activity may have demonstrated the possible development of functional overreaching rather than NFOR. The findings from this investigation provide further support for examining HRV in relation to its position within the mesocycle/loading scheme and may strengthen current hypotheses that successive HRV recordings outside of the smallest worthwhile change (i.e. ≥2 weeks) may be necessary for the development and identification of NFOR (49) .

Additionally, the trend of multiple participants achieving TL's in excess of 100 (%Max) that yielded minimal change in Ln rMSSD along with alterations which demonstrated a random effect in relation to fitness levels may provide further support that stressors beyond that of physical exertion (i.e. on-field TL) can influence weekly HRV values and should be examined along with HRV using other forms of monitoring (53, 329).

In conclusion, the results of this investigation demonstrated reductions in parasympathetic modulation when experiencing large physiological perturbations throughout a complete mesocycle, a similar outcome to previous investigations in both field hockey and team sport athletes when experiencing undulating TL's (126, 127, 129, 321, 391). Nonetheless, this investigation demonstrated the capacity to objectively quantify the magnitude of perturbation in relation to the within-participant smallest worthwhile change, beyond that of a change in standardized ES. Our observations should encourage sport practitioners working in team sport to track HRV and make recommendations established on individual physiological traits rather than simple statistical approaches. This technique may provide greater insight into the possible development of NFOR and may allow for timely alterations in the planned TL of future microcycles.

6.6 Limitations

Some limitations existed in this investigation. The examination of HRV when manually selecting partitions in R-R (ms) recordings may provide bias in the assessment of modulation during repeated measures. Furthermore, errors in the R-R (ms) recording may still exist after correcting for artifacts or noise. However, it has been suggested these possibilities do not become a major factor when repeatedly monitoring athletes if the editing process is standardized for each assessment (50). Also, the sample size (*n=12*) when investigating the development of NFOR was limited to only 60% of the participants who provided the required data collection for analysis. Although international field hockey teams travel with 18 athletes during competition, further research involving larger sample sizes may be appropriate to support this investigation's observations and recommendations. Finally, this investigation solely focused on examining HRV for identifying NFOR. As such, further research implementing both physiological and performance markers are required to confidently identify a state of NFOR.

6.7 Conclusions

This investigation supports recent advancements (126, 129, 321) suggesting a multi-faceted approach when monitoring team sport athletes using HRV. An unclear relationship was observed between the weekly TL accumulated and alterations in Ln $rMSSD_{CV}$. Furthermore, the large variations observed in the day to day (i.e. weekend) Ln rMSSD in this investigation suggest

TL’s that reside in the middle of an athlete’s continuum provide nominal perturbations to regain parasympathetic balance. These results should encourage practitioners to consider multiple HRV indices when examining the athlete’s responses to a TL and further highlights the importance to observe this response in relation to the period within the mesocycle.

Previous literature examining the positive effects of implementing complete rest over a weekend in a team sport environment have demonstrated enhanced recovery in Ln rMSSD and psychological wellbeing before entering the proceeding mesocycle (272). This investigation provides further support for the implementation of monitoring individual weekend Ln $rMSSD_{CV}$ responses throughout a mesocycle and may provide practitioners further insight into parasympathetic recovery before applying larger stimuli.

In addition, when examining alterations in parasympathetic modulation that have demonstrated to coincide with the development of NFOR(461), alterations in relation to the within athlete smallest worthwhile change (i.e. 1 x coefficient of variation) may be an effective and efficient method for sport practitioners working in team sport. Future research should focus on possible disparities in the response of HRV to achieved TL’s throughout the yearly training plan and in comparison, to pre-competitive training blocks where secondary stress effectors may be elevated.

Chapter 7: General Summary and Conclusions

7.1 Integration and Interpretation of Major Findings

High performance athletes as defined as experienced Olympians or national team athletes striving to reach the Olympics are a unique and specialized population where exploration into the physical, social or psychological demands of daily training are warranted. Further research on this population can enhance sport practitioners' levels of understanding and capabilities towards monitoring and prescribing for these sporting demands. Team sport athletes, specifically field hockey athletes, compete in a sport where repeated high intensity actions accompanied with elevated and sustained energy production is required (20, 139, 277, 285). As such, investigations towards identifying effective and efficient methods for the physiological monitoring of energy systems accompanied with identifying environmental interventions that may reduce the physiological strain experienced during competition are warranted to provide a competitive advantage.

The use of an internal TL as represented through exercise sessional ratings of perceived exertion or heart rate for monitoring the physiological stress an athlete can experience has become common practice for sport practitioners; allowing for both the acute and chronic training stimuli to be scrutinized (50, 131). Chapter five of this dissertation demonstrated a successful model for the proactive approach in designing individualized mesocycles standardized in relative exercise intensity to each athlete ($r = 0.92$, $p < 0.01$). This chapter also examined for the first time the relationship between changes in HRV and two variables of exercise intensity in a team sport setting. The identification of a moderate yet significant relationship ($r = 0.48$) between Ln rMSSD: R-R and time spent $>LT_2$ was observed. A smaller yet moderate relationship was also identified when expressing exercise intensity through an all-encompassing TL value. This discovery may support previous investigations examining injury rate (293, 345) and fitness improvements (68, 346) in relation to time spent > LT_2 in team sport. As such, the observations in chapter five encourages practitioners working within team sport to focus on time spent > LT_2 when developing sessions plan and to incorporate this marker of training stress into the weekly monitoring of their athletes.

Expanding on our present understanding of the use of Ln $rMSSD_{CV}$ for monitoring an athlete (127, 370), chapter six examined the cause and effect relationship of a weekend (i.e. 48 hours) Ln $rMSSD_{CV}$ in relation to the weekly cumulated TL. The results in this chapter identified an unclear relationship between TL and a weekend Ln $rMSSD_{CV}$. Although statistically unclear, the observations in this chapter are in inclined to support previous hypotheses that parasympathetic variability is diminished when experiencing a training stimulus at either end of the intensity spectrum (368). Additionally, this chapter demonstrated how TL's > 100 (% Max) elicited a 24 hour increase in parasympathetic activity, a response that increased the magnitude of the weekend coefficient of variation and supports previous literature examining HRV response to supramaximal exercise (57). Not surprisingly this chapter encourages practitioners to examine changes in weekly Ln $rMSSD_{CV}$ in relation to the training load experienced. This position statement is further validated when observing an enlarged Ln $rMSSD_{CV}$ in the presence of a diminished Ln rMSSD value. Such findings suggest the use of the coefficient of variation may be more valuable for sport practitioners to identify an athlete's adaptability to an accumulated training stress when compared to solely examining an Ln rMSSD value. Furthermore, the larger coefficient of variation experienced when achieving TL's that resided in the middle of an athlete's intensity continuum may suggest that decrements in performance would have been mitigated in the presence of reduced parasympathetic activity.

This chapter was further designed to establish evidence for exploring the effectiveness of HRV when examining the development of NFOR in a team sport environment. In congruence with our hypothesis, our results demonstrated that weekly changes in Ln rMSSD in relation to the smallest worthwhile change may identify the possible development of NFOR throughout a mesocycle in a team sport setting. These results should encourage integrative support staff to develop normative data in each physiological variable monitored for the proactive approach in designing training blocks to help improve the rate of athlete development. For the first time this dissertation validated the importance for establishing normative data for HRV and internal TL's in unison for the proactive approach of designing individualized training blocks in team sport to prevent the possible development of NFOR, injury occurrence, and to optimally express performance.

In summary, this dissertation was able to demonstrate the possible effectiveness of using hot yoga as short term heat acclimation protocol for enhancing performance in international level female field hockey athletes. Although the classic development of hypervolemia was nonexistent during the heat acclimation process, further evidence demonstrating secondary physiological adaptations in female athletes may have been observed and responsible for improving speeds at thresholds and possibly aerobic power. Furthermore, evidence for a supercompensation in PV% when recommencing exercise in a cool environment may be in part to the augmented presence of anti-diuretic hormones. A secondary aspect of this dissertation provided further support for sport practitioner's ability to monitor physiological alterations throughout a training cycle. The proactive approach identified in this dissertation whereby developing individually periodized mesocycles through the use of normative data accompanied with examining exercise stress using a non-invasive cardiovascular marker (HRV); may assist integrative support staff in identifying or preventing the development of NFOR in their athletes.

7.2 Future Studies

Hot Yoga: Current investigations examining the cardiovascular response to acute and chronic hot yoga sessions are limited. Additionally, the increase in popularity of this form of yoga has led to various hot yoga studios providing non-standardized possess and environmental conditions. Recent evidence examining core temperature and heart rate during a 90-minute Bikram Yoga class have demonstrated significant increases in core temperature and various responses in heart rate (372). The purpose of chapter four was to examine the minimal heat stimulus required to elicit the smallest worthwhile change in both physiological and performance measures. As such, the use of far infrared heating whereby is providing a comfortable environment (i.e. 30 ± 3 C^{O}) compared to ambient temperatures required for Bikram Yoga (i.e. 40.0 C^{O}) may influence the magnitude in cardiovascular response after repeated exposures. Future research should examine the cardiovascular adaptations to repeated Bikram Yoga sessions over a short-term period (i.e. <7 days) for comparing both physiological and performance adaptations to hot yoga performed in a far infrared studio.

Non Functional Overreaching (NFOR): The identification of NFOR is a physiological state whereby decrements in performance are observed (376). The investigation conducted in chapter five examined NFOR through weekly alterations in Ln rMSSD in relation to the smallest worthwhile change (i.e.1 x coefficient of variation) and where not associated with alterations in performance. As such a definitive conclusion on the development of NFOR was not made possible. Previous literature has already acknowledged the difficulty when examining NFOR in elite athletes as the required amount of physical testing may not be practical or accepted into the weekly training program. None the less, further research is required to improve the understanding between alterations in HRV and physical performance for identifying NFOR with special attention towards performance tests that accurately demonstrate the energy systems required in the given sport.

Heart Rate Variability & Training Load: The purpose of this investigation was to examine elite athletes in an uninterrupted environment where the psychological, emotional and physical demands are uniquely associated with the ramifications of the preceding 2016 Olympic Games. Such a situation to examine would be difficult or impossible to replicate. As such, the magnitude of autonomic modulation observed when experiencing a given TL requires further investigation to identify possible discrepancies in the HRV response to an identical TL's at different periods of the yearly training plan where external stressors may be less prevalent.

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Appendices

PAR Q+

2014 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it ***does not limit your current ability*** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

OSHF

2014 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?
If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — **YES** ☐ **NO** ☐

1b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)? — **YES** ☐ **NO** ☐

1c. Have you had steroid injections or taken steroid tablets regularly for more than 3 months? — **YES** ☐ **NO** ☐

2. Do you have Cancer of any kind?
If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a. Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck? — **YES** ☐ **NO** ☐

2b. Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)? — **YES** ☐ **NO** ☐

3. Do you have a Heart or Cardiovascular Condition? *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm*
If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — **YES** ☐ **NO** ☐

3b. Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction) — **YES** ☐ **NO** ☐

3c. Do you have chronic heart failure? — **YES** ☐ **NO** ☐

3d. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months? — **YES** ☐ **NO** ☐

4. Do you have High Blood Pressure?
If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) — **YES** ☐ **NO** ☐

4b. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure) — **YES** ☐ **NO** ☐

5. Do you have any Metabolic Conditions? *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes*
If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a. Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies? — **YES** ☐ **NO** ☐

5b. Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness. — **YES** ☐ **NO** ☐

5c. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet? — **YES** ☐ **NO** ☐

5d. Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)? — **YES** ☐ **NO** ☐

5e. Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future? — **YES** ☐ **NO** ☐

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6. Do you have any Mental Health Problems or Learning Difficulties? *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome*

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you **ALSO** have back problems affecting nerves or muscles?	YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ____________________

____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

2014 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:
You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

NAME ____________________ DATE ____________________

SIGNATURE ____________________ WITNESS ____________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ____________________

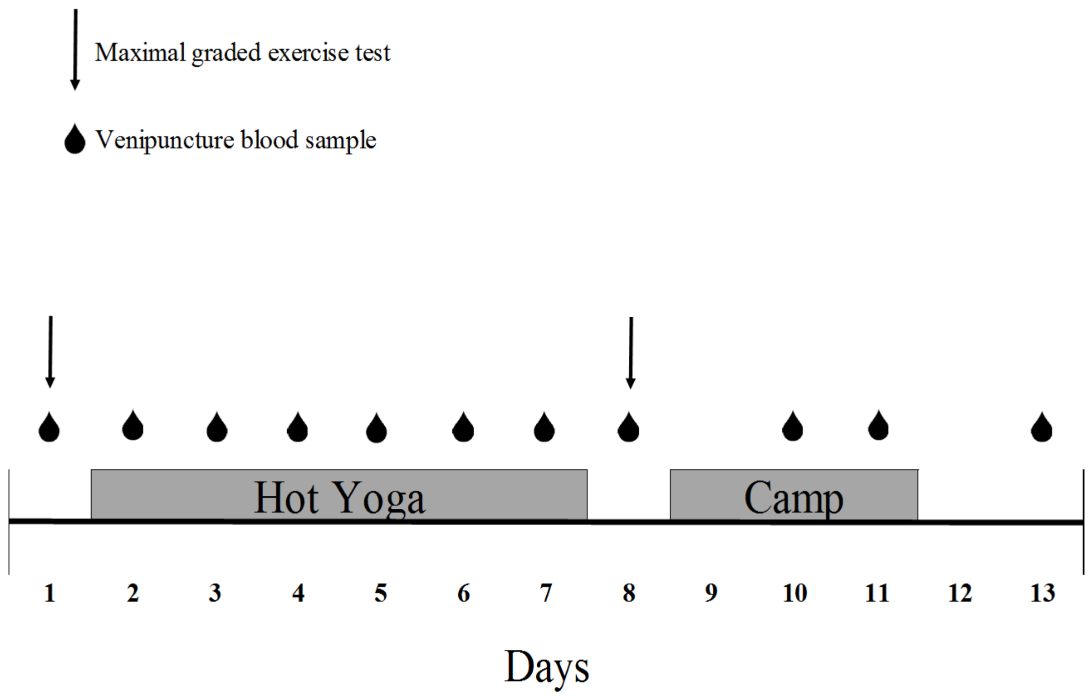
For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References
1. Jamnik VK, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.

Hot Yoga Timeline



Field Hockey Canada Letter of Support #1

FIELD HOCKEY
CANADA

March 20, 2015

University of British Columbia
Clinical Research Board of Ethics

Field Hockey Canada would like to formally state our support and approval of Andrew Perrotta's research with the Senior Women's National program. We strongly believe his research on heat acclimation using Hot Yoga can provide valuable information as we move forward to compete and qualify for the 2016 and 2020 Olympic Games.

We are excited with the potential to identify new and novel methods for heat acclimation and how to utilize heat stress as this can significantly improve future preparation and on field performance.

We are very pleased with Andrew's research progress and look forward to his outcomes. We have no doubt his research can be implemented and utilized as we move closer to the 2015 Pan American Games and World League Olympic Qualifiers.

Sincerely,

Lisa Northrup,
High Performance Manager | Gérante de Haute Performance
FIELD HOCKEY CANADA | HOCKEY SUR GAZON CANADA

ONE TEAM | POWERED BY... Canada coach.ca FIH

Incremental Test Recording Sheet

TREADMILL VENTILATORY STEP TEST

fortius

Name: ____________ Age: ____________
Height (cm): ____________ DOB: ____________
Weight (kg): ____________ Tech: ____________

INCREMENTAL Date:

Time (min)	Grade (%)	Speed (kph)	HR (bpm)	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
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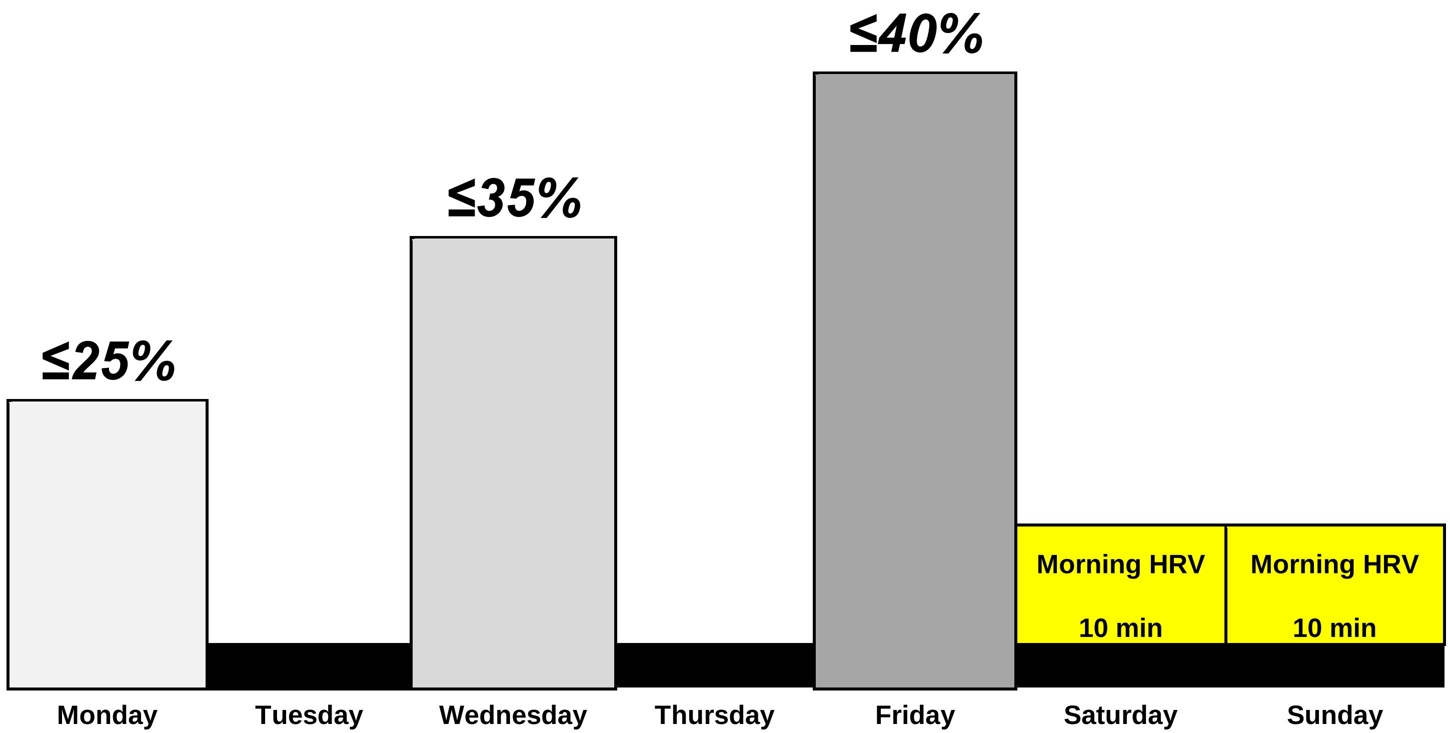
25				
26				
27				
28				
29				
30				
31				
32				
33				

Total Time: ____________

Active Recovery:
Speed (kph): ____________
Grade (%): ____________

Time (min)	HR (bpm)	
Immediate		
1		
3		
5		

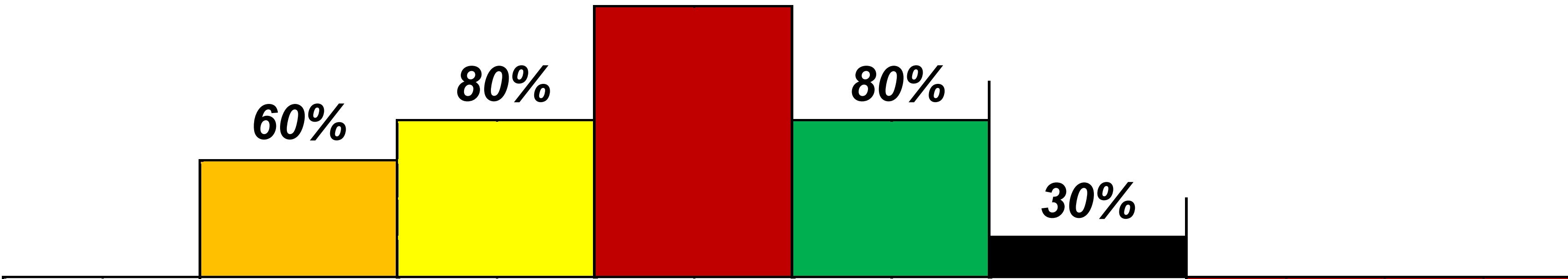
Olympic Preparation Microcycle



Training	**On-field**	**Rest**	**On-field**	**Rest**	**On-field**	**Rest**	**Rest**
Focus	PWR		Aerobic		Aerobic		

Olympic Preparation Mesocycle

≥100%



YTP Week #	14	15	16	17	18	19	20
Phase	Prep	Build	Attack	Recover	Adapt	Competition	

Field Hockey Canada Letter of Support #2

August 08, 2016

FIELD HOCKEY
CANADA

University of British Columbia
Clinical Research Board of Ethics

Field Hockey Canada would like to formally state our support and approval of Andrew Perrotta's research project focusing on athlete monitoring techniques with the Women's National Team Program. We strongly believe his research on identifying effective and efficient athlete monitoring protocols can provide valuable information as we move forward to compete and hopefully qualify for the 2018 FIH World Cup of Hockey and the 2020 Olympic Games in Tokyo.

We are very pleased with the direction and potential of Andrew's research project and look forward to his outcomes. We have no doubt his research can be implemented on a daily basis as we progress to the 2018 FIH World Cup of Hockey and future 2020 Olympic Qualifiers.

Sincerely;

Steph Andrews
Assistant Coach, Women's National Team | Entraineur-adjoint, equipe nationale féminine
FIELD HOCKEY CANADA | HOCKEY SUR GAZON CANADA |www.fieldhockey.ca
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