UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

ACUTE NEUROMUSCULAR AND ENDOCRINE RESPONSES FOLLOWING HIGH AND LOW EXTERNAL TRAINING LOADS IN COLLEGIATE BASKETBALL PLAYERS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSOPHY

By

AARON DAVID HEISHMAN
Norman, Oklahoma
2020

ACUTE NEUROMUSCULAR AND ENDOCRINE RESPONSES FOLLOWING HIGH AND LOW EXTERNAL TRAINING LOADS IN COLLEGIATE BASKETBALL PLAYERS

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

BY THE COMMITTEE CONSISTING OF

Dr. Michael G. Bemben, Chair

Dr. Debra A. Bemben

Dr. Christopher D. Black

Dr. Hugo M. Pereira

Dr. H. Michael Crowson

ACKNOWLEDGEMENTS

I am deeply endowed to a plethora of people that have supported me in this process while here at Oklahoma, but also many that have led me towards this pursuit prior to arrival. First, I would like to thank my academic mentor and committee chair, Dr. Mike Bemben, whose mentorship has been invaluable during this process. I am sincerely grateful for your willingness to take a chance on me and providing me the opportunity to join your lab. Additionally, I am so appreciative for the autonomy and support to pursue questions of my own interest and those that I felt were important to our athletes. This opportunity has empowered me to grow not only as a scientist and researcher, but also develop as an applied performance practitioner. I feel like I walked away from every conversation we have in awe at your depth of wisdom and experience, which always invigorates and motivates me to want to work harder and do more.

Thank you to the rest of my committee, Dr. Deb Bemben, Dr. Chris Black, Dr. Hugo Pereira, and Dr. Michael Crowson for your excellent mentorship, guidance, and encouragement throughout this process. Each of you have provided unique and valuable insights during the completion of this project, as well as through your instruction in the classroom which has made such a positive impact on my development.

It has been an honor to work with my colleagues and lab mates Ryan Miller and Eduardo Freitas. You are both outstanding scientists with bright futures and even better friends. We set bold goals at the start of this journey and pushed each other to achieve them all. You both have been inspirations and catalysts in my development. I will be forever grateful for the bond we have built over this academic journey, which would not have been the same without you guys. As always, I look forward to the things to come!

I owe a great deal of thanks to Coach Bryce Daub for affording me the unique and rare opportunity to work with Oklahoma Basketball Performance, where I could continue to gain valuable coaching experience while pursuing my degree, as well as collaborate on sport science initiatives in an effort to maximize student-athlete welfare and performance. From starting as a volunteer intern to transitioning into my current full-time role as the Assistant Director, you have always been open to my lofty ideas and supportive throughout the entirety of this process. This PhD journey simply would not have been the same without getting to be involvement in the applied performance setting working with athletes on a daily basis, as well as without your support and the multitude of opportunities you have provided me along the way, I am forever grateful!

Additionally, I am thankful for our Graduate Assistant, Brady Brown and our lead undergraduate intern Keldon Peak for their support and contributions during my time here at OU. It has been a joy to work with you both and seeing you grow, develop, and learn has been one of my favorite parts of my time here at Oklahoma. I can't say enough good things about your commitment to our basketball programs and your willingness to always go above and beyond what is asked of you. Both of you have bright futures in this field and I look forward to continuing to witness your progress.

I would also like to give a special thanks to my first applied performance mentors, Coach Mike Curtis and Coach Robb Hornett. My time with you both at Virginia was a life-changing experience, that ignited the spark and kindle my passion for athlete performance. I was lucky enough to work for two of the best strength and conditioning practitioners early in my career, which really laid the foundation for my pursuit of a doctoral degree. I am forever grateful for both of you.

To my parents Allen and Sherry Heishman, as well as the rest of my family, I am so thankful for your support and encouragement during this process. There is no doubt that the values instilled growing up on the farm prepared me for the essential qualities required in achieving this goal, including a level of discipline, commitment, and persistence, as well as arguably the most important, simply working incredibly hard. You all always provided me with every opportunity possible and showed me how to put your heart and everything you have into whatever you do. Again, I am so thankful.

Finally, to my loving fiancé, Lindsey. Thank you for your love, support, encouragement, and never-ending patience throughout this process. You may be the only person to truly witness how challenging this process has been. I am so thankful for you and the sacrifices you have made over these last 4 years. You have always provided that steady support, making sure the highs were never too high and the lows were never too low. I remember when I got my first manuscript accepted I was so excited and while you were incredibly happy for me you said "Sweet, sound like it's time to go get another one!" – just pushing me to do more and maximize my potential. But then at other times, I probably would have gone the entire day working at my computer and not even taken a moment to stop and eat if you wouldn't have been there to make me take a moment to put it all aside for a bit and relax over a meal that you had prepared. Its challenging to put into words what you mean to me, but I am just so thankful for you and I couldn't have done any of this without you.

DEDICATION

I would like to dedicate this work to my family and fiancé Lindsey. I would also like to dedicate this work to all the student-athletes that I have been fortunate enough to work with in the past and at the present, as well as those I may get the chance to work with in future.

"LOVE WHAT YOU DO,
LOVE WHERE YOU DO IT,
LOVE WHO YOU DO IT WITH."

-COACH SHERRI COALE

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

INTRODUCTION: Elite athletes undergo aggressive training regimens containing strategically induced fatigue in an attempt to maximize adaptation and performance improvements to meet the individual demands of the various sport. Athlete monitoring strategies are often used to track training loads and subsequent changes in performance. Inertial measurement units are often utilized to quantify the external training loads (eTL), also known as the biomechanical or locomotive stress, during indoor team sport activities, while the countermovement jump (CMJ) is employed to evaluate acute neuromuscular fatigue and performance. Little data exist examining the dose response of eTL and subsequent change in neuromuscular fatigue and performance, especially in basketball players. Additionally, although the CMJ is a commonly used field measure, exploring specific alterations in the CMJ force-time characteristics rather than gross output measures has been proposed to provide more insight with regards to changes in neuromuscular fatigue and performance compared to only considering gross output parameters, however this is yet to be explored among basketball players. **PURPOSE:** Therefore, the purpose of this dissertation was to examine the acute neuromuscular function and endocrine responses to High versus Low eTL basketball practices in a cohort of collegiate basketball players. A secondary aim sought to examine if neuromuscular alteration were primary central or peripheral in origin in response to a sport-specific basketball training session. **METHODS:** This dissertation was divided into two parts. *Part I* included 16 NCAA Division I basketball players (Male = 12; Female = 4) that performed a High and Low eTL practice, in a cross-over study design, where practice intensity measured using IMUs and intensity was characterized by PlayerLoad/minute

(PL/min). Prior to each practice, participants provided a salivary sample used to assess testosterone, cortisol, and Testosterone:Cortisol ratio, as well as performed 3 CMJs on a dual cell force platform. At the conclusion of each practice, participants provided another salivary sample and perform 3 more CMJs. Participants returned 24-hours following practice to provide another salivary sample and perform 3 more CMJs. Perceived fatigue and muscle soreness were assessed using subject recovery questionnaires prior to practice and 24-Hours following practice. *Part II* include 15 NCAA Division I basketball players (Male = 9; Female = 6) underwent neuromuscular performance assessments before, immediately-after, and 24-hours following a team practice. The eTL of each practice was captured using an IMU. Maximal voluntary contraction (MVC) and twitch responses to electrical neuromuscular stimulation were assessed during the isometric knee extensor contraction and at rest to measure central (voluntary activation) and peripheral (twitch torque) fatigue, as well as responses in twitch torque at rest were used examine the prevalence of low frequency fatigue. In addition, participants performed 3 CMJs at each time point to characterize neuromuscular fatigue and performance. **STATISTICAL ANALYSIS:** Data normality was confirmed using descriptive and graphical information supplemented by the Shapiro-Wilk test statistic. In *Part I*, a 2-way (Sex [male, female]) × Condition [high load, low load)] repeated measures (RM) analysis of variance (ANOVA), evaluate differences in eTL. Data from the recovery questionnaire exhibited a non-normal distribution, therefore the equivalent nonparametric test was utilized. Friedman's non-parametric test was used to test for significant differences in the median rank scores across the different conditions and time points. A 3-way (Sex [male, female] x Condition [high load, low load) x Time [pre-, immediately post, 24 hours-]) RM

ANOVA was used to assess sex, condition, and time main effects, as well as the interaction between Sex, Condition, and Time for each CMJ variable. Additionally, a 2-way (Condition × Time) RM ANOVA was also used to evaluate Sex × Condition, Sex × Time, and Condition × Time interactions, with significant interactions examined using a post-hoc pairwise comparison with a Bonferroni correction to isolate simple effects. In *Part II*, an independent T-Test was used to evaluate differences in Training Loads during practice between sexes. A 2-way (Sex [male, female] × Time [Pre, 24 hours-post exercise]) was utilized to evaluate difference in Recovery questionnaire parameters, with post-hoc pairwise comparison using Bonferroni corrections used when a significant difference was detected. A 2-way (Sex [male, female] × Time [Pre, immediately post, 24 hours-post exercise]) RM ANOVA was used to examine Sex and Time main effects and the interaction between sex and time for each variable: CMJ variables, MVC, voluntary activation, twitch characteristics and Low frequency fatigue. If a significant Sex × Time interaction was verified, the statistical model was decomposed by examining the simple effects with separate one-way repeated measures ANOVAs with Bonferroni correction factors for each group and time point. For both *Part I* and *Part II*, statistical significance was set at $p \leq 0.05$. When comparing three or more groups, partial eta-squared (η_{p2}) effect sizes were calculated and interpreted as small (0.0099), medium (0.0588) and large (0.1379). When comparing between two groups, Cohen's *d* (*d*) effect sizes were utilized and interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80). **RESULTS:** In *Part I*, there were significant differences in eTL during the High compared to the Low condition, including PlayerLoad per Minute and PlayerLoad ($p < 0.05$), while there were no practical differences in duration. The high condition also exhibited significantly greater iTL response ($p < 0.05$). However, there were no differences in perceived responses between condition or across time ($p < 0.05$). No significant differences emerged for any CMJ variable between condition or across time ($p < 0.05$), however, 6 of 7 CMJ Tradition Variables, 4 of 6 CMJ Concentric Alternative Variables, 3 of 5 CMJ Eccentric Alternative Variables, and 3 of 7 CMJ Phase Duration Alternative Variables did display a small effect (d = 0.20-0.49) during the High condition from Pre to Post-practice, which was none of these effects were observed during the Low condition. Additionally, the majority of these variables that showed an effect following practice during the High condition, revealed trivial to no effect at the 24-hour assessment following practice, signifying a resolved back to baseline. There were significant sex differences in endocrine responses to eTL ($p < 0.05$). There were no differences in endocrine responses between the high or low eTL conditions ($p > 0.0.5$) 4) In men, there were significant increases in testosterone from Pre to Post-Practice that returned to baseline at 24-hour following practice ($p < 0.05$) and cortisol appeared to increase from pre to post practice, but also return to baseline 24-hours following practice. In addition, testosterone:cortisol ratio appeared unaffected by condition and across time ($p < 0.05$). In testosterone, cortisol and T:C ratio appeared unaffected between conditions and unchanged across time ($p < 0.05$). In *Part II*, eTL appeared longer in duration and higher in volume (PlayerLoad), but lower in intensity (Pl/min) compared to those experienced in Part I. There were no significant differences in CMJ variables across time ($p < 0.05$), with changes exhibiting trivial to no effect. Men experienced a significant decrease in Rate of Torque Development from Pre to Post-practice ($p < 0.05$), which returned to baseline at 24-hours following practice, while women experienced no changes across

time. Low frequency fatigue appeared to emerge immediately following practice but resolved back to baseline at 24H-post practice. There were significant Sex differences in CMJ variables, MVC, Interpolated Twitch Torque, EMG, and twitch characteristics ($p > 0.05$), but no differences in percent voluntary activation. **CONCLUSIONS:** These findings suggest High eTL practice evoke a small acute effect on CMJ variables immediately following practice, which resolve to baseline by 24-hours, whereas Low eTL seems to induce no alteration in CMJ performance. In men, practices stimulated acute increase in testosterone and cortisol, while no changes occurred in T:C ratio. Varying eTL did not influence these acute responses in testosterone and cortisol. In women, testosterone, cortisol, and T:C ratio remained unchanged by both High and Low eTLs. Sport-specific practice appears to increase MVC and central components of neuromuscular function (voluntary activation), especially 24-hours following the exposure. Only small signs of mild peripheral fatigue occur following practice, which included low frequency fatigue appear immediately after practice, but resolved by 24-hours following the practice exposure.

CHAPTER I: INTRODUCTION

The primary purpose of an athlete training program is to impose acute homeostatic perturbation that elicit long-term adaptations and improvement in performance capabilities (Smith, 2003). Elite athletes undergo aggressive training regimens containing strategically induced fatigue in an attempt to maximize adaptation and performance improvements to meet the individual demands of the various sport. For example, basketball is a dynamic team sport requiring the combination of power, speed, agility, anaerobic power, aerobic capacity, and especially sport-specific skill (T. Edwards et al., 2018c; Montgomery et al., 2010b; Schelling & Torres, 2016; Stojanović et al., 2018). To prepare for these competitive demands of the sport, training regimens often include multiple training sessions with a variety of different emphases. The controlled environment of strength training or conditioning sessions allows for intuitive quantification of training loads, however quantifying training loads during sport-specific training, such as practice and competitions, becomes much more challenging. Basketball is an intermittent sport, characterized by segments of high-intensity activity that are interspersed with segments of low- to moderate-intensity activities (T. Edwards et al., 2018c; Stojanović et al., 2018). The repeated efforts performed include accelerations, decelerations, and change-of-direction in the linear, lateral, and vertical planes of motion, which can differ in terms of intensity, distance, duration, and frequency. The variability among movement activity poses inherent challenges when measuring training loads during team sport activity. The delicate balance between applying training load and allowing adequate recovery is essential in allowing positive training adaptations to be realized, while avoiding the negative consequences of stress accumulation, such as decrements in performance, illness, and injury (Bourdon et al., 2017; M. Kellmann, 2010; Michael Kellmann et al., 2018; Smith, 2003; Twist & Highton, 2013). Therefore, developing methodologies to adequately assess the dose-response relationship among the various training and competition exposures has emerged as a high priority throughout athletic performances.

The adaptive response to an acute training stimulus, regardless of the type, is thought to follow the general adaption syndrome (GAS) model described by Hans Seyle in the 1950s (Selye, 1946, 1950). The application of stress or nocuous stimulus, such as a training exposure, initiates the *alarm stage* of the GAS model, characterized by a disruption in the organism's homeostasis, resulting in acute fatigue and a suppression in physiological state. If sufficient recovery is allowed following the initial stimulus, the organism will undergo the *resistance stage*, restoring homeostasis and accruing positive adaptations to ensure future exposure to similar stimuli results in less homeostatic disruption. Further, the organism can experience enhancements in adaptations above homeostasis, known as *supercompensation*, ultimately resulting in increases in performance capacities. In contrast, the *exhaustion stage* can occur when the stress imposed is greater than the adaptive reserve of the organism. Therefore, if the magnitude of the stimuli is too great, or subsequent exposures are levied without allowing adequate recovery, maladaptation and diminished performance can occur. As illuminated in ***Figure 1***, following the GAS principles, adaptation to training is thought to occur in a dose-response fashion, therefore applying the optimal training stimuli is essential in optimizing adaptation and performance gains. Imposing too light of a training stimulus will underload the athlete marginalizing adaptive potential, while applying too intense of a training stimulus will overload the athlete resulting in greater fatigue which requires more time for the recovery-adaptation response. The GAS model forms the general basis for the development of methodologies to monitor the training process in elite athletes.

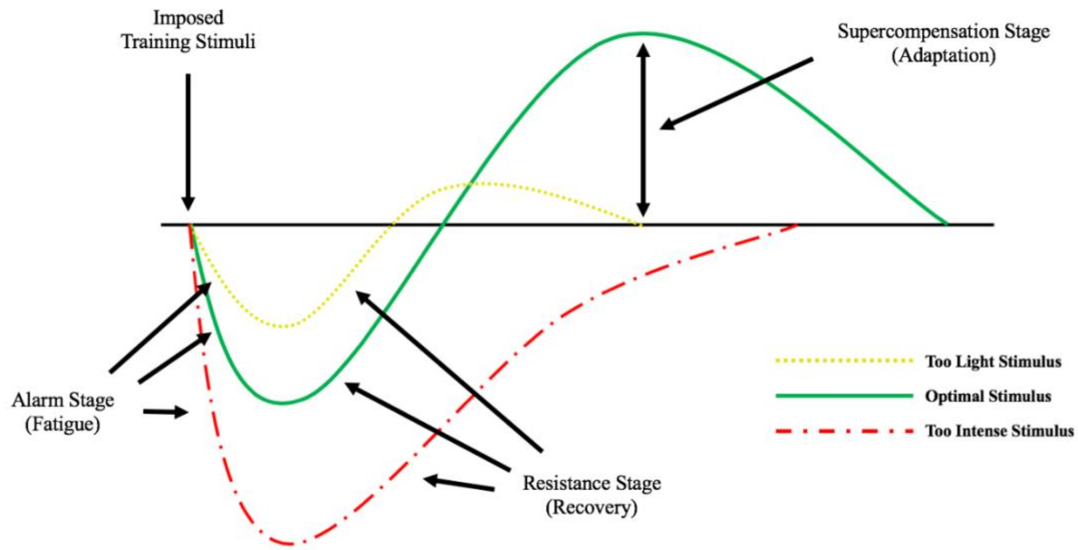


Figure 1. General Adaptation Syndrome (GAS) Model.

Athlete monitoring strategies have become a modern, scientific approach to understand imposed training loads, as well as evaluate the athlete's response to the training stimuli (Bourdon et al., 2017; Halson, 2014). The dose-response relationship of training has been monitored with a variety of strategies that can be divided into two distinct categories: 1) the quantification of training loads imposed; and 2) monitoring the fatigue/recovery responses to the applied training load (Halson, 2014; Taylor et al., 2012).

The quantification of imposed training loads can be further divided into the subcategories of either internal or external load monitoring (Bourdon et al., 2017; Halson, 2014; Heishman, Curtis, et al., 2018). Internal load monitoring strategies are defined as the relative biological stressor imposed on an athlete during training or competition (Bourdon et al., 2017; Halson, 2014; Heishman, Curtis, et al., 2018). In team sport, internal load is commonly assessed using measures such as heart rate, blood lactate, or rating of perceived exertion (RPE) (Bourdon et al., 2017; Halson, 2014). External load monitoring strategies refer to the assessment of mechanical or locomotive work completed by the athlete (Halson, 2014; Heishman, Curtis, et al., 2018). In team sport, external load is often quantified using time-motion analysis, Global Positioning Systems (GPS), or inertial measurement units (IMU), comprised of accelerometers, gyroscopes and magnetometers (Bourdon et al., 2017; Halson, 2014; Heishman, Curtis, et al., 2018; Heishman, Peak, et al., 2020).

The second approach to monitoring evaluates the athlete's response to a training stimulus, such as quantifying indices of fatigue after training or competition. While many definitions of fatigue exist (Enoka, 1995), fatigue is classically defined as the failure to maintain the required or expected force (or power) output (R. Edwards et al., 1977). Fatigue is a multifaceted and task specific phenomenon, with a plethora of factors contributing to its manifestation that are both central and peripheral in origin (Enoka & Stuart, 1992; Gandevia, 2001; Kent-Braun, 1999; Kent-Braun et al., 2012). Laboratory methods to assess fatigue are often able to isolate these origins, as well as provide evidence of mechanistic alterations facilitating the observed changes in performance in the presence of fatigue. Although laboratory assessments provide superior information regarding the origin and determinants of neuromuscular fatigue, these measures are often time consuming, require costly equipment, may provide participant discomfort, and necessitate a level of expertise to perform.

The countermovement jump (CMJ) is a common field measure used to monitor changes in neuromuscular readiness, fatigue, and recovery in response to training

(Claudino et al., 2017; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). The CMJ assessment is ideal for the team sport setting, as it can be performed in a time-efficient manner, allowing the assessment of multiple athletes in a small timeframe, while also not imposing undue stress or fatigue on the athlete (Claudino et al., 2017; Martinez, 2016). Furthermore, the CMJ utilizes the propagation of the dynamic muscle action referred to as the stretch-shortening cycle (SSC) (Komi, 1984; Martinez, 2016). Despites SSC activity requiring both concentric and eccentric muscle action, traditional CMJ analysis have focused on evaluating changes in the concentric component or gross jump output measures (i.e.- jump height, force, and power), overlooking the performance of the eccentric components. While previous literature supports the use of CMJ gross output analysis in identifying fatigue after training, the complex and multifaceted phenomenon of fatigue has catalyzed contemporary CMJ analysis to explore variables beyond the traditional CMJ tests of jump height, force, and power (Claudino et al., 2017; T. Edwards et al., 2018b; Gathercole, Sporer, Stellingwerff, et al., 2015a, 2015b). Indeed, alternative CMJ variables have been used to assess changes in performance such as reduction in eccentric components (i.e.-Force at 0 Velocity) and prolonged eccentric, concentric and total duration during the CMJ, following a bout of fatigue exercise (Gathercole *et al.*, 2015). Specifically in basketball athletes, recent data suggest changes in movement strategy (FT:CT) may alter with increases in eTL (Heishman, Daub, Miller, Freitas, & Bemben, 2020). Although CMJ testing is commonly utilized in the team sport setting to identify changes in neuromuscular function associated with fatigue, no literature exists paralleling changes in CMJ variables with changes in the gold-standard methodologies of fatigue assessment performed in the laboratory setting. Moreover, changes in neuromuscular function captured during the CMJ has been speculated as indicative of low frequency fatigue (LFF) (Cormack, Newton, & McGuigan, 2008; McLean et al., 2010; Mooney et al., 2013), however the direct assessment of LFF following a bout of team sport training has yet to be explored. Examining changes in CMJ variables compared to changes in laboratory-based fatigue assessments may direct practitioners to the key CMJ variables disrupted in the presence of fatigue manifested during team sport training. In addition, it may provide insight as to the origin of fatigue, such as whether the fatigue is more centrally or peripherally mediated after a sport specific training exposure, which may inform and direct recovery strategies, as well as assist in periodization schemes to optimize performance. Furthermore, previous literature has yet to explore potential sex difference in neuromuscular fatigue and recovery following team sport training.

The hormonal response to training and competition is commonly examined in team sport, alluding to an athlete’s physiological response to training stimuli (Andre & Fry, 2018; Cormack, Newton, & McGuigan, 2008; Rowell et al., 2017, 2018). Particularly, interests have centered around examining changes in salivary testosterone, an anabolic hormone pivotal in protein synthesis, as well as measuring alterations in salivary cortisol, a catabolic hormone important in metabolism. Furthermore, the relationship between testosterone and cortisol are often coupled as the testosterone:cortisol ratio (T:C ratio), signifying the anabolic:catabolic balance (Andre & Fry, 2018; Cormack, Newton, & McGuigan, 2008; Kraemer et al., 2009; Rowell et al., 2017). Despite evidence supporting the assessment of hormonal responses to evaluate the impact of training in team sports (Cormack, Newton, & McGuigan, 2008; Cormack, Newton, McGuigan, et al., 2008; McLellan et al., 2010; Rowell et al., 2017) and longitudinal evidence of hormone fluctuations across a season in collegiate basketball (Andre & Fry, 2018), limited evidence exists specifically examining the relationship between training loads and post-training hormone responses, especially among basketball athletes. Additionally, little to no research has specifically compared sex differences in endocrine response to team sport training.

While a variety of strategies are employed to monitor training in elite athletes, little evidence exists connecting load monitoring variables captured during training prescription with assessments of fatigue and recovery, such as the CMJ test or hormonal analyses. In addition, a paucity of evidence exists linking field measures used to identify fatigue with laboratory assessments. Coupling the two sectors of athlete monitoring strategies may enhance the capacity for performance practitioners to strategically titrate athlete fatigue generating optimal adaptations to training, but also enabling the expression of an athlete's full performance potential during competition.

Purpose

The purpose of this investigation was to examine acute neuromuscular function changes and endocrine responses to a single bout of basketball specific training at high and low training loads in a cohort of elite collegiate basketball players (*Part I*). The secondary purpose (*Part II*) sought to examine the central and peripheral contributions to neuromuscular fatigue following a sport-specific basketball training session.

Research Questions

Part I

1. Are there significant differences in the countermovement jump traditional and alternative performance variables pre-, immediately-post, and 24-hours following exposures of high and low load sport-specific basketball training?

2. Are there significant differences in testosterone, cortisol, or the testosterone:cortisol ratio pre-, immediately-post, and 24-hours following exposures of high and low load sport-specific basketball training?
3. Are there significant sex differences in countermovement jump traditional and alternative performance variables pre-, immediately-post, and 24-hours following exposures of high and low load sport-specific basketball training?
4. Are there significant sex differences in testosterone, cortisol, or the testosterone:cortisol ratio pre-, immediately-post, and 24-hours exposures of high and low load sport-specific basketball training?

Part II

5. Are there significant differences in maximal voluntary isometric contraction torque of the knee extensors pre-, immediately-post, and 24-hours following a bout of sport specific basketball training?
6. Are there significant differences, in peripheral fatigue, measured by twitch torque, pre-, immediately-post, and 24-hours following a single bout of sport-specific basketball training?
7. Are there significant differences in voluntary activation %, assessed via the twitch interpolation technique, pre-, immediately-post, and 24-hours following a bout of sport specific basketball?
8. Are there significant differences in low frequency fatigue, assessed as the ratio of torque from a single twitch to a doublet, immediately after or 24-hours following an exposure of basketball specific practice?
9. Are there sex differences in voluntary activation %, peripheral fatigue, or LFF pre-, immediately-post and 24-hours following a bout of sport specific basketball training?

Research Hypotheses

Part I

1. Significant decreases in CMJ performance would occur from pre- to immediately-post and remain below pre- values at 24-hours following the high training load in parallel with previous literature (Cormack, Newton, & McGuigan, 2008; Ferioli et al., 2018; Heishman, Curtis, et al., 2018). No significant difference in CMJ performance would be present among pre-, immediately post, or 24-hours post measures following the low load training exposure, as previous literature has reported differences in CMJ performance following high compared to low training loads (Heishman, Curtis, et al., 2018).
2. There would be a significant increase in salivary testosterone and decrease in the T:C ratio, while salivary cortisol would significantly increase from pre- to immediately-post measures following the high load training exposures in accordance with prior literature (Arruda et al., 2014; D. A. Edwards et al., 2006; Rowell et al., 2017). Salivary cortisol levels would remain elevated and the T:C ratio would remain suppressed at 24-hours following the high training loads exposure (Cormack, Newton, & McGuigan, 2008; Romagnoli et al., 2016; Silva et al., 2013). No differences would exist between testosterone levels from pre-to immediately-post, or at 24-hours measures following the low intensity exposures (Cormack, Newton, & McGuigan, 2008; McLellan et al., 2010; Silva et al., 2013). In addition, there would be a significant increase in cortisol immediately following the bout of low training load, which would return to baseline by 24-hours post. No significant differences would exist between testosterone or the T:C ratio follow the low load training exposure at pre-, immediately-post, or 24-hours post measures, as previous literature

has indicated training intensity plays a vital role in the magnitude and duration of hormonal responses (Hackney, 1989; Hackney & Lane, 2015).

3. Significant differences would exist between sexes in CMJ variables, with women having less decrement in performance measures immediately after, or 24-hours following the high load training exposure. No differences would exist between sexes following the low load training exposure.
4. Significant differences would exist between sexes in testosterone response, with men having greater decrease in testosterone immediately following and 24-hours following the high load exposure. No differences between the sexes would exist in cortisol responses following the high training load and no differences in cortisol responses would exist following the low load training exposure. Greater decrease in testosterone and similar cortisol responses would results in significant sex differences in T:C ratio, with men experiencing a greater decrease in T:C ratio.

Part II

5. There would be a significant decrease in maximal voluntary isometric contraction torque of the knee extensors immediately following and 24-hours following a bout of sport-specific basketball training.
6. There would be a significant increase in peripheral fatigue, measured by twitch torque, before, immediately post and 24-hours following a single bout of sport-specific basketball training, as previous literature has suggested high-intensity training exacerbates peripheral fatigue.
7. There would be no significant differences in voluntary activation %, assessed via the twitch interpolation technique, before, immediately post, and 24-hours following a

bout of sport-specific basketball, as the decrements in torque would be attributed to peripheral mechanisms.

8. There would be significant increases in low-frequency fatigue, assessed as the ratio of torque from a single twitch to a doublet, immediately after and 24-hours following an exposure of basketball specific practice, due to the previous literature suggesting team sport activity increases low-frequency fatigue (Fowles, 2006a; Lattier et al., 2004).
9. There would be significant sex differences in voluntary activation %, peripheral fatigue, or LFF pre-, immediately-post and 24-hours following a bout of sport-specific basketball training, with men showing greater declines in each variable.

Significance of Study

Identifying the acute neuromuscular and endocrine responses to varying external training loads potentially provide coaches and performance practitioners with enhanced information to manage training loads in the days leading into competition in an effort to optimize performance. In addition, understanding the acute responses to training loads may support the improvement of periodization schemes over various training phases. Furthermore, attempting to characterize the origin of fatigue following a sport-specific basketball training session, as well as document the relationship between sophisticated laboratory-based measures and common field-based measures of fatigue may illuminate key performance indicators most relevant to detecting acute fatigue in the applied performance setting. The culmination of this information will aid in reducing the risk of under-recovery, maladaptation, and possibly mitigate injury risk, ultimately leading to not only enhanced performance, but ultimately aid in the improvement of overall student-athlete welfare.

Assumptions

1. Participants were honest and accurate while completing the health screening questionnaire and other questionnaires.
2. Participants gave maximal effort during all countermovement jump assessments and twitch interpolation assessments.
3. Participants maintained their normal diet, as outlined by the team's sport dietician throughout the study.
4. Participants only consume water 60 minutes prior to all salivary sample collection.

Delimitations

1. The participants were recruited from the men's and women's varsity basketball team at the University of Oklahoma.
2. Participants were between the ages of 18 and 24 years of age.
3. Findings of this study only apply to collegiate men's and women's basketball players.
4. Participants with any recent musculoskeletal injuries that may affect testing were excluded.
5. Basketball training sessions were performed in the team setting to maximize ecological validity.

Limitations

1. The cohort for this study was a convenience sample of men's and women's varsity basketball players at the University of Oklahoma.

2. The results are only generalizable to men's and women's collegiate basketball players.
3. While participants were asked to maintain their normal dietary strategy, as outlined by the team's sports dietician, their compliance was not controlled.

Operational Definitions

1. **External Load**: the assessment of mechanical or locomotive work completed by the athlete (Halson, 2014; Heishman, Curtis, et al., 2018; Heishman, Peak, et al., 2020).
2. **Internal Load**: the relative biological stressor imposed on an athlete during training or competition (Bourdon et al., 2017; Halson, 2014; Heishman, Curtis, et al., 2018).
3. **Inertial Measurement Unit** (IMU): microsensor incorporating an accelerometer, a gyroscope, and a magnetometer used to measure athlete movement and activity (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020).
4. **PlayerLoad™** (PL): a vector of magnitude, expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the 3 orthogonal planes and divided by the scaling factor of 100 and is expressed in arbitrary units (au) (Barrett et al., 2014; Boyd et al., 2011; Heishman, Curtis, et al., 2018; Heishman, Peak, et al., 2020).
5. **PlayerLoad$_{2D}$** (PL$_{2D}$): a formula variation of PlayerLoad™ which omits the vertical vector and only including the two dimensions of mediolateral and

anteroposterior vectors and is expressed in arbitrary units (au) (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020).

6. **PlayerLoad$_{\mathbf{1D\text{-}FWD}}$** ($PL_{1D\text{-}FWD}$): PlayerLoad only accumulated in the anteroposterior plane of motion (Heishman, Peak, et al., 2020).
7. **PlayerLoad$_{\mathbf{1D\text{-}SIDE}}$** ($PL_{1D\text{-}SIDE}$): PlayerLoad only accumulated in the mediolateral plane of motion (Heishman, Peak, et al., 2020).
8. **PlayerLoad$_{\mathbf{1D\text{-}UP}}$** ($PL_{1D\text{-}UP}$): PlayerLoad only accumulated in the vertical plane of motion (Heishman, Peak, et al., 2020).
9. **Inertial Movement Analysis™** (IMA): instant one-step movement effort; distinct acceleration micro-movement events generated during sudden explosive movement bouts, such as accelerations, decelerations, and change of direction (CoD) movements and expressed as the number of occurrences (counts) (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Holme, 2015).
10. **Rating of Perceived Exertion** (RPE): Athlete's perception of the training session intensity, on a scale of 1 to 10 (Foster et al., 2001).
11. **Session Rating of Perceived Exertion** (sRPE): The athlete's perception of the training session intensity (scale 1-10), multiplied by the duration of the session.
12. **Maximal Voluntary Isometric Contraction** (MVC): The maximum amount of force that one can voluntarily exert by a muscle or group of muscles against an immovable object, where the muscle maintains the same length as tension in the muscle increases (Haff & Triplett, 2015).
13. **Interpolation Twitch** (IT): a twitch superimposed during a maximal volitional isometric contraction (MVC) (Shield & Zhou, 2004).

14. **Resting Twitch** (RT): a twitch evoked while the muscle in at rest following a maximal voluntary isometric contraction (MVIC), also referred to as a potentiated twitch (Shield & Zhou, 2004).
15. **Voluntary Activation** (%VA): the completeness of skeletal muscle activation during a voluntary contraction, calculated by divided the interpolated twitch (IT) superimposed during a maximal contraction, divided by a twitch evoked in the relaxed muscle, expressed as a percent (Shield & Zhou, 2004).
16. **Central Fatigue:** a reduction in voluntary activation of muscle during exercise, reflecting changes proximal to the neuromuscular junction in the central nervous system (Markus Amann, 2011; Gandevia, 2001).
17. **Peripheral Fatigue:** alterations in processes at or distal to the neuromuscular junction that decrease force or torque generating capacities of the skeletal muscle (Enoka & Stuart, 1992; Gandevia, 2001; Ross et al., 2007).
18. **Low-Frequency Fatigue** (LFF): the phenomenon in which torque produced in response to low frequency stimulation declines disproportionately to the torque produced in response to higher frequency stimulations (R. Edwards et al., 1977; Jones, 1996; Keeton & Binder-Macleod, 2006).
19. **Peak Torque:** High torque achieved during the single twitch.
20. **Rate of Torque Development:** Peak Torque during the single twitch divided by time to Peak Torque.
21. **Time to Peak Torque:** Duration from baseline to the greatest torque achieved during the single twitch.
22. **Average Rise Time:** Slope from 20-80% of Peak Torque.

23. **Rate of Relaxation:** Duration from Peak Torque back to baseline.
24. **Half Relaxation Time:** Duration from Peak Torque to halfway back to baseline.
25. **Testosterone:** a steroid hormone in the androgen family, regulated by the hypothalamic-pituitary-gonadal (HPG) axis and associated with increases in protein synthesis and decreases in protein degradation; represents anabolism, and expressed in nmol/L (Andre & Fry, 2018; Fry & Kraemer, 1997; Kraemer & Ratamess, 2005; Moore & Fry, 2007).
26. **Cortisol:** a steroid hormone, part of the glucocorticoid family, secreted from the adrenal cortex via the hypothalamic-pituitary-adrenal (HPA) axis and associated with decreases in protein synthesis and increases in protein degradation; represents catabolism expressed in nmol/L (Andre & Fry, 2018; Kraemer & Ratamess, 2005; Papacosta & Nassis, 2011).
27. **Testosterone: Cortisol** (T:C ratio): the ratio of testosterone to cortisol, reflecting the balance of anabolic: catabolic processes (Halson & Jeukendrup, 2004; Kraemer & Ratamess, 2005; Rowell et al., 2017; Twist & Highton, 2013).
28. **Countermovement Jump** (CMJ): a form of vertical jump in which the participant starts tall and drops to a self-selected depth before maximally vertically displacing in the air (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020).

Traditional Countermovement Jump Variables (Heishman, Brown, et al., 2019; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020)-

29. **Concentric Mean Force** [N] (ConcMF): Mean force during the concentric phase
30. **Concentric Mean Power** [W] (ConcMP): Mean power during the concentric phase

31. **Concentric Peak Force** [N] (ConcPF): Greatest force achieved during the concentric phase.

32. **Flight Time:Contraction Time** (FT:CT): Ratio of flight time-to-contraction time.

33. **Jump Height** [cm] (JH): Maximal jump height computed using flight time methodology.

34. **Peak Power** [W] (PP): Greatest power achieved.

35. **Reactive Strength Index Modified** [m•s-1] (RSI_{mod}): Jump height (calculated from flight time) divided by contraction time.

Countermovement Jump Concentric Alternative Variables (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020)-

36. **Concentric Impulse** [Ns] (ConcImp): Concentric force exerted multiplied by time taken.

37. **Concentric Peak Velocity** [m•s-1] (PV): Greatest velocity achieved during the concentric phase.

38. **Concentric RPD** [W•s-1] (ConcRPD): Rate of power development form the start of the concentric phase to peak power.

39. **Force at Peak Power** [N] (F@PP): Force exerted at peak power.

40. **Velocity at Peak Power** [m•s-1] (V@PP): Vertical velocity achieved at peak power during the takeoff Phase.

Countermovement Jump Eccentric Alternative Variables (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020)-

41. **Eccentric Mean Braking Force** [N] (EccMBF): Mean force during the eccentric braking phase from minimum force to zero velocity at the end of the eccentric phase.
42. **Eccentric Mean Deceleration Force** [N] (EccMDecF): Mean force during the eccentric braking phase from minimum force to zero velocity.
43. **Eccentric Mean Force** [N] (EccMF): Mean force during the eccentric phase from start of movement to zero velocity.
44. **Eccentric Mean Power** [W] (EccMP): Mean power during the eccentric phase from start of movement to zero velocity.
45. **Eccentric Peak Force** [N] (EccPF): Greatest force achieved during the eccentric phase.
46. **Force at Zero Velocity** [N] (F@0V): Force exerted at concentric onset.

Countermovement Jump Phase Duration Variables (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020)-

47. **Braking Phase Duration** [s] (BrakPDur): Period from minimum force to the start of the concentric phase.
48. **Concentric Duration** [ms] (ConcDur): Duration of the concentric phase.
49. **Contraction Time** [ms] (CT): Duration from jump initiation to take-off.
50. **Contraction Time: Eccentric Duration**: Ratio of total contraction time to eccentric duration as a percent.
51. **Eccentric Acceleration Phase Duration** [s] (EccAPD): Time period from start of movement to maximal negative velocity.

52. **Eccentric Deceleration Phase Duration** [s] (EccDPD): Time period from maximum negative velocity to zero velocity at the end of the eccentric phase.
53. **Eccentric Duration** [ms] (EccDur): Duration of the eccentric phase.
54. **Flight Time** [ms] (FT): Time spent in the air from jump take-off to landing.
55. **Flight Time: Eccentric Duration:** Ratio of Flight Time to Eccentric Duration.

List of Abbreviations

Accel = Acceleration

ConcRPD = Concentric RPD

CT = Contraction Time

CMJ = Countermovement Jump

Decel = Deceleration

Ecc = Eccentric

eTL = External Training Load

FT = Flight Time

FT:CT = Flight Time:Contraction Time Ratio

Force@PP = Force at Peak Power

Force@0V = Force at Zero Velocity

IMA = Inertial Movement Analysis™

IMU = Inertial Measurement Unit

iTL = Internal Training Load

IT = Interpolation Twitch

JH = Jump Height

LFF = Low Frequency Fatigue

MVC = Maximal Voluntary Isometric Contraction

PL = PlayerLoad™

$PL_{1D\text{-}FWD}$ = $PlayerLoad_{1D\text{-}FWD}$

$PL_{1D\text{-}SIDE}$ = $PlayerLoad_{1D\text{-}SIDE}$

$PL_{1D\text{-}UP}$ = $PlayerLoad_{1D\text{-}UP}$

PL_{2D} = $PlayerLoad_{2D}$

PV = Concentric Peak Velocity

RPE = Rating of Perceived Exertion

RSI_{Mod} = Reactive Strength Index-Modified

RT = Resting Twitch

sRPE = Session Rating of Perceived Exertion

T:C = Testosterone:Cortisol Ratio

USG = Urine Specific Gravity

Velocity@PP = Velocity at Peak Power

VA = Voluntary Activation

CHAPTER II: REVIEW OF LITERATURE

The purpose of this investigation was to examine acute neuromuscular function changes and endocrine responses to a single bout of basketball specific training at high and low training loads in a cohort of elite collegiate basketball players. The secondary purpose of this study sought to related laboratory-based metrics of fatigue with field-based assessments following a bout of sport-specific basketball training.

Athlete Monitoring in General

Athlete monitoring strategies are used to understand imposed training loads, and to evaluate an athlete's response to training stimuli. The balancing of training strategies is paramount to improving physical capacities to excel in sport (Halson, 2014; Taylor et al., 2012). Monitoring strategies can be useful in optimizing an athlete's performance by determining their position on the recovery-adaptation continuum following a training exposure, managing training loads to mitigate injury risk, as well as establishing quantitative parameters to guide return-to-play and return-to-performance protocols following an injury (Bourdon et al., 2017; Dunlop et al., 2019; Halson, 2014; Taberner et al., 2019).

Athlete monitoring strategies are increasingly popular among team sports, used in an effort to manage player workloads and reduce the inhere risk of injuries. In sport, the primary goal of performance in most organizations is winning games and team success. Not surprisingly, player injuries appear to be a debilitating component that blunt both winning and overall team success. A systematic review including 14 studies evaluating the relationship between injury and team success concluded that injuries impose a clearly detrimental effect on the final ranking in team sports, that in-game injuries influence the outcome of team success, and that increases in player availability translate to heightened team success throughout a season (Drew et al., 2017). More specifically, an 11-year follow up study of injuries among teams in the top European league revealed a significant inverse relationship between in season injury rates and improvements in team performance, which included the final league ranking, points per game, and the teams Union of European Football Association (UEFA) Season Club Coefficient (Hägglund et al., 2013). Interesting, injury data appears linked to the physical demands of the game, where player availability may not only mitigate team success, but also moderate the physical demands of the match for available players. Similarly, work in professional rugby has drawn similar conclusions, as increases in injuries were associated with substantial decreases in team success (Williams et al., 2016). Increases in player unavailability has been shown to be associated with increases in match intensity in European League football, including increases the estimated percentage of distance traversed above 14km/h and the number of sprints performed by the team (Windt et al., 2018). Contemporary evidence suggests monitoring training loads and recovery from training may play a key role in managing players to mitigate the inherent risk of injury associated with sport participation (Bourdon et al., 2017; Jacobsson & Timpka, 2015; Taberner et al., 2019). Moreover, athlete monitoring systems may play a key role in the return-to-play and return-to-performance, providing quantitative metrics to ensure a smooth transition as the athlete is reintegrated into training and competition (Taberner et al., 2019).

Quantitating training loads during individual activities, such as strength training, are relatively simplistic in the controlled environment of the weight room, with coaches often computing training volume-loads as the total number of sets multiplied by the number of repetitions per set, then multiplied by the weight lifted per repetition, leading to an overall understanding of the quantity of work prescribed during the training session (Haff & Triplett, 2015). However, the reactive and intermittent nature of team sport play makes quantitating training loads during sport-specific training sessions much more challenging and sophisticated.

Athlete monitoring strategies have become common practice to quantitate training loads and evaluate the athlete's response to training stimuli among team sports. Athlete monitoring strategies can be divided into two distinct categories: 1) the quantification of training loads imposed; and 2) monitoring the fatigue/recovery responses to the applied training load (Taylor et al., 2012). Monitoring training and subsequent recovery can provide information about the dose-response relationship of training.

Quantifying Athlete Training Load During Team Sport Activity

External Training Load Monitoring

External load monitoring strategies refer to the assessment of mechanical or locomotive work completed by the athlete (Boyd et al., 2011; Halson, 2014; Heishman, Curtis, et al., 2018; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020). These objective measures of work performed by the athlete during training or competition are measured independently of the internal response and often used to reflect the quantity of training prescribed (Bourdon et al., 2017; Halson, 2014).

The origin of monitoring external training load in basketball players dates back to the 1938-39 Big Ten conference basketball season, where researcher Lloyd Messersmith quantified the distance traveled by players during games played at the Indiana University field house at Bloomington (Messersmith & Bucher, 1939). Positioned above the playing area with a novel electrical pursuit apparatus scaled to the size of the court, the researcher would trace a player's movement during the game and the system would provide a numerical registration in the distance traversed during play.

The start of more contemporary methods to quantitate external workloads during team-sport have incorporated the use of time-motion analysis to capture movement performed by the athlete during sport-specific play (Bourdon et al., 2017; Carling et al., 2018; Halson, 2014). Although forward-thinking and innovative, the cumbersome and time-consuming analysis limits assessments to individual players and lacks efficient scalability to the entire team (Carling et al., 2018; Cummins et al., 2013; Halson, 2014). Global Positioning Systems (GPS) were then implemented for use in player monitoring systems. Originally devised for military use, GPS can provide three-dimensional movement and spatial context of athlete activity, as well as offer real-time analysis of performance during team sport play (Chambers et al., 2015; Cummins et al., 2013; Dellaserra et al., 2014; Malone et al., 2017). The validity and reliability of utilizing GPS to monitor external load in team sport is well documented (Coutts & Duffield, 2010; Duffield et al., 2010; Jennings et al., 2010; Scott et al., 2016). Despite evidence suggesting the validity of quantitating external loads in field-based sports by the use of GPS, these systems have shown a reduction in accuracy when play is confined to smaller spaces, such as small-sided games (SSG) or other activities with reduced field size (Duffield et al., 2010). Furthermore, without the assistance of local positioning systems, the potential use of GPS is quickly mitigated due to the inhibition of GPS signaling indoors. While local positioning systems are available and intriguing for implementation among indoor sports, their prevalence is stagnated by high costs, as well as a lack of portability that eliminates their utilization in alternative training or competitive venues (Chambers et al., 2015; Fox et al., 2017; Halson, 2014; Heishman, Curtis, et al., 2018; Heishman, Peak, et al., 2020; Holme, 2015). The aforementioned shortcomings of GPS systems and local positioning systems have led to the development and implementation of alternative strategies to quantitate external training loads in indoor sports (Chambers et al., 2015; Fox et al., 2017; Heishman, Curtis, et al., 2018; Heishman, Peak, et al., 2020; Howe et al., 2017; Polgaze et al., 2015; Roell et al., 2018).

Wearable microsensors known as inertial measurement units (IMUs) offer a more practical and convenient option to quantitate external training loads among indoor sports such as basketball, ice-hockey, and handball. Athletes wear the microsensor in a supportive harness, specifically designed to unobtrusively secure the unit between the scapulae at approximately the 7th thoracic vertebrae, in close proximity to their center of gravity, while imposing no interference to the athlete's movements or play (Fox et al., 2017; Heishman et al., 2017; Heishman, Curtis, et al., 2018; Hoffman et al., 2012; McLean et al., 2018). Commercially available microsensors often include an accelerometer, a gyroscope, and a magnetometer (Chambers et al., 2015; Fox et al., 2017; Holme, 2015). Working in conjunction, the three components can capture the dynamic movement signature an athlete generates during team sport play. Accelerometers are motion sensing devices used to quantitates linear acceleration (expressed in G-forces) (Yang & Hsu, 2010), alluding to the magnitude and frequency of movement in space (Aminian & Najafi, 2004). Operating based upon the principles of the Coriolis Effect, gyroscopes are motion sensing devices used to measure the angular velocity concerning one or multiple axes, facilitating the detection of changes in orientation (Aminian &

Najafi, 2004; Luinge & Veltink, 2005; Yang & Hsu, 2010). Accelerometers and gyroscopes are commonly coupled due to their complementary features, such as the capacity to improve the precision of acceleration data when the inclination with respect to gravity is unknown. Although not technically classified as a microsensor, magnetometers are often integrated within the microsensor devices to allow enhanced unit orientation. The magnetometer provides the orientation of movement in respect to the magnetic north, often supporting and revising the orientation inferred by the gyroscope (Aminian & Najafi, 2004; Holme, 2015).

The manufacturers of the commercially available microsensor technologies have developed supportive software that applies specific algorithms to transform the input of raw inertial data captured during athlete movement, into meaningful and standardized output variables used to quantitate the movement experienced. Further, units contain built-in microprocessor onboard each unit to allow "live" automatic, real-time feedback via telemetry (Fox et al., 2017; Holme, 2015; Peterson & Quiggle, 2017). The output variables used to assess movement demands during sport are classified as either "workload variables" or " event detection variables" (Chambers et al., 2015; Holme, 2015). The commonly employed variables of PlayerLoad™ and Inertial Movement Analysis™ (IMA) may provide valuable information relevant to enumerating external training demands during indoor sports, such as basketball (Heishman, Daub, Miller, Freitas, & Bemben, 2020).

Player Load

A commonly used "workload variable" utilized in team sport is termed PlayerLoad™ (Catapult Innovations, Melbourne, VIC, Australia) or BodyLoad™ (GPSports, Canberra, Australia), depending upon the which commercial IMU hardware and software are utilized (Holme, 2015; Howe et al., 2017). Commonly used to quantitate gross movement is the triaxial accelerometer derived PlayerLoad™ (Chambers et al., 2015; Fox et al., 2018; Heishman et al., 2017; Heishman, Curtis, et al., 2018; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Howe et al., 2017; Peterson & Quiggle, 2017; Rowell et al., 2017; Van Iterson et al., 2017). PlayerLoad™ variable is a vector of magnitude, expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the 3 orthogonal planes and divided by the scaling factor of 100 and is expressed in arbitrary units (au) (Barrett et al., 2014; Boyd et al., 2011; Heishman, Curtis, et al., 2018; Heishman, Peak, et al., 2020; Rowell et al., 2017; Van Iterson et al., 2017). PlayerLoad™ can be mathematically represented in accordance with the following formula:

$$\text{PlayerLoad™} = \sqrt{\frac{(a_{Y1} - a_{Y-1})^2 + (a_{X1} - a_{X-1})^2 + (a_{Z1} - a_{Z-1})^2}{100}}$$

Note: *a_Y = anteroposterior acceleration; a_X = mediolateral acceleration; a_Z* = vertical acceleration.

It should be noted, competing manufacturers compute similar variables, but are termed differently, such as BodyWork™ (GPSport) (Chambers et al., 2015; Holme, 2015; McLean et al., 2018). For the Catapult (Catapult Innovations, Melborne, VIC, Australia) IMU specifically, accelerometer data for PlayerLoad™ is sampled at 1000Hz and then down sampled to 100Hz to provide the raw sensor values, allowing enhanced sensitivity of movement detection in comparison to tradition GPS data, merely collected at 10Hz (Boyd et al., 2011; Chambers et al., 2015; Heishman, Curtis, et al., 2018; Heishman, Peak, et al., 2020; Nicolella et al., 2018; Van Iterson et al., 2017; Ward et al., 2018).

PlayerLoad™ has been demonstrated as a valid and reliable measure in quantitating the locomotive demands of team-sport play and quantifying gross human movement in both indoor and outdoor sports (Barrett et al., 2014; Boyd et al., 2011; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020; Spangler et al., 2018; Staunton et al., 2017; Van Iterson et al., 2017). Furthermore, the real-time analysis of PlayerLoad™ can deliver useful and immediate feedback for coaches and practitioners during training.

The PlayerLoad™ workload variable has been employed to characterized external load demands in a variety of team-sports during practice and competition (Chambers et al., 2015). More specifically in basketball, the use of accelerometer-derived workload variables have been employed to outline the external load demands over various training phases (Aoki et al., 2017; Fox et al., 2018; Heishman, Curtis, et al., 2018; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Hoffman et al., 2012; Montgomery et al., 2010b; Schelling & Torres-Ronda, 2013; Schelling & Torres, 2016).

Among outdoor sports using GPS, the distance an athlete travels during play is used as an index of work volume (Chambers et al., 2015; Cummins et al., 2013; Holme, 2015). Similarly, in indoor sports, PL is often the primary index used to understand the volume of work a player experiences, while PL per minute (PL/min) measures the work rate a player may experience. Previous literature has identified an association between PL and distance traveled during play in multiple team sports (Barrett et al., 2014; Gallo et al., 2015; Heishman, Peak, et al., 2020; Polgaze et al., 2015). In a preliminary analysis including a cohort 13 men's basketball players, Heishman et al. (2020) observed a very large to nearly perfect correlation between distance traveled and PL over the course of three practices and outlining the predictive capacity between the two parameters, reinforcing the value of PL as an estimation of training volume during basketball play (Heishman, Peak, et al., 2020).

PlayerLoad™ has also been used to evaluate relationships between external training loads and subsequent changes in neuromuscular performance indices in team-sport. In a cohort of elite collegiate basketball players, Heishman et al. (2018) observed the acute relationship in that an increase in PlayerLoad™ was associated with a decrease in countermovement jump performances the following day (Heishman, Curtis, et al., 2018). In more recent work by Heishman et al. (2020), elevated PL per minute during the preseason training period appeared to be associated with a moderate effect of a decrease in FT:CT and RSI_{Mod} (Heishman, Daub, Miller, Freitas, & Bemben, 2020). These data suggest the relationship between increases in eTL and subsequent changes in neuromuscular performance.

Similarly, Rowell et al. (2017) explored alterations in countermovement jump performance following match play in A-League Australian Football, finding that players with PlayerLoad™ accumulation >500 au suffered decreased countermovement jump performance for at least 42 hours post-match. Therefore, it appears the accelerometer-based activity assessments from commercial microsensor technologies offer an effective method in quantitating external load demands relevant during team-sport activity.

As previously mentioned, traditional computation and utilization of the PlayerLoad™ metric includes the summation of load vectors in all three orthogonal planes (mediolateral, anteroposterior, and vertical). However, laboratory evidence suggests the vertical components of PlayerLoad™ contributes to approximately 50-60% of the load accumulation (Barrett et al., 2014). In contrast, the mediolateral and anteroposterior vectors only contribute 20-25% of load accumulation during the 3D PlayerLoad™ analysis (Barrett et al., 2014). In fact, further field-based analyses have identified strong correlations between PL and total distance traveled, suggesting sensitivity of PL to running based activity (Gallo et al., 2015; Heishman, Peak, et al., 2020; Jennings et al., 2010; Polgaze et al., 2015). It has been speculated that such a relationship manifests from increases in vertical accelerations generated from ground reaction forces during the gate cycle (Cormack et al., 2013; Mooney et al., 2013). These findings have spawned contemporary interests in alternative formulas to either neglect the vertical acceleration activity or interpret individual movement vectors independently.

Although a dearth of literature currently exists exploring individual vector analysis in basketball, evidence in other team sports suggests delineated PL vectors for individual analysis may provide a more comprehensive assessment of athlete activity (Cormack et al., 2013; McLean et al., 2018; Page et al., 2015; Ward et al., 2018). Isolating or eliminating specific vectors of movement may provide enhanced insight of external load demands. For example, sampled and calculated in the same way as PlayerLoad™, but omitting the vertical vector and only including the 2-dimensions of mediolateral and anteroposterior vectors, termed PlayerLoad 2D ($PlayerLoad_{2D}$), has been shown to parallel agility demands in Australian Football (M. Davies et al., 2013), as well as been associated with collision demands in rugby (Gabbett, 2015). Further, research in Australian rules football has observed reductions in vertical player load to be associated with subsequent decrease in jump performance (Cormack et al., 2013). Recent work by McLean et al. (2018) speculated an abundance of vertical acceleration data may mask smaller increases in mediolateral and anteroposterior vectors, which may be pertinent in estimating external load activity. Therefore, it may be speculated that the large vertical component of basketball play could exacerbate the suppression of smaller increases in mediolateral and anteroposterior movements, such as increases in change-of-direction (CoD). Interestingly, recent work in basketball specifically, basketball has actually identified the anteroposterior (PL_{1D-UP}) and (PL_{1D-FWD}) mediolateral components contributed 2-7% more to total PL compared to previously reported data in linear running (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020). These findings likely represent the large lateral component of basketball, as well as frequent linear accelerations and decelerations, which produce more horizontal, rather than vertical ground reaction forces compared to top-end speed running (Nagahara et al., 2018) which cannot be achieved in the confined area of play of basketball (Cormack et al., 2013; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020; Ward et al., 2018). Nonetheless, enhanced quantification of these movements may be a key component in unveiling movement demands during basketball training activities that relate to the manifestation of specific fatigue. While the relationship between $PlayerLoad_{2D}$ and indices of fatigue and recovery during basketball play remain unknown, it may be speculated that individual PlayerLoad™ vector analysis could yield additional insights not captured by the gross computation of the traditional 3-dimensional PlayerLoad™ analysis, alone.

Inertial Movement Analysis (IMA™)

Intertial Measurement Analysis™, IMA™, is defined as an instant one-step movement effort and expressed as count data (ct). IMA™ aggregates triaxial accelerometer and triaxial gyroscope data to generate a non-gravity vector to detect acceleration events, while also determining the direction and magnitude of the acceleration event (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Holme, 2015; Luteberget & Spencer, 2017; Meylan et al., 2017; Peterson & Quiggle, 2017; Spangler et al., 2018) These distinct acceleration micro-movement events are generated during sudden explosive movement bouts, such as accelerations, decelerations, and change of direction (CoD) movements, which are common among team sports (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Holme, 2015; Peterson & Quiggle, 2017; Spangler et al., 2018; Ward et al., 2018).

Utilizing proprietary algorithms, post-session data analysis performed by the manufacturer software (Openfield, Catapult) quantifies IMA™ events. More specifically, IMA™ events are detected using the raw input accelerometer and gyroscope data to generate a non-gravitational acceleration vector based on advanced Kalman filtering algorithms (Holme, 2015). An IMA™ event is detected by the application of polynomial smoothing curves between the start and end point of the accelerative event (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Holme, 2015; Peterson & Quiggle, 2017; Spangler et al., 2018). The magnitude of an event (IMA™ Magnitude) is subsequently computed by summing the accelerations under the polynomial curve, measure in terms of delta-velocity, a unit of impulse ($m \cdot s_{-1}$). Based upon the magnitude of each event, IMA™ count can be characterized into narrow intensity bands, such as the default bands which include low (1.5 to 2.5 $m \cdot s_{-1}$), medium (2.5 to 3.5 $m \cdot s_{-1}$), or high (>3.5 $m \cdot s_{-1}$) intensity (Heishman, Daub, Miller, Freitas, & Bemben, 2020). Furthermore, the direction of an IMA™ events is calculated based upon the angle of the applied acceleration with respect to the relative orientation of the unit at the time of the event. Oftentimes, the total number of IMA™ events during the activity is reported (Total IMA™) (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Holme, 2015; Peterson & Quiggle, 2017). However, IMA™ count data can also be divided into the respective planes of their occurrence, ultimately creating a directional distribution of high-intensity micro-movements in all three orthogonal planes. Partitioning IMA™ count data into their directional distribution of occurrence divulges greater context into the athlete's movement signature during the activity by providing quantitative data associated with the number of accelerations and deceleration in the anteroposterior plane, CoD in the mediolateral plane, as well as jumps in the vertical plane (Holme, 2015).

While the use of IMA™ data is used in the applied sport performance setting, limited research exists exploring the use of IMA™ related variables, especially compared to the large body of literature examining other external load variables, such as PlayerLoad™. However, a recent investigation by Holme (2015), demonstrated the reliability of IMA™ count variables when expressed as total counts, as well as when delineated into low and combined medium/high intensity bands. Further, the coefficient of variations (CV < 5%) of IMA™ count variables was below the smallest worthwhile difference, supporting the capacity for IMA™ event variables capacity to detected meaningful change. Similarly, in another laboratory-based analysis, Spangler et al. (2018) reported IMA™ analysis software displayed excellent jump detection accuracy, detecting 96.9% of the jumps performed (Spangler et al., 2018). Furthermore, the system showed high levels of both sensitivity (95.8%) and specificity (99.7%), pivotal in accurately determining external load demands.

Exploring the reliability of IMA™ in a more ecologically valid method, Meylan et al. (2017) observed good reliability (CV = 14%), as compared to GPS (CV = 18%), when measuring explosiveness from game-to-game in women's soccer and proposed IMA™ data as a potential tool in quantifying match specific explosive actions (Meylan et al., 2017). A novel study in a cohort of collegiate women's basketball players by Peterson and Quiggle (2017) suggested relative changes in IMA™ variables may provide superior information with respect to changes in tissue readiness, as assessed by Tensiomyographical responses, compared to simply using accumulated PlayerLoad™ (Peterson & Quiggle, 2017). In potentially the most robust exploration of IMA™, Ward et al. (2018) characterized positional differences in activities during elite American Football training. Their findings suggest IMA™ may provide more pertinent information associated with the quantity of sport-specific movements performed by athletes, not captured by the PlayerLoad™ metric (Ward et al., 2018). The culmination of the aforementioned literature suggests a unique perspective can be derived from the use of IMA™ when monitoring athlete's external training load. However, the limited exploration of IMA™ utilization in basketball specifically, as well as the lack of data associating IMA™ variables with subsequent alteration in athlete fatigue warrants the exploration by future research.

Internal Training Load Monitoring

Internal load monitoring strategies are defined as the relative biological stressor imposed on an athlete during training or competition (Bourdon et al., 2017; Halson, 2014; Heishman, Curtis, et al., 2018). In team sport, internal load is commonly assessed using physiological parameters (Aoki et al., 2017; Berkelmans et al., 2018; Halson, 2014; Heishman, Curtis, et al., 2018; Scanlan et al., 2014), such as heart via a heart rate chest strap, but also perceptual parameters (Bartlett et al., 2016; Casamichana et al., 2013; Haddad et al., 2017; Halson, 2014; Impellizzeri et al., 2004; Scanlan et al., 2014) during or immediately following training sessions or competitions. As previously mentioned, external load is associated with athlete prescription, while internal load monitoring is associated with an athlete’s response to the prescribed training stimuli (Berkelmans et al., 2018; Bourdon et al., 2017; Halson, 2014; Heishman, Curtis, et al., 2018). The inherit dose-response relationship between external load prescriptions and internal load response may offer a unique tool to monitor training fatigue and recovery.

The linear relationship established between heart rate (HR) and VO_2 makes HR monitoring an attractive tool when monitoring internal training loads during training (Achten & Jeukendrup, 2003; Berkelmans et al., 2018). Capitalizing upon this relationship allows inferences associated with energy expenditure, oxidative metabolic recruitment, and exercise intensity, all with immediate live feedback, during team sport activity through the use of HR monitoring. Quantifying HR intensity during play can assist practitioners in designing periodization schemes to optimize physical capacities to meet the metabolic demands associated with sport-specific play (Berkelmans et al., 2018; Bourdon et al., 2017; Halson, 2014; Smith, 2003). In addition to monitoring training intensity, HR monitoring has been used to illuminate athlete fatigue and nonfunctional overreach by identifying HR responses higher than expected for a specific training stimulus (Berkelmans et al., 2018; Halson, 2014; Smith, 2003).

Heart rate data during basketball has been examined and descriptively reported, outlining the average and peak responses experience during play (Berkelmans et al., 2018; Montgomery et al., 2010a; Scanlan et al., 2014; Schelling & Torres-Ronda, 2013). While this information is of use, innovative strategies have been used to generate heart rate-based training loads that incorporate exercise duration, resting, mean, and maximal

HR. The Training Impulse (TRIMP) model which was designed to mimic the blood lactate concentrations that increase curvilinearly with increases in exercise intensity (Morton et al., 1990). Computing a training load metrics that involve a variety of HR parameters has been suggested as more favorable for the intermittent nature of team-sport, such as basketball (Berkelmans et al., 2018; Bourdon et al., 2017). The TRIMP equation as measured in arbitrary units (au) is as follows:

$$Banister's\ TRIMP = Training\ Duration(mins)\ X\ (\Delta HR\ ratio)e^{b(\Delta HR\ ratio)}$$

Note: b = sex factor (female = 1.67; males = 1.92); e= base of the natural logarithm (constant of 2.712); HR ratio = ($HR_{exercise}$ -HR_{rest})/ HR_{max} – HR_{rest}), with $HR_{exercise}$ meaning HR during the training session, HR_{Rest} meaning HR at rest pre-exercise, and HR_{max} meaning HR during maximal exercise testing.

The Banister TRIMP model has been utilized in the basketball setting to monitor training loads alone, but specific interests have centered around comparing the relationship between internal and external load monitoring strategies in basketball. Scanlan et al. (2014) outlined a positive but weak correlation between accelerometer-based loads and TRIMP scores ($r = 0.38$). Similarly, Heishman et al. (2018) identified significant differences between high and low PlayerLoad™ were paralleled with significant differences in TRIMP scores ($p < 0.001$). Aoki et al. (2017) performed a similar analysis suggesting internal load was influenced more by the volume of work, while external load was influenced to a greater extent by exercise intensity. The culmination of these data suggests that while there is a correlation between internal and external load monitoring methods, each provides different information about an imposed training stimulus. While HR monitoring does seem appealing to provide additional information describing training demands, the use of HR monitoring is not without limitations. A variety of factors can influence HR, such as hydration, nutrition, emotions, and environmental factors (Berkelmans et al., 2018).

Subjective Measures: Rating of Perceived Exertion

Contemporary work has suggested factors influencing fatigue during human performance may be more accurately be understood through the dichotomization of fatigue into the categories of (i) *performance fatigability*, defined as a decline in an objective measure of performance over a discrete period, and (ii) *perceived fatigability*, defined as changes in the sensations that regulate the integrity of the performer (Enoka & Duchateau, 2016; Kluger et al., 2013). To that effect, rating of perception of effort (RPE) is one of the most common methods of assessing internal training load, where the athlete is asked, usually occurring at the end of the session, to subjectively rate the intensity of the training session (scale 1-10) (Halson, 2014). The cost effectiveness and ease of implementation makes RPE an accessible and attractive method to assess training loads in athletes of all levels. Importantly, data shows a strong relationship between the subjective perceptual feedback of RPE during, as well as following training, with heart rate parameters and external training load indices (Halson, 2014; McLaren et al., 2018).

Additionally, Foster et al. (2001) proposed the session RPE (sRPE) strategy, calculated by multiplying the RPE subjective measure (scaled 1-10) by the duration of the training session (in minutes), providing a perceptual training load value for the entire training exposure (Foster et al., 2001). While a strong association between sRPE and other quantitative parameters of training load has been established (Impellizzeri et al., 2004; McLaren et al., 2018), some evidence suggests that sRPE lacks sensitivity to discriminate between basketball training session and competition with clear differences in external training load (Fox et al., 2018), but also limited in detecting discrepancies between- and within-game variability in other team sport (McLaren et al., 2016; West et al., 2014; Weston et al., 2015). Ultimately, it appears RPE information is useful, but is most valuable when coupled with other indices to understand the athlete's response to training, but nonetheless the perceived exertion of the athlete should be considered.

Assessing Athlete Fatigue and Recovery Responses After Training

The second strategy to monitor training is to evaluate the athlete's response to previous training stimuli, oftentimes attempting to evaluate residual fatigue from the previous training exposure. In the applied setting, practitioners are often more concerned with identifying the presence of fatigue, rather than determining the mechanistic origin of the observed fatigue, however, understanding the underlying causes and origin of the fatigue when present may provide an added benefit to enhancing overall performance.

The Physiology of Fatigue

Although many definitions exist (Simeon P Cairns et al., 2005; Enoka, 1995), fatigue has classically been defined as the failure to maintain the required or expected force (or power) output (R. Edwards et al., 1977). Fatigue is a multifactorial and task specific phenomenon. Traditional research investigating mechanisms of fatigue have employed a reductionist approach, attempting to identify one single predominant cause of fatigue, measured by a single method or approach (Abbiss & Laursen, 2005; S P Cairns, Knicker, Thompson, & Sjøgaard, 2005). This reductionist approach has potentially led to discipline bias when extrapolating the cause of fatigue outcomes (S P Cairns, Knicker, Thompson, & Sjøgaard, 2005; Simeon P. Cairns, 2013; Gathercole, Sporer, Stellingwerff, et al., 2015a). More recent approaches strive to take a holistic and interdisciplinary perspective to describe fatigue by coupling knowledge from *in vitro* and laboratory-based models as they relate to what happens during specific sport activities (Knicker et al., 2011; Mendez-Villanueva et al., 2007; Reilly et al., 2008). In actuality, the multiple physiological mechanisms of fatigue are likely acting in an integrated and dynamic fashion, rather than operating in isolation, ultimately culminating in the observed fatigue symptoms and performance decrements (Abbiss & Laursen, 2005; S P Cairns, Knicker, Thompson, & Sjøgaard, 2005; Enoka & Stuart, 1992; Hargreaves, 2008; Kent-Braun et al., 2012; St. Clair Gibson & Noakes, 2004). It is important to recognize that fatigue may arise due to the failure of one or more sites along the motor pathway from the central nervous system (CNS) all the way to the contractile apparatus of the muscle (R. Edwards et al., 1977; Enoka & Duchateau, 2008; Kent-Braun et al., 2002a). The plethora of physiologic factors contributing to fatigue along the motor pathway are typically defined as being central or peripheral mechanisms based upon their origin (Ament & Verkerke, 2009; Burnley, 2009; Gandevia, 2001).

Central Fatigue

Central fatigue is defined as the progressive reduction in voluntary activation of muscle during exercise and reflects alterations proximal and not encompassing changes at the neuromuscular junction (Markus Amann, 2011; Boerio et al., 2005; Burnley, 2009; Enoka, 1995; Gandevia, 2001). Moreover, central fatigue consists of a failure in the central nervous system (CNS) to drive the motor neurons, commonly referred to as a reduction in central motor drive (M. Amann & Calbet, 2008; Gandevia, 2001). Central fatigue mechanisms are at play to decrease motor drive and prevent potentially devastating changes in homeostasis (Enoka & Stuart, 1992; Gandevia, 2001). Deficits in CNS drive are delineated as either supraspinal fatigue or spinal fatigue. Supraspinal fatigue is associated with the reduction of motor cortex output, while spinal fatigue involved inhibition of motor neuron excitability amidst the complexities of spinal reflex network (Gandevia, 2001). Furthermore, both supraspinal and spinal fatigue can be influenced by feedback from group III and IV afferents located in peripheral tissue (M. Amann & Calbet, 2008; Markus Amann, 2011, 2012; Enoka & Stuart, 1992). The group III and IV are activated in response to the internal environmental ambiance of the peripheral muscle to provide feedback to the CNS (Markus Amann, 2012; Gandevia, 2001).

Lab-Based Assessments of Central Fatigue: Twitch Interpolation

Central fatigue can be measured in the laboratory setting via the twitch interpolation technique (Boerio et al., 2005; Gandevia, 2001; Merton, 1954; Shield & Zhou, 2004). Twitch interpolation technique involves assessing the extent of motor unit recruitment during a volitional contraction by applying a supramaximal electrical stimulation to the muscle or nerve, illuminating deficits in volitional recruitment. The following equation is used to assess voluntary activation during the twitch interpolation technique, where IT = interpolated twitch and RT = resting twitch (Shield & Zhou, 2004):

$$Voluntary\ Activation\ (\%VA) = 100\%\ X\ \left(1 - \left(\frac{IT}{RT}\right)\right)$$

Peripheral Fatigue

Peripheral fatigue reflects alterations in processes at or distal to the neuromuscular junction that decrease force-generating capacities of skeletal muscle (Burnley, 2009; Ross et al., 2007). In other words, during peripheral fatigue, skeletal muscles are simply incapable of responding to adequate central activity, leading to peripheral factors becoming the key limitation in force producing capacities (Macintosh & Rassier, 2002).

Therefore, a variety of mechanisms could play a role in the manifestation of peripheral fatigue. Factors that influence changes in muscle performance in the presence of peripheral fatigue include alterations in neuromuscular transmission and sarcolemma excitability, disruptions in excitation-contraction coupling, modifications in contractile activity, as well as decreases in metabolic energy supply and metabolite accumulations (Allen et al., 2008; Bigland-Ritchie & Woods, 1984; Kent-Braun et al., 2012).

Excitation-contraction coupling begins with neuromuscular transmission initiating action potential (AP) propagation that spreads rapidly over the sarcolemma and throughout the transverse tubule (t-tubule) system, where it will activate 1,4-dihydropyridine receptors (DHPR) which will undergo a conformational change and triggering the subsequent opening of the adjacent ryanodine receptor (RyR1) to release Ca^{2+} from the sarcoplasmic reticulum (SR), providing Ca^{2+} for cross-bridge cycling. Ion channels within the t-tubule can become compromised with chronic depolarization during activity (Allen et al., 2008; Kent-Braun et al., 2012). During repeated activation, increases in net K^{+}, or decreases in intracellular K^{+}, alter cellular depolarization, result in the inactivation of both Na^{+} channel activity and the DHPR. Alterations in voltage-gated Na^{+} channels within the t-tubule system can lessen the electrochemical gradient, through decreases in extracellular [Na^{+}] or increased in intracellular [Na^{+}], decreasing the magnitude and prolonging the duration of AP propagation. Furthermore, the elevation in the levels of intracellular Na^{+} and extracellular K^{+} blunt the electrochemical gradient, due to the inability of Na^{+}-K^{+} pumps to restore the copious Na^{+} influx and K^{+} efflux. The cellular milieu is intensified by the inhibition of Na^{+}-K^{+} pumps not only caused by the decreases in pH, but also increases in ADP and Pi that limit free ATP availability (Allen et al., 2008; Kent-Braun et al., 2012). Interestingly, the t-tubules are more susceptible to elevated [K^+] due to increases in membrane surface area throughout this system. Ultimately, the combination of these changes manifest into an overall reduction in Ca^{2+} release, which translates to less force production. While readily apparent during high frequency electrical stimulation, the aforementioned mechanisms are thought to play a more limited role in causing fatigue during normal *in vivo* exercise, as a variety of preventive mechanisms are thought to exist to attenuate losses in excitability (Allen et al., 2008; Kent-Braun et al., 2012).

The termination of muscle contractions requires the re-sequestration of Ca^{2+} back into the SR. In addition to the modifications to Ca^{2+} kinetics previously mentioned, the re-uptake of Ca^{2+} into the SR may also be altered with fatigue. SR Ca^{2+} ATPase (SERCA) performs primary active transport, pumping Ca^{2+} against its concentration gradient, back into the SR where it can be bound to calsequestrin and stored. Fatigue induces prolong relaxation time due to a reduces rate of SERCA reuptake (Kent-Braun et al., 2012).

Metabolic perturbations appear to be a key component responsible for peripheral fatigue. Working skeletal muscle utilizing energy for contractile activity results in the increase of inorganic phosphate (P_i), adenosine diphosphate (ADP), adenosine monophosphate (AMP), Mg^{2+}, and reactive oxygen species (ROS) (Kent-Braun et al., 2012). Concomitantly, decreases in pH (due to increases in H^+ accumulation), ATP, and overall substrate availability (i.e.-phosphocreatine (PCr) and muscle glycogen) are experienced, contributing to fatigue (Allen et al., 2008; Kent-Braun et al., 2012). The accumulation of metabolites can affect contractile activity, as well as excitation-contraction coupling.

The accumulation of P_i is thought to decrease myofibrillar Ca^{2+} sensitivity, while increasing titanic [Ca^{2+}] in early fatigue and decreasing [Ca^{2+}] in during late fatigue (Allen et al., 2008; Kent-Braun et al., 2012). High levels of P_i have been postulated to induce precipitation of SR Ca^{2+}, aiding apparent modifications in Ca^{2+} release. In addition, P_i increases Ca^{2+} leakage into the intracellular fluid, as well as inhibits the SERCA pump, prolonging relaxation time. Both P_i and H^+ accrual is hypothesized to directly affect actomyosin interactions by limiting the transition from the weakly-bound cross-bridge state to the strongly-bound cross-bridge state, translating to reductions in force production, as well as altering in fiber efficiency (Allen et al., 2008; Kent-Braun et al., 2012). In addition, H^+ is thought to depress force, but also inhibit myofibrillar ATPase activity, thus decreasing maximal shortening velocity. Reductions in maximal shortening velocity occur at all loads, therefore significantly suppressing peak power. Important to note, power is often impacted to the greatest extent due to the combined effect of apparent reductions in both force and velocity. While less clear, ADP accumulation may evoke similar consequences on shortening velocity, as ADP accumulation can slow ADP release from the myosin head. Increases in Mg^{2+} manipulate a reduction in Ca^{2+} sensitivity, which appear to be additional to the effects of H^+ and P_i previously mentioned. Additionally, Mg^{2+} strongly inhibits RyR1 release channels, reducing Ca^{2+} availability. In parallel, high levels ADP have been shown to decrease twitch amplitude and prolongs twitch duration as well as promote SERCA leakage (Allen et al., 2008; Kent-Braun et al., 2012).

ROS are produced through mitochondrial respiration and thought to contribute to muscle fatigue through the oxidation of critical proteins, such as Na^+-K^+ pump, myofilaments, DHPR, and RyR1 (Kent-Braun et al., 2012). More specifically, ROS is thought to play a role in decreasing Ca^{2+} sensitivity, altering maximal Ca^{2+} activated force, reducing Ca^{2+} release, as well as blunting SERCA function, limiting Ca^{2+} re-uptake into the SR (Allen et al., 2008; Kent-Braun et al., 2012).

Substrate depletion and alteration in energy availability influence fatigue. Decreases in [ATP] and [CrP] can lead to reduced SERCA function, as well as increases in leakage leading to elevated intracellular [Ca^{2+}] during fatigue. Ultimately, these factors may lead to a slower rate of muscle relaxation when attempting to terminate contractile activity. Furthermore, decreases in muscle glycogen have been linked with reductions in SR Ca^{2+} release, likely occurring in an effort to reduce the quantity of cross-bridge cycling with the dwindling energy stores, by limiting Ca^{2+} availability (Allen et al., 2008; Hargreaves, 2008; Kent-Braun et al., 2012).

Low Frequency Fatigue

Low frequency fatigue (LFF) is a form of peripheral fatigue defined as the disproportionate loss of force at low firing rates as compared to high firing frequencies. First described by Edwards et al. (1977), LFF is notorious for being long-lasting which may take days for adequate recovery, and continue to persist even in the absence of metabolic disturbances in the muscle (Allen et al., 2008; Fowles, 2006b; Jones, 1996; Kent-Braun et al., 2012). The long-lasting effects of LFF makes it particularly insidious among athletic populations. LFF is thought to be spawned during high intensity, moderate-to high force, repetitive eccentric, or stretch shortening cycle activities (Fowles, 2006b; Jones, 1996; Lattier et al., 2004; Martin et al., 2004; Strojnik & Komi, 2000).

While the definitive mechanisms underlying LFF remain elusive, principle disruption is rooted in a decrease in Ca^{2+} transient, likely associated with alteration in the SR Ca^{2+} release channel or the associated proteins (Bigland-Ritchie & Woods, 1984; R.

Edwards et al., 1977). More specifically, structural changes to RyR1 are hypothesized as a key component in Ca^{2+} release alterations. Structural changes in RyR1 may result from the excessive activation of Ca-Calmodulin dependent protein kinase (CaMKII), phosphodiesterase 4D3 (PDE4D3), and protein phosphatase 1 (PP1) (Kent-Braun & Ng, 1999). While the primary cause of LFF likely revolves around the RyR1 structural changes above, previous literature has proposed the hypothesis of SERCA pump inhibition and/or SR leakage as a potential contributor in LFF. Important to note, the most likely event facilitating LFF manifestation involve calmodulin (CaM), calcium-activated protease, or ROS (Kent-Braun et al., 2012). The detrimental effects LFF are well documented in the laboratory (Jones, 1996; Keeton & Binder-Macleod, 2006) and LFF is often speculated as a principle component of fatigue in team sports (Cormack, Newton, & McGuigan, 2008; Cormack, Newton, McGuigan, et al., 2008; McLean et al., 2018) however, there remain little to no evidence exist directly assessing LFF among athletes following team sport activity.

Laboratory Assessment of Peripheral Fatigue

Studying peripheral fatigue is often performed through the use of electric nerve or muscle stimulation, eliminating the central component and isolating peripheral mechanisms, as measurements can be captured via surface electromyography (EMG) and measured in terms of area or amplitude. Similarly, electrical stimulation is employed to isolate and assess contractile properties associated with force generation capacities, as well as Ca^{2+} kinetics, which may be altered during fatigue. Primary variables of interest are outlined with their associated physiologic change that may be influenced in the presence of fatigue.

Field-Based Assessment of Neuromuscular Fatigue and Recovery

Countermovement Jump Test

The countermovement jump (CMJ) is routinely used in the high-performance sport settings to evaluate functional performance, as well as monitor changes in neuromuscular readiness, fatigue, and subsequent recovery in response to training (Claudino et al., 2017; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). The CMJ test is time efficient to perform and does not impose undue fatigue on the athlete, permitting frequent testing as part of an athlete monitoring routine in team sport. The CMJ has been suggested superior to other field-based testing options, such as the drop-jump or field test, as it has been demonstrated to be more sensitive to neuromuscular fatigue at later stages in recovery. Increases in sensitivity are likely due to the CMJ utilizes the propagation of the dynamic muscle action referred to as the stretch-shortening cycle (SSC) (Cronin & Hansen, 2005; Gathercole, Sporer, Stellingwerff, et al., 2015a; Komi, 1984, 2000; Nicol et al., 2006; Strojnik & Komi, 2000). More specifically, the CMJ elicits the use of the slow-SSC (>250 milliseconds in duration), which has generally been associated as key to sprint acceleration where ground contact time is longer (Cronin & Hansen, 2005; Martinez, 2016). In contrast, the drop-jump measures the fast SSC (<250 milliseconds), generally related to top end speed (Cronin & Hansen, 2005). Therefore, the CMJ may also be more relevant to the sports specific performance of basketball play where acceleration capacities are highly important, due to the intermittent nature of play, whereas the court size often restrains expression of top end speed performance.

During dynamic human locomotion (i.e.- walking, running, jumping, etc), the SCC is characterized by the pre-activation phase in an effort to resist ground impact, followed an active braking phase where the muscle is stretched and eccentrically loaded, which is subsequently followed by the final shortening phase where the muscle undergoes concentric action and push-off occurs (Komi, 1984, 2000). The SSC capitalizes on the elastic properties of the musculature which stores energy during and immediately following the eccentric contractions, which can then be released during the subsequent concentric contraction, ultimately improving force and power production during the concentric action (Gollhofer et al., 1987; Komi, 2000; Nicol et al., 2006; Strojnik & Komi, 2000).

Despite SSC activity requiring both concentric and eccentric muscle action, traditional CMJ variables of interest have centered around the components of the concentric phase or gross jump outputs (i.e. jump height, force, and power), overlooking the performance of the eccentric components (T. Edwards et al., 2018b; Gathercole, Sporer, Stellingwerff, et al., 2015a). The complex and multifaceted changes associated with neuromuscular fatigue have catalyzed the exploration of CMJ variables beyond that of the traditional CMJ tests of jump height, force, and power (T. Edwards et al., 2018a; Gathercole, Sporer, Stellingwerff, et al., 2015a, 2015b). Examining these alternative CMJ variables may illuminate specific changes in neuromuscular function, such as those associated with the eccentric phase, which are not commonly obtained in traditional CMJ analyses focused on gross jump outcomes (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020).

The CMJ test is also attractive because it has consistently exhibited high inter- and intraday reliability (Cormack, Newton, McGulgan, et al., 2008; T. Edwards et al., 2018b; Gathercole, Sporer, Stellingwerff, et al., 2015a, 2015b; Heishman, Brown, et al., 2019; Heishman, Daub, et al., 2019; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). Pertinent to basketball, recent work by Heishman et al. specifically examine the reliability of the CMJ traditional and alternative variables when performed with and without the arm swing in a cohort of skilled jumpers (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). The results indicated that the majority of variables met the reliability criteria and appeared capable of detecting the smallest worthwhile change between test sessions during both CMJ protocols. However, due to reduced variability and the isolation of lower extremity function, the CMJ performed without the arm swing was recommended for use during the assessment of acute neuromuscular fatigue and readiness monitoring (Heishman, Brown, et al., 2019; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). In addition to the previous established reliability of the CMJ, the earliest work implementing CMJ utilized the best of three trials in their analysis (Glencross, 1966), however, subsequent work challenged this perspective (Smith, 2003). Results of a meta-analysis revealed the enhanced sensitivity of the CMJ variables to detect performances changes when the average of across trials is used, rather than reporting the highest observed value (Claudino et al., 2017).

The CMJ has been speculated capable of detecting acute changes in low-frequency fatigue (LFF), as well as long-term changes over a season. Previous literature (Cormack, Newton, & McGuigan, 2008; Cormack, Newton, McGuigan, et al., 2008; McLean et al., 2010) has interpreted changes in Flight:Contraction time as potentially indicative of the presence of LFF. Prior work by Lattier et al. (2004) outlined alteration suggestive of LFF following a session of high-intensity uphill running (Lattier et al., 2004). However, only maximal isometric voluntary contractions and contractions evoked from electrical stimulation were included in the analysis, not the CMJ for comparison. The need to develop a field assessment to detect LFF is clear (Fowles, 2006b), CMJ metrics must be paralleled with laboratory assessments to allow appropriate inferences about its capacity to detect LFF. The lack of research examining changes in CMJ performance in relation to changes in laboratory measurements of fatigue warrants more research in this area.

Monitoring Fatigue and Recovery with the Countermovement Jump

Basketball Specific

The CMJ has been used to specifically evaluate acute neuromuscular changes in basketball athlete following either a sport-specific training session or competition, however, the majority of studies have only measured jump height as the performance indices of fatigue and recovery following the event. Regardless, previous literature has consistently shown decrements in CMJ performance after a game or sport-specific training session.

Decreases in CMJ jump height (JH) have been well documented following a bout of basketball activity. Pliauga et al. (2015) reported decreases in JH from pre- to 24-hours and 48-hours after a simulated game in 10 collegiate male players, while no differences were observed immediately after the game (Pliauga et al., 2015). In parallel, Pinto et al. (2015) documented a decrease in JH among 12 male athletes following 2 consecutive game in a tournament, whereas Chatzinikolau et al. (2014) noted decreases in JH 48-hours post-game (ES = 0.6) in 20 national level players (Chatzinikolaou et al., 2014; Pinto et al., 2018). Similarly, Heishman et al. (2018a) observed increases in external training loads were associated with significant decreases in CMJ JH 24-hours after the training session during the pre-season training phase (Heishman, Curtis, et al., 2018).

In contrast, Spiteri et al. (2013) reported increases in JH ($p = 0.03$; ES = 0.4) and power $p < 0.001$; ES = 0.49) two days following a game (Spiteri et al., 2013). These contradictory findings may be due to their calculation of the JH via the impulse-momentum method, rather than the flight time method like the research previously discussed (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). While JH appeared unchanged, Spiteri et al (2013) did identified a significant reduction in Flight Time:Contraction Time (FT:CT) ($p = 0.002$; ES = 0.45). FT:CT is the ratio of an outcome variable, Flight Time (FT), defined as the time spent in air from jump take-off to landing, and a process variable, Contraction Time (CT), defined as the duration (ms) from jump initiation (start of movement) to take-off, in an attempt to evaluate the athlete's jumping strategy (Heishman, Brown, et al., 2019; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). Similarly, in recent work by Heishman et al. (2020), observations of increases in PL/min during the preseason training phase of collegiate men's basketball players were associated with decreases in FT:CT and RSI_{Mod}, of a moderate effect, while no differences appeared in JH (Heishman, Daub, Miller, Freitas, & Bemben, 2020). These observations of a decrease in FT:CT with no apparent reduction in JH may allude to the athletes' ability to preserve power and JH by altering their movement strategy and increasing the duration of the contraction time during the CMJ, ultimately allowing themselves to achieve the desired gross output goal of maximal jump height (Gathercole, Sporer, Stellingwerff, et al., 2015a; Gathercole, Stellingwerff, et al., 2015; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). Cumulatively, these data may suggest alterations in movement strategy (FT:CT) may be more sensitive to changes in neuromuscular performance and that examining CMJ variables beyond the traditional gross output variables may be impactful in recognizing the presence of neuromuscular fatigue following basketball activity.

Similar to acute alterations, changes in CMJ performance have been shown to alter in association with accumulating sport-specific training loads among basketball athletes. Previous literature has documented decreases in JH over the course of the pre-season, potentially in response to the mounting training loads typical of the pre-season training phase (Heishman et al., 2017). Likewise, Cruz et al. also observed similar trends, as increasing training loads were met with subsequent decreases in JH in a cohort of 10 female national level players (Cruz et al., 2018). In addition, Ferioli et al. observed increases in training loads during the preparatory period were negatively correlated to peak power output ($r_2 = -0.53$) in professional and semi-professional basketball players (Ferioli et al., 2018). While these data suggest a relationship between training loads and subsequent performance during the CMJ, limited data exists evaluating changes in CMJ performance beyond the traditional variables of JH or power. In addition, a paucity of data exists comparing the influence of various training loads on subsequent CMJ performance to examine the potential dose-response relationship of exercise prescription and recovery-adaptation in basketball athletes.

Other Sports

The CMJ has been used extensively among field-based team sports, to examine neuromuscular fatigue and readiness, such as Australian Rules Football, soccer, and rugby. Cormack et al. explored changes in CMJ performance following a match in a group of professional Australian Rules Football players (Cormack, Newton, & McGuigan, 2008). They found decreases in FT, FT:CT, and mean force immediately after and 24 hours after the match. Decreases in mean power were observed immediately post, 24-

hours post, and 72- hours post-match. In addition, no differences were observed in JH or mean force and all measures returned to baseline at 72-hours and 120-hours after the match. These findings suggest mean power as an effected variable in monitoring neuromuscular responses to after a match. Rowell et al. also evaluated CMJ performance before and after a match in professional Australian Rules Football players, and also concluding match load mediated depressions in CMJ parameters following the match (Rowell et al., 2017). Specifically, their findings suggested FT:CT as the most sensitive to acute training loads, as decreases were apparent 30-minutes after, 18-hours after, and 42- hours after the match, while variables such JH alone was only suppressed 30-minutes after the game and 18-hours after the game with no difference existed beyond that timeframe.

Alteration in CMJ parameters have also been explored among soccer athletes. Decreases in JH has been documented, especially at 24-hours post-match (Silva et al., 2013). In addition, after a soccer match, both Andersson et al. and Romagnoli et al. noted decreases in JH immediately post, 30 minutes post, 24-hours-post, and 48-hours post (Andersson et al., 2008; Romagnoli et al., 2016). In addition, Romagnoli et al. reported no differences in peak power or peak force at any timepoint (Romagnoli et al., 2016).

Small-sided games are often utilized in team sport to improve technical and tactical performance in team sport, as they are thought to reproduce the demands of competition (Hill-Haas et al., 2011). In a unique study, Sparkes et al evaluated responses in CMJ performance following a small sided game in professional soccer players (Sparkes et al., 2018). Some literature suggests small sided games as being more demanding due to increases in the number of change-of-direction movements (Hill-Haas et al., 2011). Their findings illuminated small sided games evoking decreases in both peak power and JH immediately post and 24-hours post (Sparkes et al., 2018). Observations in soccer performance are not limited to professional athletes. Decreases in peak force and peak power have been observed 24-hours following an NCAA Division III soccer match (Hoffman et al., 2003).

Among rugby athletes, a plethora of data suggests the CMJ is an effective tool at detecting neuromuscular fatigue. McLean et al. documented decreases in FT 24 hours following match play, while no differences in peak power were detected (McLean et al., 2010). In addition, all differences subsided by 96 hours after the match. In contrast, McLellan et al. observed decreased in peak power immediately after and 24-hours after a match (Mclellan et al., 2011). Decreases in peak force were also evident immediately after match play, but peak force portrayed no difference thereafter up to 120 hours. Interesting, rate of force development was declined immediately post and at 24 hours, but was not different at 48 hours, then significantly decreased at 72 and 96 hours, and returned to baseline at 120 hours. Although "rate" variables have been reported as much less reliable (Gathercole, Sporer, Stellingwerff, et al., 2015a; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020), these findings coincide with the bimodal recovery pattern often observed following exercise involving high quantities of SSC activity (Dousset et al., 2007; Gollhofer et al., 1987; Strojnik & Komi, 2000). In parallel, West et al. found significant decreases in peak power at 12 hours and 36 hours after a match ($p < 0.05$) in 14 professional rugby players, while also finding significant decreases in JH at the same time points ($p < 0.05$) (West et al., 2014). Johnston et al. noted similar decreases in peak power (ES = -0.70; $p < 0.001$), but occurring at 48-hours post-match, while no changes were observed immediately post or 24-hours post (Johnston et al., 2013). No significant differences in peak force were observed.

Importantly, the first use exploration of countermovement alternative variables was performed in rugby athletes. In a comparison of the capacity of varies field-based test s to detect neuromuscular fatigue, Gathercole et al. (2015) explored the use of the CMJ traditional and alternative variables (Gathercole, Sporer, & Stellingwerff, 2015; Gathercole, Sporer, Stellingwerff, et al., 2015a, 2015b). In conjunction with a reliability analysis, Gathercole et al. (2015) examine changes in CMJ variables after a fatiguing protocol, with CMJ measurements occurring at baseline, immediately post, 24-hours post and 72-hours post. Immediately following the fatiguing protocol, CMJ variables declined and returned to baseline at approximately 24 hours (Gathercole, Sporer, Stellingwerff, et al., 2015b). The return to baseline was paralleled by a subsequent secondary decline at 72-hours, again possibly symbolizing the bi-modal recovery pattern following SSC activity (Dousset et al., 2007; Strojnik & Komi, 2000). At 72-hours, alteration in performance were related to the modifications in movement strategy suggestive of each phase taking longer to perform. More specifically, they noted an increase in eccentric, concentric and total duration, as well as increasing time to peak force and FT:CT, while noting decreases in Force at Zero Velocity (F@0V) (Gathercole, Sporer, Stellingwerff, et al., 2015b). They concluded the CMJ was superior in detecting neuromuscular fatigue at later stages of fatigue.

Gathercole employed the same approach of CMJ testing to a cohort of national level snowboard-cross athletes (Gathercole, Stellingwerff, et al., 2015). Although there was a small sample size (n = 5), their findings reinforced their previous work, in that CMJ alternative were associated with greater post-exercise changes (Gathercole, Stellingwerff, et al., 2015). In a similar approach, Kennedy et al. (2017) more recently explored changes among CMJ traditional and alternative variable sin rugby players (Kennedy & Drake, 2017). After performing a bout of intense training to mimic that of the pre-season phase, athletes displayed a small decrease in peak power, mean force, mean eccentric-concentric power, and FT:CT and a moderate decrease in mean power, peak velocity, JH, and force at zero velocity 24-hours post-training. At 48-hours post-training, mean power, peak force, eccentric duration, concentric duration, total duration, mean eccentric-concentric power, and FT:CT exhibited small effects, while force at zero velocity demonstrated a moderate effect (Kennedy & Drake, 2017). While a number of studies are emerging including both traditional and alternative CMJ variables, the precise understanding of the key variables remains elusive.

Although not as extensive as the studies previously mentioned, de Hoyo et al. looked beyond the traditional gross output variables by isolating changes in the eccentric component of the CMJ for comparison following a soccer match (de Hoyo et al., 2016). Their findings showed decrements in eccentric force, 30-minutes post-match, as well as 24-hours post-match. They also reported decreased in JH and concentric power at 24- and 48-hours.

The majority of literature has examined changes in CMJ following a match or training session without placing key emphasis on training loads during the fatiguing activity. Recent work by Noon et al. compared CMJ performance 20-hours after a high load (90 minutes) and a low load (15 minutes) rugby sport-specific training session and observed no differences in JH (Noon et al., 2018). These findings may allude to the compensatory capacity of elite athletes more so than an absence of neuromuscular fatigue after varying loads, iterating their ability to manipulate their jumping strategy to achieve the desired gross jump output, JH in this case. More research in needed coupling varying training loads with responses in CMJ performance, especially with respect to basketball activity.

Alterations in CMJ performance have been measured in other sports outside of field-based sports, with varying results. Ronglan et al. identifying changes in CMJ performance in a cohort of national level handballers, a sport with similar demands as basketball (Ronglan et al., 2006). Their findings noted decreases in JH of 6.9 ± 1.3% and 6.7 ± 1.3% following a training camp and intense tournament, respectively ($p < 0.01$) (Ronglan et al., 2006). Hoffman et al observed no changes in maximal rate of force development, power, or force over a game of American football (Hoffman et al., 2002). Although, Watkins et al. outlined observed an 8% decrease in JH 48-hours following a strength training session with an emphasis on muscle hypertrophy in a group of healthy, recreationally trained males (Watkins et al., 2017).

Monitoring Endocrine Response to Training

The endocrine system plays an important role during recovery and adaptation in response to an imposed training stimulus. Therefore, monitoring biochemical and/or hormonal responses to a training exposure may provide practitioners with unique insight into the physiological stress of that athlete, supporting the identification of an athlete’s position on the recovery-adaptation continuum. Previous research has monitored endocrine responses in an effort to detect and delineate between function overreaching, non-functional overreaching, overtraining, and overtraining syndrome in athletes (Halson

& Jeukendrup, 2004; Moore & Fry, 2007; M. H. Stone et al., 1991; Urhausen et al., 1995; Urhausen & Kindermann, 2002). More specifically, previous literature has longitudinally and acutely examined the responses of testosterone, cortisol, and the testosterone: cortisol ratio in athletic populations.

Testosterone

Testosterone is a steroid hormone in the androgen family, regulated by the hypothalamic-pituitary-gonadal (HPG) axis (Fry & Kraemer, 1997; Kraemer & Ratamess, 2005). Testosterone is an anabolic hormone associated with increases in protein synthesis and decrease in protein degradation. Testosterone also supports indirect anabolic action by stimulating the secretion of other anabolic hormones, such as growth hormone (Fry & Kraemer, 1997; Kraemer & Ratamess, 2005). Previous literature has reported values of salivary free testosterone ranging from 0.37-0.69 nmol/L in a cohort of male collegiate basketball players across a season (Andre & Fry, 2018). Limited data exist specifically assessing concentrations among collegiate female athletes, however previous literature has reported salivary testosterone concentrations ranging from 15.0-24 pg/ml before and after an intercollegiate soccer match (D. A. Edwards et al., 2006). Increases in testosterone have been paralleled to increases in muscular strength and muscle growth, therefore thought to be a key component in understanding the anabolic status of an athlete as it relates to performance (Kraemer & Ratamess, 2005). Moreover, acute bouts of resistance training have demonstrated increases in testosterone among men (Häkkinen et al., 1988; Kraemer et al., 1990; Kraemer & Ratamess, 2005), while increasing or having no effect in women (Kraemer & Ratamess, 2005). Furthermore, increased training status appears to enhance the response of testosterone after exercise (Pliauga et al., 2015). Similarly, engaging in exercise that incorporates larger quantities of muscle mass has been shown to generate a higher elevation in testosterone, as compared to exercises involving small muscle mass (Kraemer & Ratamess, 2005). Increasing the load or increasing the number of sets appear to increase the magnitude of testosterone response following resistance training (Kraemer & Ratamess, 2005). While alterations in testosterone associated with resistance training are often of primary focus, it is generally accepted that short-term, maximal endurance exercise promotes increases in testosterone (Hackney, 1989). However, submaximal aerobic exercise responses are less clear, often inducing variable responses, but duration and intensity of the exercise are likely key (Hackney & Lane, 2015). Chronic adaptations in resting levels of testosterone in response to resistance training remain less clear. In men, levels of testosterone appear to increase at rest (Häkkinen et al., 1998; Kraemer et al., 1998) and during exercise (Kraemer et al., 1998), while changes in women have been documented to both increase (Kraemer et al., 1998) and exhibit no change at rest (Häkkinen et al., 1990).

Cortisol

Cortisol is a steroid hormone, part of the glucocorticoid family, secreted from the adrenal cortex via the hypothalamic-pituitary-adrenal (HPA) axis (Kraemer & Ratamess, 2005; Papacosta & Nassis, 2011). Cortisol is the primary catabolic hormone which is thought to increase with stress and has been associated with decreases in protein synthesis, increases in protein degradation, the stimulation of lipolysis in adipose tissue, as well as the inhibition of inflammation and immune processes. Therefore, cortisol is thought to be a key indicator for assessing gross stress as it pertains to athlete training and competition. Salivary cortisol concentrations of 6.9-20.3 nmol/L have been reported in male collegiate basketball players (Andre & Fry, 2018). While little evidence exists specifically examining concentrations among women's collegiate basketball players, salivary cortisol values of 5.5-22.5 nmol/L have been reported in other female team sports (D. A. Edwards et al., 2006; Filaire et al., 2001). Both cortisol and adrenocorticotropic hormone (ACTH) have been documented to increase with acute exposure to resistance training in both men and women (Kraemer & Ratamess, 2005). In addition, high intensity aerobic exercise >60% has been shown to elicit noticeable increase cortisol post-exercise (Kindermann et al., 1982), while lowering intensity aerobic exercise may exert no change or even decrease cortisol (Bloom et al., 1976; Galbo et al., 1977; M. H. Stone et al., 1991; Tabata et al., 1984) unless performed for a long duration (Brisson et al., 1977; M. H. Stone et al., 1991). Increases in blood lactate have been correlated with increases in serum cortisol, suggesting exercise intensity may be influential in the magnitude of cortisol response (Kraemer & Ratamess, 2005). Further, an increase in the number of sets or decreasing rest intervals during resistance exercise appears to generate a greater cortisol response (Hackney & Lane, 2015; Kraemer & Ratamess, 2005). Chronic training may decrease resting cortisol, while sometimes no alteration occurs (Halson & Jeukendrup, 2004; Urhausen et al., 1995). In addition, during overreaching scenarios, maximal cortisol responses may be blunted (Halson & Jeukendrup, 2004; Urhausen et al., 1995). The acute post-exercise elevation in cortisol likely reflects acute metabolic stress and may be a part of tissue remodeling processes, while long-term perturbations are thought to allude to homeostatic disruptions involving alterations in protein metabolism (Casto & Edwards, 2016b; Gatti & De Palo, 2011; Kraemer & Ratamess, 2005).

Testosterone: Cortisol Ratio

In addition to examining changes in testosterone and cortisol individually, the ratio of testosterone:cortisol (T:C ratio) is often examined. The T:C ratio is thought to reflect the balance of anabolic:catabolic processes (Halson & Jeukendrup, 2004; Kraemer

& Ratamess, 2005; Twist & Highton, 2013). Increasing testosterone, decreasing cortisol, or both, would reflect a state of anabolism, whilst decreasing testosterone, increase cortisol, or both, would represent a state of catabolism (Gatti & De Palo, 2011; Kraemer & Ratamess, 2005). While not solidified as a clear estimate of long term overtraining, a decrease in the T:C ratio by 30% has been proposed as an indicator of a state of overtraining (Meeusen et al., 2004; Viru & Viru, 2004). Regardless, elevated levels of stress without adequate recovery will likely induce a suppression in the T:C ratio.

Measuring T, C, T:C

Blood draws have been used to measure both testosterone and cortisol hormonal responses to exercise however, these methods are invasive and time-consuming, making their implementation in the field setting of team sport challenging. Salivary hormone analysis has become increasingly popular among athlete performance and exercise science as it offers a non-invasive strategy to gain insight into endocrine responses to training within the field setting (Gatti & De Palo, 2011; Papacosta & Nassis, 2011). In addition, salivary analysis allows samples to be collected more frequently, as well as from a large quantity of athletes in a time efficient manner, without imposing undue stress (Andre & Fry, 2018; Cormack, Newton, & McGuigan, 2008; Cormack, Newton, McGuigan, et al., 2008; Crewther et al., 2015; Gatti & De Palo, 2011; Papacosta & Nassis, 2011; Rowell et al., 2017). Furthermore, salivary collection requires less expertise and medical training, making it more conducive for collection among team sports in the field setting. Collecting salivary samples by the use of cotton swabs to absorb the saliva or the collection of whole saliva by passive drool have both been deemed acceptable methods (Papacosta & Nassis, 2011). However, some evidence argues the passive drool methodology is superior, as the cotton or polyester-based swabs have been suggested to interfere with the assessment of salivary components, possibly by changing the sample acidity (Granger et al., 2005; Strazdins et al., 2005). In addition, salivary testosterone and cortisol concentrations are independent of salivary flow rate (O'Connor & Corrigan, 1987).

Salivary concentrations of testosterone have been correlated to blood concentration of both serum free testosterone ($r = 0.75$- 0.97; $p < 0.001$) (Baxendale et al., 1982; Johnson et al., 1987; Sannikka et al., 1983; Vittek et al., 1985; Wilcoxson et al., 2017) and serum total testosterone ($r = 0.80$-0.94; $p < 0.01$) (Vittek et al., 1985; Wang et al., 1981). Therefore, salivary analysis has been suggested as a valid indicator of serum or plasma testosterone levels (Papacosta & Nassis, 2011). Similarly, the assessment of changes is cortisol is commonly performed through both salivary and blood analyses. Salivary cortisol represents the biologically active or free portion of blood cortisol (Gozansky et al., 2005). While significant correlations between salivary and blood analysis have been established ($r = 0.82$-0.93; $p < 0.01$), salivary cortisol measures have been reported to express a greater relative response to exercise as compared to blood cortisol measures (Crewther et al., 2010; Gozansky et al., 2005). Consequently, previous literature has suggested salivary analysis as a useful measure in assessing the dynamic HPA axis function (Gatti & De Palo, 2011; Gozansky et al., 2005). Although previous literature has validated the use of salivary cortisol analysis, monitoring responses should be limited to within-individual comparisons due to the sizable between-individual variability observed within athletic populations (Papacosta & Nassis, 2011).

Longitudinal Endocrine Responses in Team Sport

Basketball

The majority of studies specifically examining testosterone, cortisol, and T:C ratio responses in basketball players have focused on longitudinal changes over a season, rather than acute responses to a single sport-specific training or competition exposure. Hoffman et al measured testosterone, cortisol, and T:C ratio over a 4-week pre-season training period in a cohort of 10 profession basketball players, reporting increases in blood cortisol as the pre-season progressed while observing no changes in testosterone or T:C ratio (Hoffman et al., 1999). Similarly, He et al. denoted increases in salivary cortisol during a training phase leading into competition, however they neglected to measure testosterone levels and T:C ratio (He et al., 2010). In contrast, Martinez et al. reported fluctuating cortisol levels over a season in professional players, with decreases in T:C ratio at the end of the season (Martínez et al., 2010). These findings suggest professional basketball players have the capacity to maintain a good anabolic-catabolic balance throughout a season. In parallel, Schelling et al. reported more constant cortisol levels when observing 20 male European professional basketball players overtime, while noting testosterone levels and T:C ratio were significantly lower during the later stages of data collection (Schelling et al., 2015). Importantly, Schelling identified an increase in testosterone levels with decreases in training loads during a taper. Potentially the most robust study design evaluating alterations in testosterone, cortisol, and T:C ratio was executed by Andre et al, in which they observed 12 NCAA Division I basketball players over a 7-week pre-season and 23-week competitive season (Andre & Fry, 2018). Capturing weekly salivary samples, they observed increases in cortisol during the pre-season, with no change in testosterone, or T:C ratio (Andre & Fry, 2018). Furthermore, a taper employed to decrease training loads during the transition from pre-season to the competitive season resulted in increase in T:C ratio. A significant negative correlation between playing time and T:C ratio was documented, suggesting increases in playing time were related to the suppression of T:C ratio, although this is not necessarily a direct causal relationship. Discrepancies in responses observed within the literature are likely due to the frequency of sampling but may also relate to level of play (profession vs. collegiate).

Other Team Sports

Cormack et al. evaluated changed in endocrine function over a competitive season in 15 professional Australian Rules Football players (Cormack, Newton, McGuigan, et al., 2008). These results demonstrated a consistent decrease in cortisol in the majority of time points tested throughout the course of the season. Decrease in cortisol may have related to baseline measures taken following 20-weeks of pre-season training. Responses in testosterone markedly varied, with observations of increase, decreases, and no change occurring, making meaningful interpretation challenging. The T:C ratio fluctuated at a more predictably, predominantly increasing over the season, which likely alludes to athletes maintaining an anabolic environment, which means athletes were able to cope with competitive season demands and/or the periodization scheme allowed for adequate recovery. More recently, Dubios et al. (2018) examined 14 professional rugby players over the duration of a competitive season (Dubois et al., 2018). Significant increases in testosterone, cortisol, and T:C ratio ($p < 0.05$) were noted from week 30 to week 45. Interestingly, T:C ratio was lowest during the second competitive training block, which coincided with increases in player injury, however no significant spikes in injury were observed among any of the training phases.

A variety of studies have examined hormonal changes throughout various training phases in American Football. Stone et al. observed changes in testosterone, cortisol, and T:C ratio in 19 NCAA Division I football players over the course of a 189-day season, comprised of summer training (57 days), pre-season camp (23 days), and competitive season (109 days) (J. D. Stone et al., 2017). In addition, the analysis incorporated a comparison in changes among starters and non-starter on the team. A decrease in testosterone was likely observed in both groups after pre-season camp relative to baseline, although the magnitude of change was larger in starters. During conference play, starters observed a secondary drop in testosterone levels relative to baseline (ES = 0.4). In contrast, during conference play, non-starters expressed an increase in testosterone relative to baseline (ES = 0.4) which continued to rise in magnitude by the end of the competitive season (ES = 0.5). Cortisol levels remained relatively unchanged over the course of the season in both starters and non-starters relative to baseline. The T:C ratio declined in starters post-camp, likely driven by decreases in testosterone, however, no changes were observed in non-starters (J. D. Stone et al., 2017). The finding of relatively no change in cortisol levels over a training phase or season parallel findings of other research in American Football. Kraemer et al. observed no changes in 22 NCAA Division I players over the course of the competitive season (Kraemer et al., 2013). Similarly, Moore et al. noted no change in cortisol levels over an aggressive 15-week off-season training block in nine NCAA Division I players, however significant ($p < 0.05$) decreases in testosterone were document (Moore & Fry, 2007). In contrast, Hoffman et al. described significant decreases in cortisol after a preseason camp among a cohort of 22 NCAA

Division III football players, which later significantly increased to baseline and remained constant throughout the duration of the competitive season (Hoffman et al., 2005).

Acute Endocrine Responses in Team Sport

Basketball

Limited research has been performed examining acute physiologic changes in testosterone, cortisol, and T:C ratio among basketball athletes in response to sport-specific training or competition. Gonzalez-Bono et al. examined the acute pre- to post-game responses of 21 professional European basketball players (Gonzalez-Bono et al., 1999). Their findings outlined an acute spike in cortisol levels, while no changes in testosterone were observed. Arruda et al. documented an acute increase in cortisol and testosterone following a home and away game in a group of 24 U-19 Brazilian national team players (Arruda et al., 2014), while Moreira et al. also observed increases in cortisol levels from pre- to post-training (Moreira et al., 2014). In another study by Arruda et al., cortisol levels were compared following various levels of match intensity, categorized by the rank of the opponent in which they faced (Arruda et al., 2017). Results showed cortisol levels were significantly elevated following easy, medium, and hard matches, as well as after a sport-specific training session ($p < 0.05$). Furthermore, cortisol levels were significantly greater following the hard match in comparison to the other 4 conditions. Likewise, Chatzinikolaou et al. reported elevation an increase in cortisol levels by 33% ($p < 0.05$), which remained elevated for 24 hours and recovered thereafter (Chatzinikolaou et al., 2014). In addition, no significant fluctuations in testosterone were noted.

Other Team Sports

Although the exploration of acute hormonal response to sport specific training or competition is limited among basketball athletes, an abundance of literature has examined changes in testosterone, cortisol, and T:C ratio in other team sports. Acute hormonal responses to both sport specific training and competitions have been commonly explored in both professional and amateur soccer. In professional soccer athletes, recent work by Silva et al. observed changes in salivary testosterone, cortisol, and T:C ratio before and after a competition in a group of 7 male professional soccer players, reporting significant elevations ($p < 0.05$) in cortisol at 24 hours, and 48 hours post-match, while observing no change in testosterone (Silva et al., 2013). Furthermore, decreases the T:C ratio, likely driven by the increases in cortisol, also exhibited a statistically significant difference ($p < 0.05$) at 24-hours (5.9%) and 48-hours (9.8%) post-match. Congruent with these findings, Romagnoli et al. identified significant increases in cortisol levels at 24-hours and 48-hours post-match, as well as significant decreases ($p < 0.001$) in testosterone 30-minutes, 24 hours, and 48 hours after a simulated soccer game in a cohort of 22 male professional soccer players (Romagnoli et al., 2016).

Previous literature has also examined changes in amateur soccer players and these investigations have uniquely included the direct comparisons of responses following sport-specific practice verse a competition, as well as also including female athletes. In a group of 25 women's collegiate soccer players, Casto et al. reported rises in testosterone and cortisol levels immediate post-competition ($p < 0.001$) (Casto & Edwards, 2016a). Haneishi et al. (2007) examined a cohort of 20 female collegiate players, comparing difference in cortisol responses between practice and competition, as well as between starters and non-starters (Haneishi et al., 2007). The results indicated a significant increase in cortisol after both practice and games, with starters experiencing increases in cortisol levels to a greater degree than non-starters. In parallel, Edwards et al. examined endocrine responses to a collegiate soccer game in both male ($n = 21$) and female ($n = 16$) athletes. In addition, their analysis included a comparative analysis between athletes that played during the game and those who earned no playing time (D. A. Edwards et al., 2006). Their findings illuminated significant increases of both cortisol in both males and females following competition ($p < 0.01$). Increases in testosterone were also observed, however only the females were significantly different from pre- to post-game ($p < 0.001$). Furthermore, the adequate sample size of men that played during the game ($n = 13$) compared to athletes that did not play ($n = 8$) allowed for a hormonal comparison between groups. Significant differences were observed between groups, as men that played in the game expressed increases ($232 \pm 90.9\%$) in cortisol, while those that did not play had a decrease ($44.9 \pm 15.9\%$) in cortisol ($p < 0.03$) (D. A. Edwards et al., 2006).

While the majority of evidence in soccer has alluded to increases in cortisol immediately following a match, contradicting findings are apparent. In study by Moreira et al. measured changes in cortisol in 22 male professional players, noting no change in cortisol from pre- to post-match (Moreira et al., 2009). As previously mention, the benefit of small-sided games (SSG) to improve technical and tactical skills in team sport has led to the exploration of endocrine responses following SSG activity (Hill-Haas et al., 2011). A small decrease in cortisol was noted after a SSG in 16 male professional soccer players (Sparkes et al., 2018). These data suggest cortisol responses may not be unconditional and the intensity of play may be key in spawning alteration following an event. The culmination of these data suggests soccer evokes acute increases in cortisol, lasting up to

48 hours, while changes in testosterone are more trivial, but appear to not change in men, while potentially increasing in female players. In addition, the intensity and duration of play should be considered when interpreting response.

Endocrine responses to matches have also been explored among other team sports, such Australian rules football, rugby, volleyball, and handball. Earlier work by Cormack et al. reported increases in cortisol and decreases in T:C ratio immediately post-match and 24 hours following a match, which subsided to baseline at both 96- and 120-hours post-match. No substantial changes were witnessed in testosterone (Cormack, Newton, & McGuigan, 2008). More recently, work by Rowell et al. examined endocrine responses in a group of 18 professional players, further supporting the findings by Cormack et al. (2008), by clearly identifying increases in cortisol and decreases in T:C ratio 30 minutes post-match, however they also observed increases in testosterone 30 minutes post-match regardless of the external load experienced during the match (Rowell et al., 2017). In a group of 20 professional ruby players, Elloumi et al. reported cortisol levels elevated 2.5 times higher and T:C ratio decreased 2.5 times below baseline measurements immediately following a match (Elloumi et al., 2003), which continued to be elevated for 2 hours after the match, but had subsided by 4 hours post-match. In addition, they reported a decrease in testosterone by 20% immediately following the match. McLellan et al. evaluated changes in endocrine responses among professional rugby players, noting increases in cortisol levels and decrease in testosterone levels immediately post-match, which returned to baseline by 48 hours and 24 hours, respectively ($p < 0.05$) (McLellan et al., 2010). The T:C ratio also decreased following the match. These findings are further supported by West et al., which measured increased in C ($p = 0.003$) and decreases in T:C ratio (p = 0.001) post-match, but also witnessed decreases in testosterone levels post-match (p = 0.011) (West et al., 2014). In contrast, McLean et al. found diminished cortisol response 24 hours following a rugby match in 12 profession players, however study design and measurement timing may have confounded these observations (McLean et al., 2010). Filaire et al. compared hormonal responses female volleyball players (n = 7) and handball players (n = 13) before and after a competition, again noting significant increases in both cohorts following the match (Filaire et al., 1999). Interestingly, greater increases in cortisol were observed pre- to post-game among the handball players when compared to the volleyball athletes. Differences in responses may allude to differences in energy demands between sports, as well as the intensity and duration of each activity.

These studies provide evidence among a variety of team sports outlining acute changes in response to sport specific training or competition, which include clear increases in cortisol and decreases in T:C ratio. However, a clear directional response of testosterone remains more elusive. In addition, these data suggest potential sex differences, as well as allude to possible differences in the magnitude of the response depending upon the sporting event.

Influence of Hydration Status

Humans have been interested in hydration status and fluid loss since as early as 1614, when Sanctorious of Venice started performing the first serial measurements in an attempt to quantitate "*perspiration insensibilis*," or the insensible loss of water and other substance from the body (Benedict & Benedict, 1927; Benedict & Root, 1926; Cheuvront & Kenefick, 2014). During exercise, the evaporation of sweat plays an essential role in thermoregulation, however excessive loss of body water through sweating can cause dehydration and subsequently lead to a deficit in body water, known as the state of hypohydration (Armstrong, 2005; Casa et al., 2000; Cheuvront & Kenefick, 2014; Thigpen et al., 2014). Hypohydration can range in severity from mild-moderate, related to a loss of 2-5% body mass and severe, which refers to a >5% loss in body mass (Cheuvront & Kenefick, 2014; Maughan & Shirreffs, 2010; Thigpen et al., 2014). While our body normally regulates a narrow range of total body water to maintain optimal hydration, referred to as euhydration, larger fluctuations in body fluids can result in negative consequences for both health and performance. Specifically, evidence suggests the deleterious effects of hypohydration can influence decreases in physical, cognitive, and sport-specific performance (Cheuvront & Kenefick, 2014; Maughan & Shirreffs, 2010; McDermott et al., 2017).

Physically, a dehydration threshold of ≥2% body mass leads to impairments in aerobic and endurance performance (Cheuvront & Kenefick, 2014; McDermott et al., 2017), which can include a decrease in time to exhaustion, a decrease in exercise intensity, or a combination of the two. While not fully elucidated in the literature, mechanistically, these performance deficits likely result from reduction in muscle blood flow (Cheuvront & Kenefick, 2014; McDermott et al., 2017; Murray, 1996), modification in skeletal muscle metabolism, as well as increases in subjective feelings of fatigue and reduced feelings of vigor (Cheuvront & Kenefick, 2014). Undoubtedly, hyperosmolality plays a critical role in the observed aerobic and endurance performance alterations while dehydrated by mediating the body's thermoregulatory capacities, as well as reducing plasma volume, which leads to reductions in cardiac filling and stroke volume, ultimately exacerbating concomitant increases in cardiovascular strain (Cheuvront & Kenefick, 2014; Ganio et al., 2006; McDermott et al., 2017). While the negative ramification of dehydration on aerobic and endurance performance are well documented, the influence of dehydration on anaerobic performance, as well as on strength and power remain less clear, often due to confounding factors when interpreting outcomes. However, dehydration still appears to exert at least a subtle negative impact on anaerobic performance, as well as strength and power performance (Carlton & Orr, 2015; Cheuvront et al., 2010; Cheuvront & Kenefick, 2014; Gann et al., 2016; Minshull & James, 2013; Pallarés et al., 2016). Similarly, dehydration has been shown to negatively affect sport-specific skill performance in basketball players (Baker, Conroy, et al., 2007; Baker, Dougherty, et al., 2007) and in other sports (MacLeod & Sunderland, 2012). Previous literature has outlined a progressive deterioration of skill performance with increases of 1-4% dehydration compared to the euhydrated state (Baker, Dougherty, et al., 2007). In addition, dehydration has been shown to negatively influence reactive and response times, as well as impair attentional performance in basketball players (Baker, Conroy, et al., 2007). Physiologically, dehydration has been shown to modify endocrine responses during exercise, driving an increased catabolic response that appears to modulate subsequent metabolic responses and metabolic flexibility (Judelson et al., 2007).

Although appropriate hydration standards have been well-defined, and the negative ramifications of suboptimal hydration levels are evident, athletes still appear to start practices and competitions with some degree of fluid deficit (Casa et al., 2000; Heishman, Daub, et al., 2018; McDermott et al., 2017; Volpe et al., 2009). For example, Thigpen et al. (2014) examined the hydration status of both a men's and women's collegiate basketball team prior to training and observed 2 out of ever 3 players arrived to both a sport-specific practice session and a conditioning session hypohydrated (Thigpen et al., 2014). Heishman et al. (2018) investigated the hydration status on NCAA Division I collegiate basketball players, reporting longitudinal evidence of systematic dehydration over various training phases, but significant improvements in hydration status during the preseason compared to the competitive season (Heishman, Daub, et al., 2018). Similarly, Volpe et al. (2009) examine 14 NCAA college teams and reported 66% of all athletes, regardless of their sport, reported to practice in a hypohydrated state (Volpe et al., 2009). These findings are not limited to collegiate athletes as professional basketball players in the National Basketball Association (NBA) and European National level displayed 52% and 100% of players, respectively, were reported as hypohydrated before competition and practice (Hamouti et al., 2011; Osterberg et al., 2009). These data suggest a high prevalence of hypohydration among athletes prior to practice, with specific evidence among basketball players. These data combined with the apparent influences of hypohydration on physical performance and endocrine responses may make examine hydration status a relevant factor when evaluating acute neuromuscular and endocrine responses to exercise.

Summary

External load monitoring strategies offer a valid solution to monitoring training load and have been associated with subsequent changes in CMJ performance. In addition, the CMJ has been demonstrated to detect changes in neuromuscular fatigue, with the exploration of variables beyond the traditional CMJ variables potentially offering greater insight into changes associated with fatigue. Limited evidence has compared the external training load variables with subsequent time course of change in CMJ performance variables, which may support clarifying the dose-response relationship of sport-specific training sessions. Furthermore, little to no evidence exists comparing lab-based assessments of fatigue with the field-based measurement of the CMJ. Moreover, external load has yet to be coupled with subsequent laboratory-based measures of fatigue.

While endocrine response may help identify the anabolic to catabolic balance following training, limited evidence exists among basketball players outlining the endocrine response to an acute bout of sport-specific training. Cortisol appears to increase from pre- to immediately post and may stay elevated up to 24-hours after training or competition among basketball athletes specifically. Changes in testosterone and testosterone:cortisol following training or competitions remains less understood among basketball athletes due to the paucity of data exploring the topic. In other team sports, conflicting evidence has been reported with some suggesting no change in either testosterone or testosterone:cortisol, while other evidence of both an increase and a decrease in testosterone, as well as a decrease in testosterone:cortisol immediately following and up to 48-hours post have been reported. These inconsistent findings may be due to the majority of studies not quantitatively measuring training loads as they explored the subsequent endocrine responses. The magnitude and time course of the response may be influenced by the volume and intensity of the activity performed, making the comparison of endocrine responses at varying training loads a logical future direction to research.

Previous literature has focused on evaluating the neuromuscular and endocrine responses to training loads during competition, rather than sport-specific training sessions, like a team practice. It may be more efficacious to evaluate responses to various training loads during practice, as college basketball teams play approximately 30 games per season, while they will engage in approximately 100 practices in the same time frame. Furthermore, the training loads during a practice can be manipulated to a greater degree than those during a competitive game.

CHAPTER III: METHODOLOGY

The purpose of the present investigation was to evaluate the neuromuscular and endocrine responses immediately post-, and 24-hours post-, following single bouts of high and low training load basketball practices. Furthermore, this study looked to examine the origin of fatigue following an average basketball practice.

Study Conceptualization and Collaboration

The relevant literature and study proposal were presented to both men's and women's basketball programs at the University of Oklahoma. The head coach, performance staff, and medical staff of each team acknowledge the value of this project, with the study's potential capacity to not only support performance optimization, but also enhance overall student-athlete welfare. Ultimately, each expressed support for the research project and allowed the recruitment of athletes to voluntarily participate in the study.

Experimental Design

The proposed study consisted of two separate parts, both including NCAA Division 1 men's and women's intercollegiate basketball players. The first part (***Part 1***) utilized a cross-over design to examine the time course of fatigue and recovery following a bout of high-load sport-specific training and a bout of low load sport specific training. The second part (***Part II***) sought to examine alteration in neuromuscular function derived from measurements of countermovement jump and twitch interpolation techniques following an average bout of sport-specific basketball training. In brief, the study consisted of a total of 8 visits divided into two parts, with ***Part I*** consisting of 5 visits and ***Part II*** consisting of 3 visits, as outlined in ***Figure 2***.

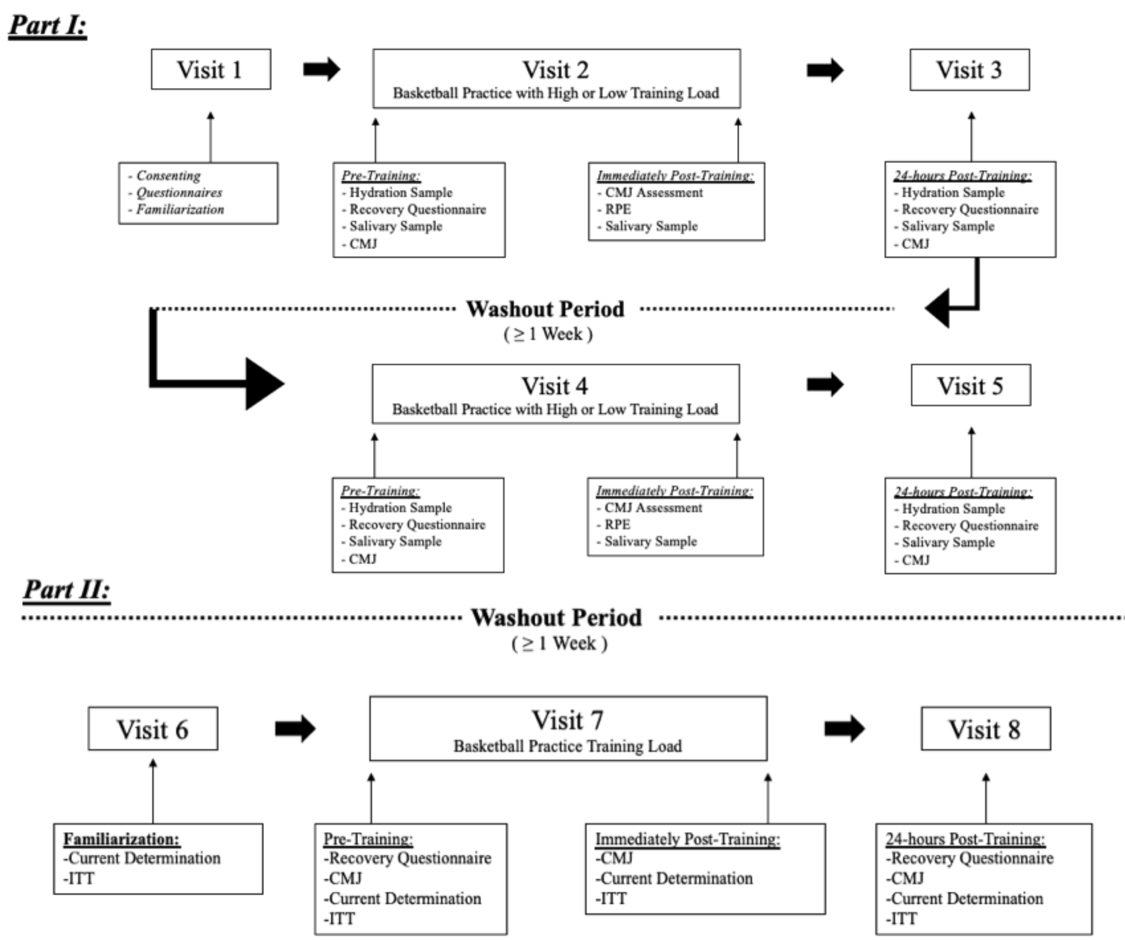


Figure 2. Diagrammatic representation of the research design.

All visits occurred at the University of Oklahoma's basketball training facilities (Lloyd Noble Center and Griffin Family Performance Center), maximizing the ecological validity of the findings. Visits during ***Part I*** occurred in the following order: *visit 1*- consenting, questionnaires, testing familiarization; *visit 2*- recovery questionnaire, pre-practice salivary sample and CMJ testing, followed by a bout of high or low sport-specific training load in the form of team practice, followed by participants providing a RPE, performing the CMJ testing and providing a salivary sample immediately post-practice; *visit 3*- recovery questionnaire, salivary sample and CMJ testing 24-hours post-practice.

After at least a 1-week washout period, participants returned to complete *visit 4*- recovery questionnaire, pre-practice salivary sample and CMJ testing, followed the reciprocal training load in the form of team practice of which they did not perform during visit 2, followed by participants providing a RPE, performing the CMJ testing and providing a salivary sample and CMJ testing immediately post-practice; *visit 5*- recovery questionnaire, salivary sample and CMJ testing 24-hours post-practice. Participation in ***Part II*** of the experimental design was not contingent on participation in ***Part I***. Following a washout period of at least one week, participants returned for *visit 6* which consisted of familiarization of the twitch interpolation protocol; *visit 7* included CMJ testing and twitch measurements, prior to an average bout of basketball practice, followed by post-practice measurements of CMJ and twitch interpolation, which occurred within approximately 15 minutes of the conclusion of practice; and finally, *visit 8* occurred 24-hours after the average bout of basketball practice and included CMJ testing and twitch interpolation assessment.

Visit 1 lasted approximately 60 minutes. Visit 2, 4, and 7 lasted approximately 150 minutes, while visits 1, 3 and 5 lasted approximately 45 minutes each. Each variable of interest as collected at the same time of day, within-subject, to account for diurnal variations of hormones (Kraemer & Ratamess, 2005) and mitigate apparent time of day influences on jump performance (Heishman et al., 2017). Furthermore, recruited participants elected to engage in either, both, or no parts of the experimental design.

Participants

A convenience sample of 16 NCAA Division 1 collegiate basketball players participated in Part I and 15 NCAA Division 1 collegiate basketball players participated in Part II. All participants were recruited from the University of Oklahoma men's and women's varsity basketball programs to participate in this study. Prior to partaking in the study, each participant provided written informed consent after receiving a detailed explanation of the investigation's aims, benefits, and risks. Furthermore, participants were informed that their participation in this investigation would have no bearing on their status as a member of the basketball squad and that they were free to withdraw from participating in the investigation at any point without penalty.

Inclusion Criteria

1. Participants included men and women between the ages of 18 and 25 years that were members of University of Oklahoma Varsity basketball team.
2. Men and women free of any musculoskeletal injuries at the time of testing and healthy for participation.

Exclusion Criteria

1. Individuals that were not members of the University's Varsity basketball programs.
2. Men or women who had experienced a recent musculoskeletal injury, surgery, or other medical reasons restricting their participation in team training sessions.
3. Men and women not fully cleared to participate in an entire team practice.

Questionnaires and Documentation

The research design incorporated questionnaires regarding current and previous health status, menstrual history (for female participants only), and current and previous physical activity levels. The following documentation and questionnaires completion will be required by each participant prior to their participation:

Consent

Each participant was informed of the inherent risk and benefits of the study, while also providing written informed consent, approved from the Institutional Review Board (IRB#: 10752) at the University of Oklahoma before participating.

Health Insurance Portability and Accountability Act

The Health Insurance Portability and Accountability Act (HIPPA) informed the participant of the potential use of protected health information acquired during the project.

Sport Specific Health Status Questionnaire

The health status questionnaire gathered information pertaining to the health, wellness and previous medical history, assisting in the determination of participant inclusion. The questionnaire included a series of questions related to age, demographics, medical history, exercise habits, medications, and smoking behavior.

Menstrual History Questionnaire (Women only)

The menstrual history questionnaire included a variety of questions pertaining to menstrual cycle characteristics. These questions are broken down into two sections: A) current menstrual status and B) previous menstrual status, including questions related to present menstrual status, length of menstrual cycle, and irregular or missing periods, as well as questions related to menarche and hormonal abnormalities. In addition, the questionnaire gathered information regarding the use of contraceptives, such as the type, dosage, and duration of use.

Physical Activity Readiness Questionnaire

The physical activity readiness questionnaire (PAR-Q) acted as the initial screening tool before engaging in physical activity. The questionnaire included a series of questions determining the participant’s capacity to engage in physical activity. If a participant responds ‘yes’ to any of the questions, clearance by the University’s Sports Medicine staff was sought prior to participation.

Anthropometric Measurements

Body height and weight were measured during visit 2. Body height was measured to the nearest cm using a wall stadiometer. Participants placed their back against the wall with their heel together and head position at a 90-degree angle looking forward. Body weight was measured to the neared 0.1 kg with the ForceDecks FD4000 Dual Force Platforms (ForceDecks, London, UK) prior to each countermovement jump test. Body height was measured without participants wearing their shoes, while was measured with the participants wearing their shoes.

Hydration Assessment

Hydration was assessed first during each visit upon arrival. Participant provided a urine sample in a clear, transparent disposable cup. Hydration samples were evaluated using a two method approach, including Urine Specific Gravity (USG) and Urine Color, to increase the validity of the assessment (Armstrong et al., 2010).

Urine Specific Gravity

Urine Specific Gravity was assessed using a digital pen refractometer (PEN-PRO; Atago Co., Ltd., Tokyo, Japan) in accordance with previous methods, which has been shown to be a valid and reliable technique for assessing hydration (Heishman, Daub, et al., 2018; Minton et al., 2015). First, the pen refractometer was calibrated in a water sample. The tip of the pen refractometer was then dried and submerged in the urine sample. Each sample was assessed 3 times, consecutively, with the average of 3 trials used as the participants USG value. Hydration status from the USG values were classified based upon the National Athletic Trainers Association recommended criteria, which has also been used by previous literature: euhydrated, USG < 1.020; hypohydrated, USG = 1.020–1.030; and significantly hypohydrated, USG > 1.030 (Casa et al., 2010; Heishman, Daub, et al., 2018; McDermott et al., 2017; Thigpen et al., 2014).

Urine Color Technique

Urine color was also used to evaluate urine concentration alluding to hydration status, using the classic urine color chart (available at www.hydrationcheck.com). Urine color evaluation is a popular field-based assessment technique as it is noninvasive, inexpensive, and has demonstrated good sensitivity and specificity in relation to other measures of hydration (McDermott et al., 2017). Each sample was evaluated by two independent rates, with the average score from the two raters used as the Urine Color value for each sample. All samples were assessed by the same two independent raters throughout the study. Hydration was classified as: 1, 2, or 3 = well hydrated; 4 = normally hydrated or slightly dehydrated; 5 or 6 = dehydrated; and 7 or 8 = extremely dehydrated (Casa et al., 2000; McDermott et al., 2017).

Recovery Questionnaires

Upon arrival and after providing the urine sample for the hydration assessment, participants completed a well-being recovery questionnaire to gain insight into perceived recovery, utilized in previous literature (McLean et al., 2010). The questionnaire inquired about 5 categories: Fatigue, Sleep Quality, General Soreness, Stress Levels, and Mood, reported on a scale of 1-5, as well as sleep quantity which was reported in hours sleep to the nearest half hour. While no team practices or other training was scheduled during the time course of recovery observed following each practice exposure monitored in the study, the recovery questionnaire also included a question to gain insight on the potential quantity and intensity of basketball activity performed outside of the study (e.g. self-selected individual skill development, shooting, etc.), in an attempt to control for such extra work.

Load Monitoring, Performance Measures, and Saliva Sampling Familiarization

After meeting the inclusion criteria and completing the required documentation, each participant was familiarized with each component of the study design. As the fit of the garment used to hold the inertial measurement unit (IMU) may influence accelerometer loads (McLean et al., 2018), each participant was fitted with the appropriate size support garment to house the external load monitor during training sessions. The garment was fit as tight as possible without impeding movement, such that all areas of the supportive garment are securely in contact with the skin and no visible loose areas were evident. Participants wore the same supportive garment during each training session. Participants provided verbal instructions and received a visual demonstration of the CMJ procedure, as well as the process of providing the salivary sample. In addition, each participant performed familiarization trials for each procedure prior to testing.

Load Monitoring during Practice Training Session

External Load Monitoring

Each participant underwent both a high and low load basketball training session, which were both facilitated by the sport coaches to maximize ecological validity. Training loads during the basketball practice was quantified with the Catapult Sport OptimEye T6 Inertial Measurement Unit (IMU) (Catapult Innovations, Melborne, VIC, Australia) with all data analyzed via the Catapult software (Openfield, Catapult, Innovations, Melborne, VIC, Australia). The IMU is comprised of a triaxial accelerometer, gyroscope, and magnetometer, collecting at a sampling at a rate of 100Hz. Each participant wore the IMU in the manufacturer provided supportive harness, positioning the unit between the scapulae, as presented in ***Figure 3***.

Figure 3**. Inertial Measurement Unit (IMU) Placement.**

Athlete external training load accumulation commenced upon the athlete taking the floor for pre-practice activities and completed when the athlete left the floor at the conclusion of practice. All load accumulation was monitored live during the basketball practice. PlayerLoad™, defined as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three orthogonal places and divided by 100 (Heishman, Curtis, et al., 2018; Heishman, Peak, et al., 2020), served as the key metric in determining the athlete external training load accumulation during the practice bout.

Internal Load Monitoring

Participants also wore a FirstBeat SPORT heart rate monitor (FirstBeat SPORT, Jyvaskyla Finland) during practice to evaluate the internal stress and response to the practice bout. The heart rate monitor was securely positioned around the torso at approximately the height of the xiphoid process. Heart rate monitoring started with the onset of team practice and conclude at the end of team-based activities.

Rating of Perceived Exertion

At the conclusion of practice and just prior to countermovement jump testing, participants provided a rating of perceived exertion (RPE), where participants were asked, "How hard do you think practice was today?" and then asked to point to the RPE value corresponding to the intensity they perceived practice on a scale of 0-10, with 0/1 = no exertion and 10 = Maximal, and responding to the nearest half-digit (Foster et al., 2001). Importantly, participants provided RPE values isolated and by pointing to the value on the chart to ensure other participants were not influenced by their response. Session-RPE was obtain by multiplying the RPE by the duration of the practice, in parallel with previous work (Casamichana et al., 2013).

Countermovement Jump Testing

Countermovement Jump (CMJ) testing was performed on the ForceDecks FD4000 Dual Force Platforms hardware (ForceDecks, London, UK), with a sample rate of 1000Hz. ForceDecks software (ForceDecks, London, UK) was used to analyze all CMJ tests and to generate the CMJ variables. The ForceDecks software used a 20N offset from the measured bodyweight, quantified before the jump, to define the start of movement. The end of eccentric and start of concentric is defined as minimum displacement (absolute) which is equal to zero velocity, while take-off is defined as the time point at which total vertical force falls below the threshold of 20N below body weight.

Prior to each CMJ test, the same standardized warm-up was performed, which include dynamic stretching and locomotion patterns (i.e.-skipping, jogging and running, and 3 practice jumps), similar to that of previous literature (Heishman et al., 2017; Heishman, Brown, et al., 2019; Heishman, Curtis, et al., 2018; Heishman, Daub, et al., 2019; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020). Movement intensities gradually increased over the warmup duration to prepare participants for maximal performance during the jump testing. Importantly, participants did not perform the warmup prior to the CMJ testing immediately post-practice, as their system should have already been prepared for movement and as to not accrue any more load accumulation.

When performing the CMJ, as previously described in the literature (Heishman, Brown, et al., 2019; Heishman, Daub, et al., 2019; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020), participants started in the tall standing position, with feet placed hip width to shoulder width apart and hands on hips (akimbo). The participant was then instructed to start with equal weight distribution on both force cells. A visual representation of weight distribution was displayed on a monitor in front of the participant to provide synchronized and integrated feedback, allowing the participant to adjust their positioning for equal quantities of body weight to be distributed on each force cell for the start of the jump. The participant then dropped into the countermovement position to a self-selected depth, followed by a maximal effort vertical jump, and land in an athletic position on the force platforms. The participant reset to the starting position after each jump, and the procedure was completed for a total of three jumps. If at any point the participant removed their hands from their hips, exhibited excessive knee flexion once airborne, or failed to fully land on the force platform, the jump was ruled invalid and repeated. To limit the impact of instructions on the CMJ performance characteristics (Young et al., 1995), consistent instructions and verbal cues were provided to all participants during each CMJ trial. In an effort to maintain ecological validity, participants wore their standard practice gear, including shoes of their choosing, however, each participant was required to wear the same pair of shoes during each testing session. In addition, verbal encouragement was provided to promote maximal effort during each jump attempt.

Salivary Sample Collection and Analysis

Salivary samples were utilized instead of serum sample because it is non-invasive method and allowed simultaneous collection from all participants in the field setting (Andre & Fry, 2018; Rowell et al., 2017). Previous literature has established salivary methods as a safe and reliable measuring testosterone and cortisol (Andre & Fry, 2018; Papacosta & Nassis, 2011). Further, salivary values have been strongly correlated with serum values (Baxendale et al., 1982; Papacosta & Nassis, 2011; Wang et al., 1981; Yi & Moochhala, 2013) and previously been suggested as a valuable marker for sport science monitoring (Papacosta & Nassis, 2011). All saliva samples were collected at the same time of day within-subject and while participants were at rest, with pre-practice samples collected from men between 1330 and 1400, while pre-practice samples were collected from women between 630 and 700. Before collection, participants rinsed their mouth out with water and sat quietly for 5 minutes. Next, participants provided 2 mL of unstimulated whole saliva samples, collected via passive drool with SalivaBio's 2 mL cryovials and the Saliva Collection Aid (exclusively from Salimetrics, State College, PA). Samples were immediately frozen at or below -80 degrees C and stored cryostorage boxes for later analysis. Participants were instructed not to eat, brush their teeth, or consume any drinks other than water 60 minutes prior to providing a salivary sample. °

Testosterone salivary samples were assayed at the Salimetrics' SalivaLab (Carlsbad, CA) using the Salimetrics Salivary Testosterone Assay Kit (Cat. No. 1-2402), without modifications to the manufacturers' protocol. Samples were thawed to room temperature, vortexed, and then centrifuged for 15 minutes at approximately 3,000 RPM (1,500 x g) immediately before performing the assay. Samples were tested for salivary testosterone using a high sensitivity enzyme immunoassay (Cat. No. 1-2402). Sample test volume was 25 µl of saliva per determination. The assay has a lower limit of sensitivity of 1 pg/mL, a standard curve range of 6.1-600 pg/mL, and an average intra-assay coefficient of variation of 4.60%, and an average inter-assay coefficient of variation 9.85%, which meets the manufacturers' criteria for accuracy and repeatability in Salivary Bioscience and exceeds the applicable NIH guidelines for Enhancing Reproducibility through Rigor and Transparency.

Similarly, cortisol salivary samples were assayed at the Salimetrics' SalivaLab (Carlsbad, CA) using the Salimetrics Salivary Cortisol Assay Kit (Cat. No. 1-3002), without modifications to the manufacturers' protocol. Samples were thawed to room temperature, vortexed, and then centrifuged for 15 minutes at approximately 3,000 RPM (1,500 x g) immediately before performing the assay. Samples were tested for salivary cortisol using a high sensitivity enzyme immunoassay (Cat. No. 1-3002). Sample test volume was 25 µl of saliva per determination. The assay has a lower limit of sensitivity of 0.007 µg/dL, a standard curve range from 0.012-3.0 µg/dL, and an average intra-assay coefficient of variation of 4.60%, and an average inter-assay coefficient of variation

6.00%, which meets the manufacturers' criteria for accuracy and repeatability in Salivary Bioscience, and exceeds the applicable NIH guidelines for Enhancing Reproducibility through Rigor and Transparency.

Twitch Current Determination

A twitch current determination protocol was performed to determine the optimal amplitude of stimulation required during a maximal doublet current (milliamps – mA) to evoke maximal torque. A doublet consists of a 1ms pulse followed by another 1ms pulse, separated by 5ms. Maximal doublet current was defined as the highest current tolerable upon which further increases in current do not result in increased torque production.

Stimulation electrodes (3" X 4", PALS Platinum, Axelgaard, LTX, Fallbrook, CA, USA) was placed over the proximal vastus lateralis and distal vastus medialis. Stimulation electrode sites were prepared by shaving to remove excess hair if necessary, cleaned with an alcohol wipe, and abraded to remove any dead outermost epithelium. Electrode placements were marked with semi-permanent marker to ensure consistent electrode placement among testing days. Electrodes were connected to a current stimulator (Digitimer DS7A Current Stimulator, Digitimer North America, LLC, Ft. Lauderdale, FL, USA) and stimulation of the muscles started at 30 mA doublet. Following 15 seconds of rest, the current was increased 10-20 mA. These procedures were continued until the twitch force reaches a plateau. Twitch force was recorded during each contraction using the Biopac Acknowledge software (Biopac, Goleta, CA, USA). The twitch current determined upon the day of testing was used for the interpolated twitch technique during the maximal voluntary isometric contraction (MVC) recordings and for assessing central fatigue. EMG electrodes were also placed and marked on the subjects with a semi-permanent marker. Similar to electrical stimulation electrode place, the sites of EMG electrode placement were prepared by shaving (if necessary), cleaned with an alcohol wipe, and abraded. The EMG electrodes (10 mm, diameter) were placed on the vastus lateralis in compliance with SENIAM recommendations, while a ground electrode was placed on the patella. The interelectrode distance was set at 30mm, with at least 50mm of separation between the stimulation and EMG electrodes (Gruet et al., 2014). Bipolar EMG signals were captured via the Acknowledge software using BioNomadix dual channel wireless receiver (Biopac, Goleta, CA, USA), and provided an additional insight associated with muscle activation. Furthermore, the signal was captured at a sampling rate of 2000 Hz, with low and high pass filters at 500 Hz and 10 Hz, respectively (Szczyglowski et al., 2017).

Twitch Interpolation Technique

The interpolated twitch technique was utilized to examine voluntary activation before and after the exposure to basketball practice. Participants were set up in a custom built isokinetic dynamometer similar to that previously described (Burnley, 2009). During the familiarization visits, participants were positioned in the isokinetic dynamometer, with their right leg at 110 degrees of knee flexion (20 degrees above 90-degree knee flexion). The axis of rotation of the lever arm was positioned to parallel the participant's anatomical axis of rotation the knee joint. The distal tibia was secured via a velcro strap. The same participant positioning was utilized for each testing session. The upper extremity was harnessed to mitigate movement while performing the test.

Following set up, participants performed a 3 second maximal voluntary isometric contraction (MVC) with the dominant. Participants were cued to begin the MVC by a metronome and verbal instruction from the researcher. At approximately 2.5 seconds into the 3 second MVC the participant received a doublet twitch, which is the interpolated twitch (IT), also referred to as the superimposed twitch (Shield & Zhou, 2004). The doublet consists of two 0.2 millisecond pulses separated by 10 milliseconds, equating to a frequency of 98 Hz. The twitch current (mA) provided during the twitch was determined during the twitch-current determination protocol, as outlined above. At the end of 3 seconds, participants relaxed, and another doublet twitch was administered 1 second after the conclusion of the MVC. This twitch constituted the resting twitch (RT), which can also be referred to as the potentiated or control twitch (Shield & Zhou, 2004). Strong verbal encouragement was provided by the researcher during each effort to support maximal effort. Voluntary activation was computed with the following equation (Shield & Zhou, 2004):

$$Voluntary\ Activation\ (\%VA) = 100\%\ X\ \left(1 - \left(\frac{IT}{RT}\right)\right)$$

Note: IT = interpolated twitch; RT = resting twitch

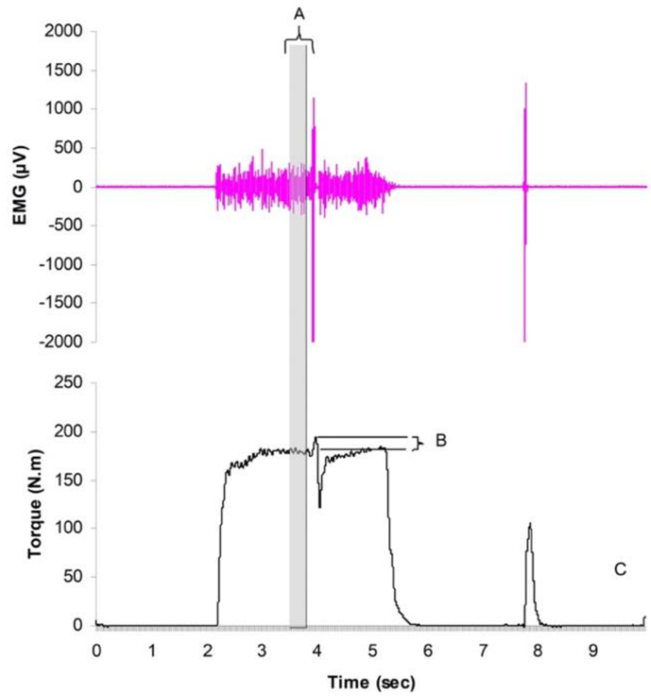


Figure 4. Interpolated Twitch Technique Diagram

Note: A = maximal voluntary isometric contraction EMG (top) and torque (below); B = Superimposed electrical muscle stimulation, referred to as the interpolated twitch; C = Electrical muscle stimulation following the contraction, referred to as the resting twitch.

Low-Frequency Fatigue

Low-Frequency Fatigue (LFF) was examined pre-, immediately-post, and 24-hours following the basketball training exposure. LFF was assessed with the application of a doublet twitch, followed by a single twitch 3 seconds later, consisting of one pulse lasting 1 millisecond in duration. The current amplitude employed during the LFF assessment was determined during the twitch determination protocol. Each doublet followed by a single twitch makes a pair, with each participant receiving 1 pair at each testing time point. The single to doublet ratio was utilized to assess the presence of LFF, where LFF = Single Twitch Torque / Doublet Twitch Torque.

Dietary Restrictions

While no dietary restrictions were implemented, athletes were instructed to maintain normal dietary intake, as outlined by the team's sports dietitian, throughout the study. However, they were instructed to refrain from consuming food 1-hour before arriving for the visit, only consuming water within 1-hour of the visit and not to consume any form of stimulates (i.e.-caffeine) on test days. In addition, participants were only allowed to consume water during the high and low load exposure training sessions, as not to interfere with post-practice salivary sampling.

Data Analyses

Data were analyzed using SPSS, Version 23 (SPSS INC., Chicago, IL). Descriptive statistics were reported as mean ± SD, unless otherwise mentioned. Initially, data normality was confirmed using descriptive and graphical information supplemented by the Shapiro-Wilk test statistic.

Part I:

The inter- and intra-assay reliability of the hormone assay duplicates were evaluated using coefficient of variation (CV%).

A 2-way (Sex [male, female]) × Condition [high load, low load)] repeated measures (RM) analysis of variance (ANOVA), evaluate differences in Hydration Status, External Training Load parameters, including Duration PL, PL/min, PL_{2D}, $PL_{1D\text{-}FWD}$, $PL_{1D\text{-}SIDE}$, $PL_{1D\text{-}UP}$, IMA_High, IMA_Medium, IMA_Low, and Jumps, as well as Internal Training Load parameters, including Average HR, TRIMP, TRIMP/min, Training Effect, RPE, and sRPE. If there was a significant Condition × Time interaction, a Bonferroni post hoc analysis was performed to isolate simple effects.

Data from the Recovery Questionnaire exhibited a non-normal distribution, therefore the equivalent nonparametric test was utilized. Friedman's non-parametric test was used to test for significant differences in the median rank scores across the different conditions and time points.

A 3-way (Sex [male, female] x Condition [high load, low load) x Time [pre-, immediately post, 24 hours-]) RM ANOVA was used to assess sex, condition, and time main effects, as well as the interaction between Sex, Condition, and Time for each CMJ variable, as well as testosterone, cortisol and T:C ratio. Additionally, a 2-way (Condition × Time) RM ANOVA was also used to evaluate Condition × Time interactions, with significant interactions examined using a post-hoc pairwise comparison with a Bonferroni correction to isolate simple effects.

According to an a priori G*Power (G*Power, version 3.1.9.2) analysis, a sample size of 20 participants ($n = 20$) was required to achieve a power ≥ 0.8, based off an effect size = 0.25 and an alpha level set at $\alpha = 0.05$.

Part II:

An independent T-Test was used to evaluate differences in Training Loads during practice between sexes. A 2-way (Sex [male, female] × Time [Pre, 24 hours-post exercise]) was utilized to evaluate difference in Recovery questionnaire parameters, with post-hoc pairwise comparison using Bonferroni corrections used when a significant difference was detected.

A 2-way (Sex [male, female] × Time [Pre, immediately post, 24 hours-post exercise]) RM ANOVA was used to examine Sex and Time main effects and the interaction between sex and time for each variable: CMJ variables, MVIC, %VA, twitch characteristics and LFF. If a significant Sex × Time interaction was verified, the statistical model was decomposed by examining the simple effects with separate one-way repeated measures ANOVAs with Bonferroni correction factors for each group and time point.

According to an a priori G*Power (G*Power, version 3.1.9.2) analysis a sample size of 18 participants ($n = 18$) was required to achieve a power ≥ 0.8, based off an effect size = 0.25 and an alpha level set at $\alpha = 0.05$, as suggested by previous literature (Rhea, 2004).

For both *Part I* and *Part II*, statistical significance was set at $p \leq 0.05$. When comparing three or more groups, partial eta-squared (η_{p2}) effect sizes were calculated and interpreted as small (0.0099), medium (0.0588) and large (0.1379) (Richardson, 2011). When comparing between two groups, Cohen's *d* (*d*) effect sizes were utilized and interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80) (Cohen, 1992).

CHAPTER IV: RESULTS AND DISCUSSION

Results-*Part I*

Participant Anthropometrics

Sixteen Division I NCAA collegiate basketball players (*Male* n = 12: age = 20.3±1.2 years, height = 201.7 ± 7.5 cm, mass = 97.5 ± 9.8 kg; *Female* n = 4: age = 20.2 ± 0.2 years, height = 178.1 ± 3.9 cm, mass = 82.3 ± 5.2 kg) completed *Part I*.

No significant differences were detected with the 3-way Sex × Condition × Time interaction for Body Mass. However, there was a significant Sex × Time interaction (p = 0.038, η_{p2} = 0.217), with post hoc pairwise comparisons revealing that men were significantly heavier than women at Pre (Men = 97.3 (2.6); Women = 81.9 (4.5), p = 0.011, *d* = 1.69), Post (Men = 96.4 (2.7); Women = 82.1 (4.6), p = 0.018, *d* = 1.55), and 24H-Post (Men = 97.3 (2.7); Women = 82.2 (4.6), p = 0.014, *d* = 1.63). Additionally, post-hoc analysis showed significant decrease in Body Mass for Men between Pre to Post (Pre = 97.3 (2.6); Post = 96.4 (2.7), p < 0.001, *d* = 0.10), which returned to baselines from Post to 24H-Post (24H-Post = 97.3 (2.7), p = 0.004, *d* = 0.10), with no differences evidence between Pre and 24H-Post (p > 0.999, *d* < 0.01). No differences in Body Mass were observed in women across time (p > 0.05).

There was not a significant Condition × Time interaction for differences in Body Mass (p = 363, η_{p2} = 0.070), as well as no main effects for differences between Condition (p = 0.893, η_{p2} = 0.001) or Time (p = 0.061, η_{p2} = 0.182). Finally, there was a significant main effect of Sex, with men (97.0 (2.6)) significantly heavier than women (82.1 (4.6), p = 0.014, *d* = 1.63).

Hydration Status

Descriptive statistics of Hydration parameters are outlined in Table 1. There was a significant 3-way Condition × Sex × Time interaction for both USG (p = 0.004, η_{p2} = 0.493) and Urine Color (p = 0.049, η_{p2} = 0.266), as women appeared to decrease from Pre- to 24h-Post during the Low condition.

Table 1. Hydration Status Descriptive Statistics.

		Men (n = 12)		Women (n = 4)		Total (n = 16)	
		Low	*High*	*Low*	*High*	*Low*	*High*
USG	Pre	1.022 ± 0.009	1.024 ± 0.008	1.029 ± 0.003	1.024 ± 0.001	1.024 ± 0.008	1.024 ± 0.007
	24H-Post	1.023 ± 0.007	1.023 ± 0.008	1.013 ± 0.005	1.021 ± 0.004	1.024 ± 0.008	1.023 ± 0.008
Urine Color	Pre	4.1 ± 1.2	4.1 ± 1.2	5.4 ± 1.3	5.3 ± 0.7	4.4 ± 1.3	4.4 ± 1.2
	24H-Post	4.3 ± 1.4	4.2 ± 1.2	3.3 ± 1.6	5.2 ± 0.5	4.1 ± 1.4	4.4 ± 1.2

Data presented at Mean ± Standard Deviation. Low = Low external training load condition; High = High external training load condition; Pre = Pre-Practice; 24H-Post = 24 Hours Post-Practice; USG = Urine Specific Gravity.

As outlined in Figure 6, there was a significant Sex × Time interaction for USG (p = 0.001, η_{p2} = 0.579), as well as Urine Color (p = 0.048, η_{p2} = 0.268), with post-hoc analyses revealing that USG significantly decreased in Women from Pre to 24H-Post (Pre = 1.027 (0.004); 24H-Post = 1.017 (0.004), p < 0.001, *d* = 0.65), and Urine Color was significantly less in Women from Pre to 24H-Post (Pre = 5.3 (0.6); 24H-Post = 4.3 (0.7), p = 0.50, *d* = 0.44), but no differences were observed in Men from Pre to Post for USG (Pre = 1.023 (0.002); 24H-Post = 1.023(0.002), p = 0.871, *d* < 0.00) or for Urine Color (Pre = 4.1 (0.3); 24H-Post = 4.3 (0.3), p = 0.573, *d* = 0.12). There were no differences between sex in USG at Pre (p = 0.479) or 24H-Post (p = 0.187), nor differences between sex in Urine Color at Pre (p = 0.098) or 24H-Post (p > 0.999).

In addition, as presented in Figure 5, there was a significant Condition × Time interaction for USG ($p = 0.009$, $\eta_{p2} = 0.419$), but not Urine Color ($p = 0.101$, $\eta_{p2} = 0.193$). Follow-up pairwise comparisons outlined significant differences at 24H-Post, with an increase in USG during the High Condition (Low = 1.018 (0.002); High = 1.022 (0.003), $p = 0.046$, $d = 0.39$), but no differences were observed between Conditions at Pre (Low = 1.026 (0.003); High = 1.024 (0.002), $p = 0.193$, $d = 0.20$). Additionally, post-hoc pairwise comparisons revealed a significant difference in USG across time within the Low Condition, as there was a significant decrease in USG from Pre to 24H-Post (Pre = 1.026 (0.003); 24H-Post = 1.018 (0.002), $p < 0.001$, $d = 0.81$), but no differences were apparent from Pre to 24H-Post during the High condition (Pre = 1.024 (0.002); 24H-Post = 1.022 (0.003), $p = 0.308$, $d = 0.20$).

There were no significant Sex × Condition interactions for USG ($p = 0.929$, $\eta_{p2} = 0.001$) or Urine Color ($p = 0.070$, $\eta_{p2} = 0.230$). However, as also visualized in Figure 6**,** there was a significant main effect for differences in USG across Time ($p = 0.001$, $\eta_{p2} = 0.562$), but not Urine Color ($p = 0.120$, $\eta_{p2} = 0.175$). A follow-up post-hoc pairwise comparison revealed a significant decrease in USG from Pre to 24H-Post (Pre = 1.025 (0.002); 24H-Post = 1.020 (0.002), $p = 0.001$, $d = 0.65$). Additionally, there were no significant Condition main effects for USG (Pre = 1.022 (0.002); 24H-Post = 1.023 (0.002), $p = 0.535$, $\eta_{p2} = 0.030$) or Urine Color (Pre = 4.3 (0.4); 24H-Post = 4.7 (0.4), $p = 0.113$, $\eta_{p2} = 0.181$) and no significant Sex main effects for USG (Men = 1.023 (0.002); Women = 1.022 (0.004), $p = 0.774$, $d = 0.08$) or Urine Color ((Men = 4.2 (0.3); Women = 4.8 (0.6), $p = 0.660$, $d = 0.33$).

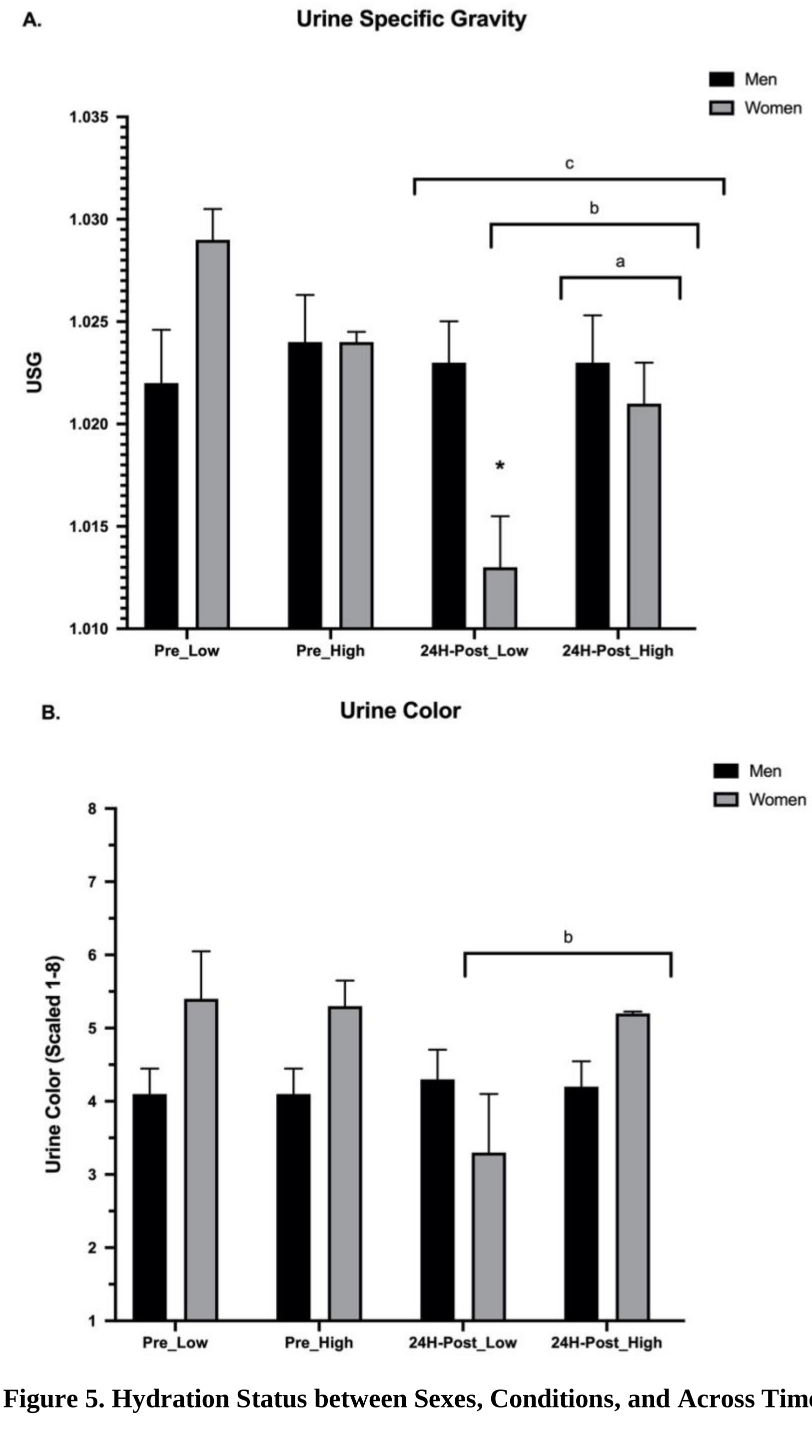


Figure 5. Hydration Status between Sexes, Conditions, and Across Time.

Data presented as Mean (Standard Error); Pre = Pre-practice assessment; 24H-Post = 24 Hours Post-practice assessment; Low = low external training load condition; High = High external training load condition; A. = Urine Specific Gravity Results (USG); B = Urine Color, scaled 1-7; * = Women significantly different from Pre to 24H-Post during Low Condition; a = Significant difference between Pre and 24H-Post during the High Condition; b = Women significantly different from Pre to 24H-Post; c = Significant Time difference between Pre and 24H-Post; statistical significance set at $p \leq 0.05$.

Subjective Questionnaires

As presented in Table 2, there were no significant difference significant differences in Hours Sleep, Sleep Quality, Fatigue, Soreness, Stress, or Mood between Conditions or across Time ($p > 0.05$).

Table 2. Subjective Questionnaire Descriptive Statistics.

	Low		High	
Variable	Pre	24H-Post	Pre	24H-Post
Sleep (hours)	6.5 ± 1.6	6.5 ± 1.5	6.3 ± 1.0	6.8 ± 1.2
Sleep Quality	3.7 ± 0.6	3.8 ± 0.5	3.8 ± 0.8	3.9 ± 0.7
Fatigue	2.9 ± 0.7	3.3 ± 0.6	3.4 ± 0.8	3.3 ± 0.9
Soreness	2.8 ± 0.8	3.1 ± 0.9	3.3 ± 0.8	3.4 ± 0.8
Stress	3.9 ± 1.0	4.2 ± 0.8	3.9 ± 0.9	4.0 ± 0.9
Mood	4.4 ± 0.5	4.4 ± 0.7	4.4 ± 0.6	4.6 ± 0.5

Data presented as Mean ± Standard Deviation. Low = Low external training load condition; High = High external training load condition; Pre = Pre-Practice; 24H-Post = 24 Hours Post-Practice; There were no significant differences observed, statistical significance was set at $p \leq 0.05$.

Training Loads During the High and Low Load Practices

External Training Load:

Descriptive statistics and the results for differences in parameters of eTL during the High and Low eTL practice exposures are outlined in Table 3. There were significant Sex × Condition interactions, as well as significant main effects for both Condition and Sex.

There were significant Sex × Condition interactions for Duration ($p < 0.001$, $\eta_{p2} = 0.624$) and PL/min ($p = 0.014$, $\eta_{p2} = 0.305$). Post-hoc pairwise comparisons revealed that men performed a significantly longer Duration of practice than women during both the High (Men = 86.4 (0.2); Women = 67.4 (0.2), $p < 0.001$) and Low (Men = 86.5 (1.0); Women = 70.0 (0.2), $p < 0.001$) external load exposures. Additionally, significant differences Duration were identified between Conditions within the Women (High = 67.5

(0.2); Low = 70.0 (0.2), $p < 0.001$, $d = 4.85$), but no differences in Duration was observed between Conditions within Men (High = 86.4 (0.2); Low = 86.5 (0.1), $p = 0.551$, d = 0.31).

Similarly, there were significant differences between sexes in PL/min during the High Condition, with Women undergoing a significantly greater PL/min compared to Men (Men = 5.2 (0.3); Women = 6.5 (0.3), $p = 0.009$, $d = 1.39$), but there were no sex differences observed during the Low Condition (Men = 4.7 (0.4); Women = 5.2 (0.5), $p = 0.455$, $d = 0.36$). Additionally, there were significant differences in PL/min between Conditions within Men (High = 5.2 (0.30); Low = 4.7 (0.4), $p = 0.005$, $d = 0.49$), as well as between Conditions within Women (High = 6.5 (0.3); Low = 5.2 (0.5), $p < 0.001$, d = 1.18). There were no significant Sex × Condition interactions of for PL ($p = 0.261$, η_{p2} = 0.074), PL_{2D} ($p = 0.468$, $\eta_{p2} = 0.033$), $PL_{1D\text{-}FWD}$ ($p = 0.439$, $\eta_{p2} = 0.045$), $PL_{1D\text{-}SIDE}$ (p = 0.522, $\eta_{p2} = 0.026$), or $PL_{1D\text{-}UP}$ ($p = 0.610$, $\eta_{p2} = 0.017$).

Additionally, results of the Inertial Measurement Analysis™ (IMA) variables revealed no significant Sex × Condition interactions for IMA_Low ($p = 0.372$, η_{p2} = 0.050), IMA_Medium ($p = 0.824$, $\eta_{p2} = 0.003$), IMA_High ($p = 0.623$, $\eta_{p2} = 0.015$), or Jumps ($p = 0.562$, $\eta_{p2} = 0.021$) events.

As presented in Figure 6, the High external load exposure was significantly shorter in duration (High = 76.3 (0.1); Low = 78.3 (0.1), $p < 0.001$, $d = 4.54$), while exhibiting significantly greater PL (High = 449.9 (17.5); Low = 388.0 (26.4), $p < 0.001$, $d = 0.82$), and PL/min (High = 5.9 (0.2); Low = 5.0 (0.3), $p < 0.001$, $d = 1.00$) compared to the Low external load exposure. In addition, there were significant condition main effects for PL_{2D} (High= 302.8 (13.1) min; Low = 265.0 (18.3), $p < 0.001$, $d = 0.65$), $PL_{1D\text{-}}$

FWD (High = 187.5 (8.8) min; Low = 163.4 (11.9), $p < 0.001$, $d = 0.61$), $PL_{1D-SIDE}$ (High = 198.2(8.6) min; Low = 173.9 (12.0), $p < 0.001$, $d = 0.60$), or PL_{1D-UP} (High = 288.2 (11.1) min; Low = 254.1 (17.0), $p = 0.001$, $d = 0.58$), which were all significantly greater during the High exposure compared to the Low exposure.

Additionally, as presented in Table 3, IMA_Low (High = 445.6 (26.2); Low = 354.6 (32.0), $p = 0.002$, $d = 0.48$) and IMA_Medium (High = 112.7 (10.0); Low = 88.7 (8.5), $p = 0.009$, $d = 0.62$) were significant greater during the High exposure compared to the Low exposure, however there no differences in IMA_High (High = 45.2 (5.2); Low = 34.8 (4.9), $p = 0.076$, $d = 0.75$) or Jumps (High = 83.2 (7.1); Low = 73.5 (7.9), $p = 0.100$, $d = 0.29$) between conditions.

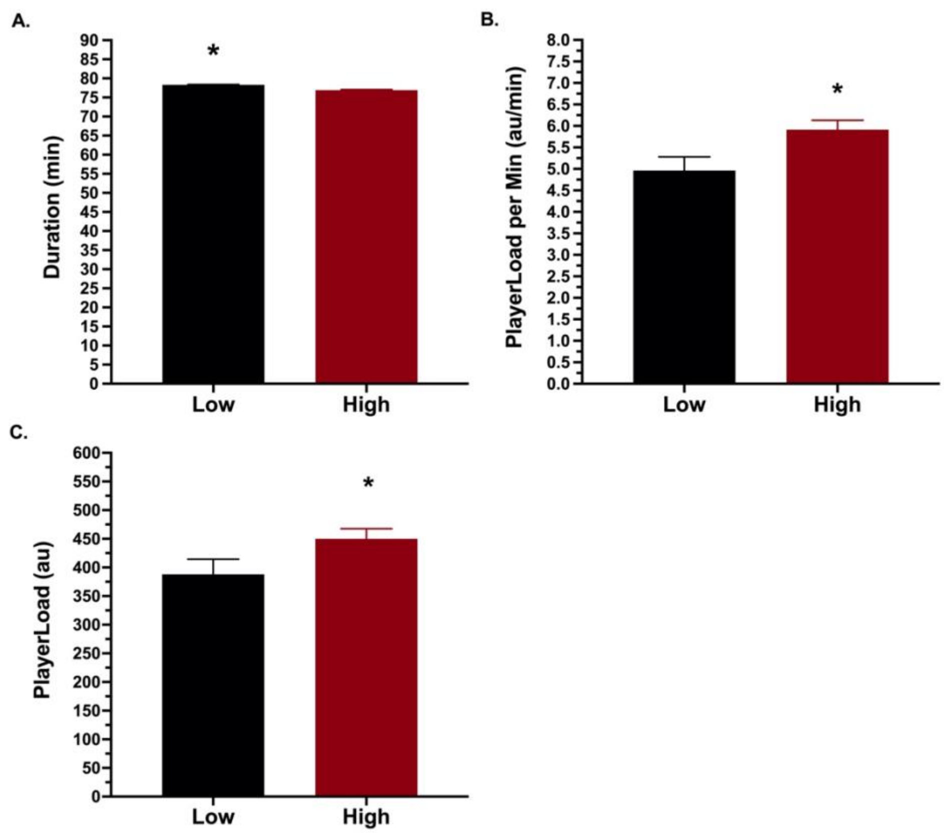


Figure 6. Differences in External Training Loads between Conditions

Note: Data presented as Mean (Standard Error); A. = Duration; B. = PlayerLoad per Minute; C. = PlayerLoad; Low = Low External Training Load Condition; High = High External Training Load Condition; * = Significant difference between conditions, set a $p \leq 0.05$.

Table 3. Differences in External Training Loads between Conditions.

Variable	Low	High	p-value	Effect (*d*)
Duration (min)	78.3 (0.1)	76.9 (0.1)**	<0.001	4.54
PL (au)	388.0 (26.4)	449.9 (17.5)**	<0.001	0.82
PL/Minute (au/min)	5.0 (0.3)	5.9 (0.2)**	<0.001	1.00
PL_{2D} (au)	265.0 (18.4)	302.8 (13.1)*	<0.001	0.65
$PL_{1D\text{-}FWD}$ (au)	163.4 (11.9)	187.5 (8.8)**	<0.001	0.61
$PL_{1D\text{-}SIDE}$ (au)	173.9 (12)	198.2 (8.6)**	<0.001	0.60
$PL_{1D\text{-}UP}$ (au)	254.1 (17)	288.2 (11.2)**	0.001	0.58
IMA_High (cts)	354.6 (32)	445.6 (26.2)*	0.002	0.75
IMA_Medium (cts)	88.7 (8.6)	112.7 (9.9)*	0.009	0.62
IMA_Low (cts)	34.8 (4.9)	45.2 (5.2)	0.076	0.48
Jumps (cts)	73.6 (7.9)	83.2 (7.2)	0.100	0.29

Data presented as Mean (Standard Error). PL = PlayerLoad™; PL_{2D} = 2-Demensional PlayerLoad™; $PL_{1D\text{-}FWD}$ = 1-Demensional PlayerLoad™ Forwards; $PL_{1D\text{-}SIDE}$ = 1-Demensional PlayerLoad™ Side; $PL_{1D\text{-}UP}$ = 1-Demensional PlayerLoad™ Up; IMA_High = High Intensity (>3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; IMA_Medium = Medium Intensity (2.5 to 3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; IMA_Low = Low Intensity (1.5 to 2.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; Jumps = Total number of Jump events (including High, Medium, and Low Intensities); au = arbitrary units; cts = counts; * = statistical significant, $p \leq 0.05$; ** = statistically significant, $p \leq 0.001$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

As presented in Table 4, there were only significant sex differences in Duration (Men = 86.5 (0.1) min; Women = 68.7 (0.1) min, $p < 0.001$), with no evidence of differences between men and women in PL (Men = 434.4 (26.2) min; Women = 403.5 (34.3), p = 0.485, *d* = 0.34), or PL/min (Men = 5.0 (0.3) min; Women = 5.9 (0.4), p = 0.113, *d* = 0.86). Additionally, there were no significant differences in PL_{2D} (Men = 293.5 (25.2); Women = 274.5 (17.8), p = 0.553, *d* = 0.29), $PL_{1D\text{-}FWD}$ (Men = 183.5 (11.8), Women = 167.4 (16.6), p = 0.439, *d* = 0.38), $PL_{1D\text{-}SIDE}$ (Men = 189.7 (11.7); Women = 182.3 (16.5), p = 0.721, *d* = 0.18), or $PL_{1D\text{-}UP}$ (Men = 269.7 (15.8); Women = 272.6 (22.4), p = 0.918, *d* = 0.05) between sexes.

Table 4. Sex Differences in External Training Load during Part I.

Variable	Men (n = 12)	Women (n = 4)	p-value	Effect (*d*)
PL (au)	434.4 (26.2)	403.5 (34.3)	0.485	0.34
PL/Minute (au/min)	5.0 (0.3)	5.9 (0.4)	0.113	0.86
PL_{2D} (au)	293.3 (17.8)	274.5 (25.2)	0.553	0.29
$PL_{1D\text{-}FWD}$ (au)	183.5 (11.8)	167.4 (16.6)	0.439	0.38
$PL_{1D\text{-}SIDE}$ (au)	189.7 (11.7)	182.3 (16.5)	0.721	0.18
$PL_{1D\text{-}UP}$ (au)	269.7 (15.9)	272.6 (22.4)	0.918	0.05
IMA_High (cts)	53.2 (4.9)	26.8 (6.9)*	0.007	0.70
IMA_Medium (cts)	120.7 (9.6)	80.8 (13.6)*	0.029	1.15
IMA_Low (cts)	438.9 (30.8)	361.2 (43.5)	0.164	1.50
Jumps (cts)	97.7 (8.1)	59.1 (11.5)*	0.014	1.32

Data presented as Mean (Standard Error). PL = PlayerLoad™; PL_{2D} = 2-Demensional PlayerLoad™; $PL_{1D\text{-}FWD}$ = 1-Demensional PlayerLoad™ Forwards; $PL_{1D\text{-}SIDE}$ = 1-Demensional PlayerLoad™ Side; $PL_{1D\text{-}UP}$ = 1-Demensional PlayerLoad™ Up; IMA_High = High Intensity (>3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; IMA_Medium = Medium Intensity (2.5 to 3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; IMA_Low = Low Intensity (1.5 to 2.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; Jumps = Total number of Jump events (including High, Medium, and Low Intensities); * = statistically significant, set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

In addition, there were significant differences between sex revealed, with men having a significant greater number of IMA_Medium (Men = 120.7 (9.6); Women = 80.8 (13.6), p = 0.029, *d* = 1.15), IMA_High (Men = 53.2 (4.9); Women = 26.8 (6.9), p = 0.007, *d* = 0.70), and Jump (Men = 97.7 (8.1); Women = 59.08 (11.5), p = 0.014, *d* = 1.32) events compared to women, but no significant sex differences in IMA_Low (Men = 438.9 (30.8); Women = 361.3 (43.5), p = 0.164, *d* = 1.50).

Internal Training Load

The Internal Training load results from the High and Low load exposures are presented in Table 5. There were no significant Sex × Condition interactions for Average HR (p = 0.792, η_{p2} = 0.004), TE (p = 0.682, η_{p2} = 0.010), TRIMP (p = 0.968, η_{p2} < 0.001), or TRIMP/min (p = 0.595, η_{p2} = 0.017).

The main effects for Condition are outlined in Table 5. There were significant differences between conditions, with the High eTL exposure stimulating a higher average

HR (High = 155.6 (3.2); Low = 146.9 (4.5); p = 0.026, *d* = 0.76), Training Effect (TE) (High = 3.6 (0.1); Low = 3.3 (0.2), p = 0.036, *d* = 0.69), TRIMP (High = 103.8 (5.7); Low = 89.6 (7.1), p = 0.013, *d* = 0.74), and TRIMP/min (High = 1.9 (0.103); Low = 1.6 (0.128), p = 0.010, *d* = 0.82) compared to the Low eTL exposure.

Table 5. Differences in Internal Load Between Conditions.

Variable	Low	High	p-value	Effect (*d*)
Average HR (bpm)	146.9 (3.2)	155.6 (3.2)*	0.026	0.76
Training Effect (au)	3.3 (0.1)	3.7 (0.1)*	0.039	0.69
TRIMP (au)	89.6 (5.7)	103.8 (5.7)*	0.013	0.74
TRIMP/min (au/min)	1.6 (0.1)	1.9 (0.1)*	0.010	0.82
RPE	5.6 (0.4)	5.2 (0.4)	0.314	0.36
sRPE	444.8 (36.3)	396.4 (36.3)	0.314	0.43

Data presented as Mean (Standard Error). HR = Heart Rate; TRIMP = Training Impulse; RPE = Rating of Perceived Exertion; sRPE= Session Rating of Perceived Exertion; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Additionally, as outlined in Table 6, there were no differences between Sex in Average HR (Men = 150.9(4.2); Women = 151.7 (5.5), p = 0.910, *d* = 0.05), TE (Men = 3.3(0.2); Women = 3.6 (0.3), p = 0.472, *d* = 0.35), TRIMP (Men = 95.9 (7.1); Women = 97.4 (9.4), p = 0.898, *d* = 0.06), or TRIMP/min (Men = 1.7 (0.1); Women = 1.8(0.2), p = 0.804, *d* = 0.12).

Table 6. Sex Differences in Internal Training Load.

Variable	Men (n = 12)	Women (n = 4)	p-value	Effect (*d*)
Average HR (bpm)	150.9 (4.2)	151.7 (5.5)	0.910	0.05
Training Effect (au)	3.4 (0.2)	3.6 (0.3)	0.472	0.35
TRIMP (au)	95.9 (7.2)	97.4 (9.4)	0.898	0.06
TRIMP/min (au/min)	1.7 (0.1)	1.8 (0.2)	0.804	0.12
RPE	5.6 (0.5)	5.2 (0.6)	0.629	0.23
sRPE	483.1 (38.0)	358.1 (49.8)	0.062	0.95

Data presented as Mean (Standard Error). HR = Heart Rate; TRIMP = Training Impulse; RPE = Rating of Perceived Exertion; sRPE= Session Rating of Perceived Exertion; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Rating of Perceived Exertion

Descriptive statistics for results in RPE and Session-RPE (sRPE) following the high and low exposures are presented in Table 5. There was no significant Sex × Condition interaction ($p = 0.473$, $\eta_{p2} = 0.031$), nor significant Condition ($p = 0.314$, $d = 0.36$) or Sex ($p = 0.629$, $d = 0.23$) main effects for differences in RPE. In parallel, there were no significant Sex × Condition interactions ($p = 0.534$, $\eta_{p2} = 0.023$), nor significant main effects for differences by Condition ($p = 0.314$, $d = 0.43$) or Sex in sRPE ($p = 0.062$, $d = 0.95$).

Countermovement Jump (CMJ) Results

Countermovement Jump Traditional Variables

The descriptive statics of the CMJ Traditional Variables are outlined in Table 7. There were no significant 3-way interactions for any CMJ Traditional Variable, including: Conc Mean Force ($p = 0.793$, $\eta_{p2} = 0.016$), Conc Mean Power ($p = 0.836$, $\eta_{p2} = 0.013$), Conc Peak Force ($p = 0.735$, $\eta_{p2} = 0.022$), FT:CT ($p = 0.858$, $\eta_{p2} = 0.011$), Jump Height ($p = 0.936$, $\eta_{p2} = 0.005$), Peak Power ($p = 0.877$, $\eta_{p2} = 0.009$), and RSI_{Mod} ($p = 0.833$, $\eta_{p2} = 0.013$).

Table 7. Countermovement Jump Tradition Variable Descriptive Statistics.

		Men (n = 12)			Women (n = 4)			Total (n = 16)		
Variable	*Condition*	Pre	Post	24H-Post	Pre	Post	24H-Post	Pre	Post	24H-Post
Conc Mean Force (N)	*Low*	2014.3 ± 305.9	2054.4 ± 330.6	2064.4 ± 279.6	1685.3 ± 113.6	1640 ± 102.3	1627.5 ± 107.2	1932.1 ± 304.8	1950.8 ± 341.4	1955.2 ± 312.7
	High	2031.5 ± 236.2	2001.8 ± 258.7	2042.6 ± 230.8	1656.5 ± 122.2	1577 ± 129.2	1632.3 ± 129.3	1937.8 ± 268.3	1895.6 ± 297.5	1940 ± 275.8
Conc Mean Power (W)	*Low*	2992.8 ± 625.6	3032.8 ± 616.7	3108.9 ± 554.3	2227.3 ± 242.7	2134.5 ± 275.4	2129.3 ± 219.8	2801.4 ± 645	2808.3 ± 674.9	2864 ± 653.4
	High	3047.0 ± 444.9	2930.8 ± 554.2	3010.3 ± 411.7	2196.8 ± 268.7	1971.8 ± 369.2	2102.8 ± 270.6	2834.4 ± 551.5	2691 ± 660.6	2783.4 ± 551
Conc Peak Force (N)	*Low*	2550.6 ± 406.5	2670.7 ± 463.9	2592.9 ± 404.0	2230.8 ± 146.8	2162.3 ± 197.5	2144.3 ± 129.5	2470.6 ± 382	2543.6 ± 466.2	2480.8 ± 404.1
	High	2566.0 ± 419.2	2589.1 ± 419.4	2594.8 ± 355.5	2184.3 ± 146.6	2103.5 ± 131.7	2136.8 ± 156.5	2470.6 ± 402.9	2467.7 ± 423.8	2480.3 ± 373.6
FT:CT	*Low*	0.75 ± 0.13	0.77 ± 0.15	0.77 ± 0.15	0.76 ± 0.09	0.74 ± 0.07	0.71 ± 0.07	0.75 ± 0.12	0.76 ± 0.14	0.76 ± 0.13
	High	0.74 ± 0.13	0.72 ± 0.14	0.74 ± 0.15	0.76 ± 0.06	0.69 ± 0.14	0.72 ± 0.06	0.74 ± 0.12	0.71 ± 0.14	0.73 ± 0.13
Jump Height (cm)	*Low*	38.0 ± 5.9	37.5 ± 6.5	38.0 ± 6.9	28.2 ± 4.5	27.5 ± 5	27.7 ± 4.9	35.5 ± 7	35 ± 7.5	35.4 ± 7.8
	High	38.0 ± 5.6	36.1 ± 6.5	37.7 ± 5.7	26.6 ± 3.8	24.6 ± 6.3	26.6 ± 3.9	35.1 ± 7.2	33.2 ± 8.1	34.9 ± 7.2
Peak Power (W)	*Low*	5674.2 ± 823.9	5738.6 ± 1082.7	5600.1 ± 845.0	3840.8 ± 602.6	3824.3 ± 645.9	3797 ± 615.2	5215.8 ± 1114.8	5260 ± 1294.6	5149.3 ± 1117.8
	High	5559.5 ± 650.4	5500.8 ± 715.6	5401.4 ± 636.5	3860.5 ± 718.6	3583.3 ± 503.2	3712.5 ± 628.7	5134.8 ± 995.4	5021.4 ± 1077.7	4979.2 ± 973
RSI_{Mod} (m/s)	*Low*	0.50 ± 0.13	0.52 ± 0.13	0.53 ± 0.13	0.45 ± 0.07	0.43 ± 0.06	0.41 ± 0.06	0.49 ± 0.12	0.50 ± 0.12	0.50 ± 0.12
	High	0.51 ± 0.11	0.48 ± 0.12	0.51 ± 0.12	0.44 ± 0.05	0.38 ± 0.11	0.41 ± 0.05	0.49 ± 0.10	0.45 ± 0.12	0.48 ± 0.11

Data presented as Mean ± Standard Deviation. Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; Conc = Concentric; FT:CT = Flight Time to Contraction Ratio; FT = Flight Time; Jump Height, computed based off flight time method; cm = centimeters.

There were no significant Sex × Condition interactions for any CMJ Traditional Variable, including: Conc Mean Force ($p = 0.858$, $\eta_{p2} = 0.002$), Conc Mean Power ($p = 0.845$, $\eta_{p2} = 0.003$), Conc Peak Force ($p = 0.838$, $\eta_{p2} = 0.003$), FT:CT ($p = 0.617$, $\eta_{p2} = 0.018$), Jump Height ($p = 0.223$, $\eta_{p2} = 0.104$), Peak Power ($p = 0.675$, $\eta_{p2} = 0.013$), RSI_{Mod} ($p = 0.975$, $\eta_{p2} < 0.001$).

There were no significant Sex × Time interactions for any CMJ Traditional Variable, including: Conc Mean Force ($p = 0.323$, $\eta_{p2} = 0.078$), Conc Mean Power ($p = 0.496$, $\eta_{p2} = 0.049$), Conc Peak Force ($p = 0.055$, $\eta_{p2} = 0.187$), FT:CT ($p = 0.212$, $\eta_{p2} = 0.106$), Jump Height ($p = 0.971$, $\eta_{p2} = 0.001$), Peak Power ($p = 0.501$, $\eta_{p2} = 0.048$), RSI_{Mod} ($p = 0.444$, $\eta_{p2} = 0.056$).

As presented in Table 8 and Figures 7 and 8, There were no significant Condition × Time interactions for any CMJ Traditional Variables, including: Conc Mean Force ($p = 0.551$, $\eta_{p2} = 0.042$), Conc Mean Power ($p = 0.596$, $\eta_{p2} = 0.036$), Conc Peak Force ($p = 0.480$, $\eta_{p2} = 0.036$), FT:CT ($p = 0.295$, $\eta_{p2} = 0.084$), Jump Height ($p = 0.355$, $\eta_{p2} = 0.071$), Peak Power ($p = 0.425$, $\eta_{p2} = 0.059$), RSI_{Mod} ($p = 0.453$, $\eta_{p2} = 0.055$).

Table 8. CMJ Traditional Variables by Condition Across Time.

Variable	*Condition*	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Conc Mean Force (N)	*Low*	1849.8 (79.7)	1847.2 (85.7)	1846.0 (73.0)	0.01	0.00	0.01
	High	1844.0 (62.6)	1789.4 (68.4)	1837.4 (61.5)	0.21	0.18	0.03
Conc Mean Power (W)	*Low*	2610.0 (163.3)	2583.7 (162)	2619.1 (144.8)	0.04	0.06	0.01
	High	2621.9 (119.4)	2451.3 (150.2)	2556.5 (111.4)	0.31	0.20	0.14
Conc Peak Force (N)	*Low*	2390.7 (105.8)	2416.5 (121.6)	2368.6 (104.8)	0.06	0.11	0.05
	High	2375.1 (109.0)	2346.3 (108.7)	2365.8 (93.3)	0.07	0.05	0.02
FT:CT	*Low*	0.75 (0.04)	0.75 (0.04)	0.74 (0.04)	0.00	0.06	0.07
	High	0.75 (0.04)	0.70 (0.04)	0.73 (0.04)	0.33	0.19	0.14
Jump Height (cm)	*Low*	33.1 (1.6)	32.5 (1.8)	32.8 (1.9)	0.09	0.04	0.04
	High	32.3 (1.5)	30.3 (1.9)	32.1 (1.6)	0.29	0.26	0.03
Peak Power (W)	*Low*	4757.5 (225.7)	4781.4 (290.2)	4698.5 (231.3)	0.02	0.08	0.06
	High	4710.0 (192.2)	4542.0 (195.1)	4557.0 (183.3)	0.22	0.02	0.20
RSI_{Mod} (m/s)	*Low*	0.47 (0.03)	0.47 (0.03)	0.47 (0.03)	0.00	0.00	0.00
	High	0.47 (0.03)	0.43 (0.04)	0.46 (0.03)	0.32	0.23	0.08

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; Conc = Concentric; FT:CT = Flight Time to Contraction Ratio; FT = Flight Time; Jump Height, computed based off flight time method; * = statistical significance, set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

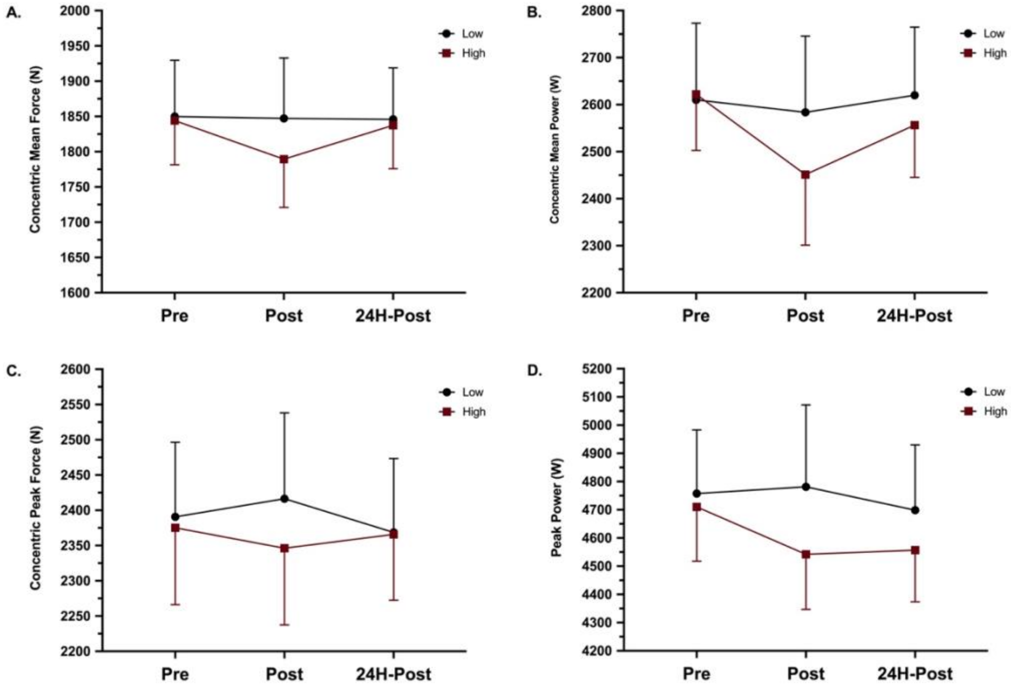


Figure 7. CMJ Traditional Variables by Condition Across Time

Note: Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load.

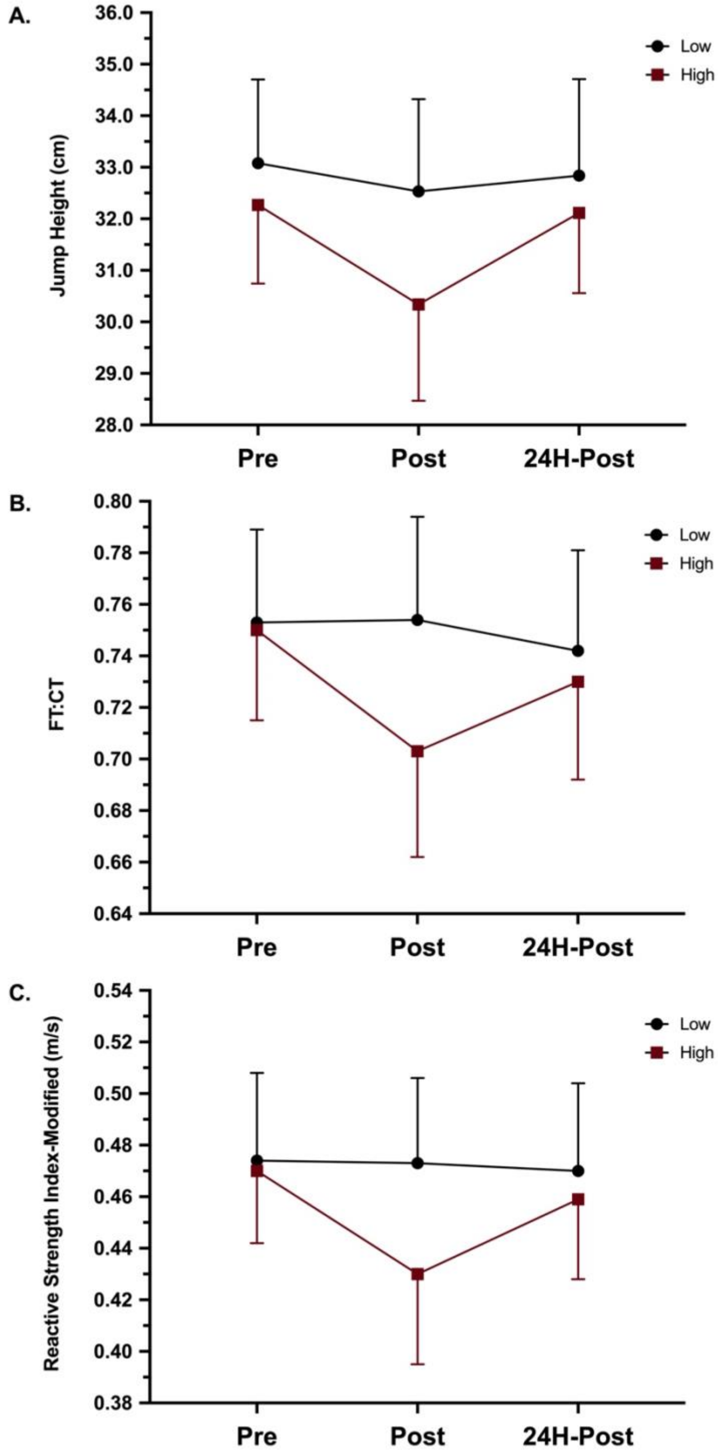


Figure 8. CMJ Traditional Variables by Condition Across Time

Note: Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; Jump Height, computed based off flight time method; FT:CT = Flight Time to Contraction Ratio.

There was a significant Condition main effect for Jump Height (Low = 32.8 (1.7); High = 31.6 (1.5), p = 0.030, *d* = 0.26). There were no other significant Condition main effect for Conc Mean Force (p = 0.390, *d* = 0.12), Conc Mean Power (p = 0.336, *d* = 0.16), Conc Peak Force (p = 0.460, *d* = 0.10), FT:CT (p = 0.265, *d* = 0.23), Peak Power (p = 0.158, *d* = 0.22), RSI_{Mod} (p = 0.161, *d* = 0.23).

There were no significant main effect for Time for any CMJ Traditional Variable, including: Conc Mean Force (p = 0.518, η_{p2} = 0.046), Conc Mean Power (p = 0.279, η_{p2} = 0.087), Conc Peak Force (p = 0.843, η_{p2} = 0.012), FT:CT (p = 0.416, η_{p2} = 0.059), Jump Height (p = 0.212, η_{p2} = 0.108), Peak Power (p = 0.381, η_{p2} = 0.064), RSI_{Mod} (p = 0.444, η_{p2} = 0.056).

As outlined in Table 9, there were significant Sex main effect for Conc Mean Force (p = 0.011, *d* = 1.70), Conc Mean Power (p = 0.004, *d* = 0.2.00), Conc Peak Force (p = 0.050, *d* = 1.21), Jump Height (p = 0.005, *d* = 1.91), Peak Power (p = 0.001, *d* = 2.51), all exhibiting large effects. Additionally, there were no significant differences between sexes in FT:CT (p = 0.817, *d* = 0.14) or RSI_{Mod} (p = 0.160, *d* = 0.86), there appeared to only be a trivial effect for FT:CT, however, with RSI_{Mod} there still appeared to be a large effect.

Table 9. Sex Differences in CMJ Traditional Variables

Variable	Men (n = 12)	Women (n = 4)	Effect (*d*)
Concentric Mean Force (N)	2034.8 (67.7)	1636.4 (117.3)*	1.70
Concentric Mean Power (W)	3020.4 (129)	2127 (223.5)*	2.00
Concentric Peak Force (N)	2594 (103.2)	2160.3 (178.8)*	1.21
FT:CT	0.75 (0.03)	0.73 (0.06)	0.14
Jump Height (cm)	37.5 (1.6)	26.9 (2.8)*	1.91
Peak Power (W)	5579.1 (208.5)	3769.7 (361.1)*	2.51
RSI_{Mod} (m/s)	0.51 (0.03)	0.42 (0.05)	0.86

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; FT:CT = Flight Time to Contraction Ratio; FT = Flight Time; Jump Height, computed based off flight time method; cm = centimeters; * = statistical significance, set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Countermovement Jump Concentric Alternative Variables

Descriptive statistics of the CMJ Concentric Alternative Variables are presented in Table 10. There were no significant 3-way interactions for any CMJ Concentric Alternative Variable, including: Conc Impulse ($p = 0.776$, $\eta_{p2} = 0.018$), Peak Velocity ($p = 0.724$, $\eta_{p2} = 0.023$), Conc RPD ($p = 0.801$, $\eta_{p2} = 0.016$), Force@PP ($p = 0.966$, $\eta_{p2} = 0.002$), and Velocity@PP ($p = 0.773$, $\eta_{p2} = 0.018$).

There were no significant Sex × Condition interaction for an CMJ Concentric Alternative Variable, including: Conc Impulse ($p = 0.678$, $\eta_{p2} = 0.013$), Peak Velocity ($p = 0.914$, $\eta_{p2} = 0.001$), Conc RPD ($p = 0.697$, $\eta_{p2} = 0.011$), Force@PP ($p = 0.515$, $\eta_{p2} = 0.031$), and Velocity@PP ($p = 0.650$, $\eta_{p2} = 0.015$).

There were no significant Sex × Time interactions for any CMJ Concentric Alternative Variable, including: Conc Impulse ($p = 0.931$, $\eta_{p2} = 0.005$), Peak Velocity ($p = 0.762$, $\eta_{p2} = 0.019$), Conc RPD ($p = 0.208$, $\eta_{p2} = 0.106$), Force@PP ($p = 0.181$, $\eta_{p2} = 0.116$), and Velocity@PP ($p = 0.907$, $\eta_{p2} = 0.007$).

As outlined in Table 11 and Figures 9, there were no significant Condition × Time interactions for any CMJ Concentric Alternative Variable, including: Conc Impulse ($p = 0.418$, $\eta_{p2} = 0.060$), Peak Velocity ($p = 0.439$, $\eta_{p2} = 0.057$), Conc RPD ($p = 0.529$, $\eta_{p2} = 0.044$), Force@PP ($p = 0.599$, $\eta_{p2} = 0.036$), and Velocity@PP ($p = 0.621$, $\eta_{p2} = 0.033$).

Table 10. Countermovement Jump Concentric Alternative Variable Descriptive Statistics.

		Men (n = 12)			Women (n = 4)			Total (n = 16)		
Variable	*Condition*	Pre	Post	24H-Post	Pre	Post	24H-Post	Pre	Post	24H-Post
Conc Impulse (Ns)	*Low*	264.3 ± 27.3	259.2 ± 31.2	262.5 ± 28.4	193.3 ± 23.9	189.6 ± 24.2	191.4 ± 23.7	246.5 ± 40.9	241.8 ± 42.4	244.7 ± 41.4
	High	264.2 ± 24.6	254.9 ± 26.8	257.9 ± 23.1	192.7 ± 25.9	178.8 ± 22.5	187.5 ± 23.5	246.3 ± 40	235.9 ± 42.3	240.3 ± 38.6
Peak Velocity (m•s-1)	*Low*	2.88 ± 0.22	2.85 ± 0.27	2.84 ± 0.21	2.46 ± 0.17	2.44 ± 0.2	2.45 ± 0.18	2.77 ± 0.27	2.74 ± 0.31	2.74 ± 0.26
	High	2.85 ± 0.17	2.79 ± 0.21	2.79 ± 0.22	2.47 ± 0.2	2.33 ± 0.22	2.4 ± 0.17	2.75 ± 0.24	2.68 ± 0.29	2.69 ± 0.27
Conc RPD (W•s-1)	*Low*	32512.8 ± 11658.8	36311.5 ± 13618.0	34827.8 ± 11209.4	25679.7 ± 3621.1	24941.7 ± 4022.1	23595.6 ± 3275.4	30804.5 ± 10566.0	33469.1 ± 12848.6	32019.7 ± 10932.6
	High	32656.8 ± 9002.4	33396.8 ± 10688.4	33192.6 ± 8721.4	25354.5 ± 5042.5	23083.8 ± 5212.7	24406.2 ± 5209.5	30831.2 ± 8670.7	30818.6 ± 10511.1	30996 ± 8754.8
Force@PP (N)	*Low*	2253.8 ± 261.4	2325.7 ± 297.7	2258.8 ± 258.8	1783.0 ± 212.0	1800.8 ± 236.5	1765.8 ± 240.4	2136.1 ± 321.6	2194.4 ± 362.3	2135.5 ± 330.6
	High	2227.4 ± 202.4	2269.4 ± 219.9	2222.4 ± 227.3	1787.5 ± 218.4	1771.3 ± 201.6	1773.5 ± 210.5	2117.4 ± 279.8	2144.9 ± 305.3	2110.2 ± 295.1
Velocity@PP (m•s-1)	*Low*	2.51 ± 0.19	2.45 ± 0.23	2.47 ± 0.18	2.15 ± 0.16	2.12 ± 0.19	2.15 ± 0.18	2.42 ± 0.24	2.37 ± 0.26	2.39 ± 0.23
	High	2.49 ± 0.15	2.42 ± 0.19	2.43 ± 0.18	2.15 ± 0.17	2.03 ± 0.21	2.09 ± 0.14	2.41 ± 0.22	2.32 ± 0.26	2.35 ± 0.23

Data presented as Mean ± Standard Deviation. Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; Conc = Concentric; Peak Velocity = Concentric Peak Velocity; RPD = Rate of Power Development; Force@PP = Force at Peak Power; Velocity@PP = Velocity at Peak Power.

Table 11. CMJ Concentric Alternative Variables by Condition Across Time.

Variable	*Condition*	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Conc Impulse (Ns)	*Low*	228.8 (7.7)	224.4 (8.6)	227 (7.9)	0.13	0.08	0.06
	High	228.4 (7.2)	216.8 (7.5)	222.7 (6.7)	0.39	0.21	0.21
Peak Velocity (m•s-1)	*Low*	2.67 (0.06)	2.64 (0.07)	2.65 (0.06)	0.11	0.04	0.08
	High	2.66 (0.05)	2.56 (0.06)	2.60 (0.06)	0.44	0.16	0.26
Conc RPD (W•s-1)	*Low*	29096.3 (3022.3)	30626.6 (3525.8)	29211.7 (2901.5)	0.12	0.11	0.01
	High	29005.7 (2400.1)	28240.3 (2822.3)	28799.4 (2337.7)	0.07	0.05	0.02
Force@PP (N)	*Low*	2018.4 (72.6)	2063.2 (82.5)	2012.3 (73.6)	0.14	0.16	0.02
	High	2007.5 (59.4)	2020.3 (62.4)	1998 (64.6)	0.05	0.09	0.04
Velocity@PP (m•s-1)	*Low*	2.33 (0.05)	2.29 (0.06)	2.31 (0.05)	0.17	0.09	0.1
	High	2.32 (0.05)	2.23 (0.06)	2.26 (0.05)	0.44	0.14	0.31

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; Conc = Concentric; Peak Velocity = Concentric Peak Velocity; RPD = Rate of Power Development; Force@PP = Force at Peak Velocity@PP = Velocity at Peak Power; statistical significance set at $p \leq 0.05$; d = Cohen's d, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

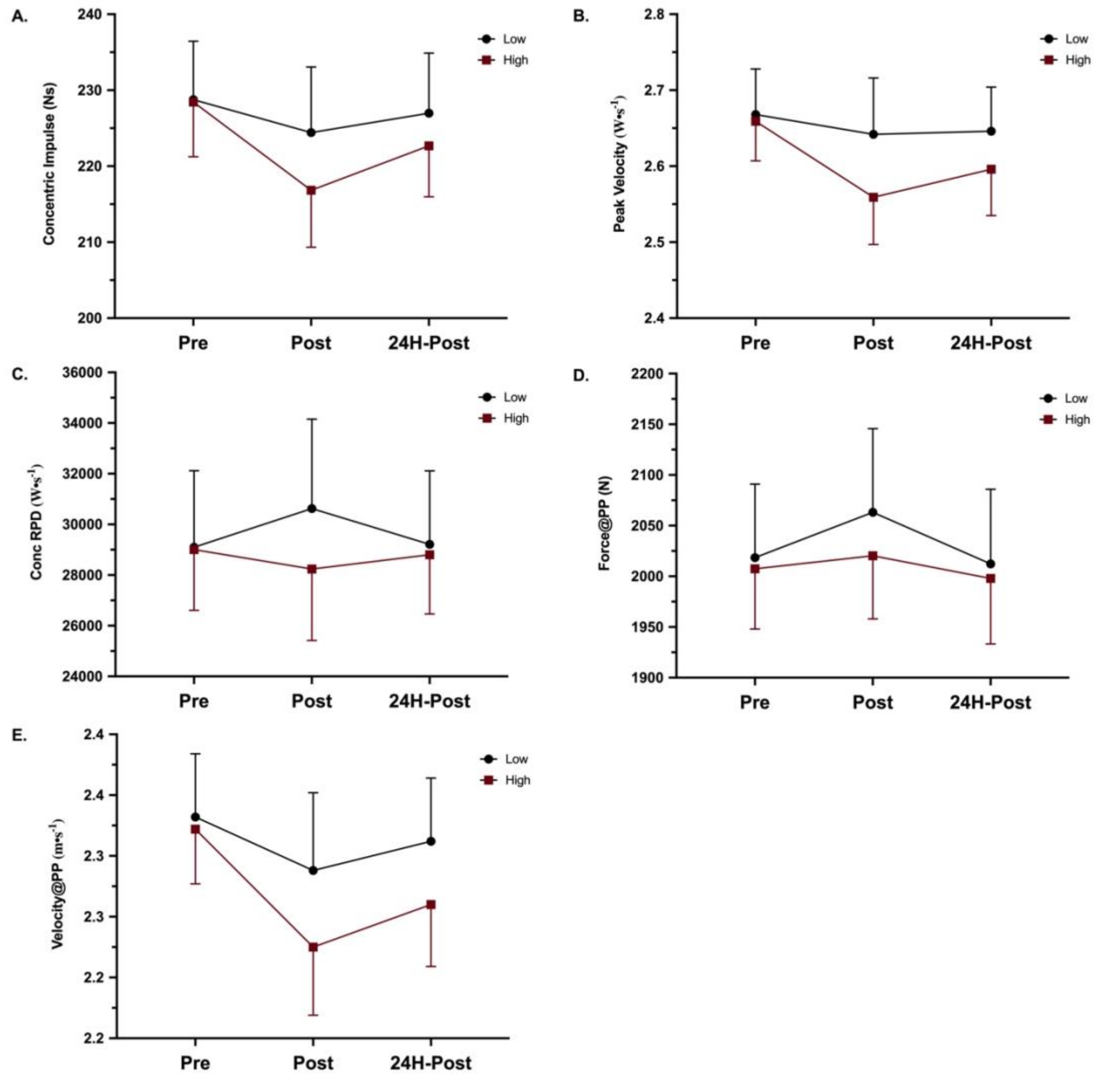


Figure 9. CMJ Concentric Alternative Variables by Condition Across Time

Note: Data presented as Mean (Standard Error); Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; Conc = Concentric; Peak Velocity = Concentric Peak Velocity; RPD = Rate of Power Development; Force@PP = Force at Peak Power; Force@0V = Force at Zero Velocity; Velocity@PP = Velocity at Peak Power.

There were no significant Condition main effects for any CMJ Concentric Alternative Variable, including: Conc Impulse (p = 0.126, *d* = 0.19), Peak Velocity (p = 0.096, *d* = 0.29), Conc RPD (p = 0.462, *d* = 0.12), Force@PP (p = 0.387, *d* = 0.11), Force@0V (p = 0.447, *d* = 0.09), and Velocity@PP (p = 0.097, *d* = 0.09).

There was a significant main effect for Time for Conc Impulse (p = 0.040, η_{p2} = 0.206), with follow-up post-hoc pairwise comparisons revealing no significant differences between any timepoints, but a small effect appeared from Pre to Post (p = 0.068, *d* = 0.26). No other CMJ Concentric Alternative variable demonstrated a significant main effect for Time, including: Peak Velocity (p = 0.207, η_{p2} = 0.108), Conc RPD (p = 0.911, η_{p2} = 0.007), Force@PP (p = 0.053, η_{p2} = 0.189), Force@0V (p = 0.237, η_{p2} = 0.098), and Velocity@PP (p = 0.106, η_{p2} = 0.148).

As presented in Table 12, there were significant Sex main effects for Conc Impulse (p < 0.001, *d* = 2.89), Conc Peak Velocity (p = 0.002, *d* = 2.17), Force@PP (p = 0.003, *d* = 2.06), and Velocity@PP (p = 0.002, *d* = 2.20), but no there were no statistical differences between Sex in Conc RPD (p = 0.100, *d* = 1.02) although there still appeared to be a medium to large effect.

Table 12. Sex Differences in CMJ Concentric Alternative Variables

Variable	Men (n = 12)	Women (n = 4)	Effect (*d*)
Conc Impulse (Ns)	260.5 (7.2)	188.9 (12.4)**	2.89
Peak Velocity ($m \bullet s^{-1}$)	2.83 (0.05)	2.43 (0.09)*	2.17
Conc RPD ($W \bullet s^{-1}$)	33816.4 (2645.8)	24510.3 (4582.7)	1.02
Force@PP (N)	2259.6 (67.2)	1780.3 (116.4)*	2.06
Velocity@PP ($m \bullet s^{-1}$)	2.47 (0.05)	2.11 (0.08)*	2.20

Data presented as Mean (Standard Error); Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Conc = Concentric; Peak Velocity = Concentric Peak Velocity; RPD = Rate of Power Development; Force@PP = Force at Peak Power; Velocity@PP = Velocity at Peak Power; # = significantly greater than Pre; * = statistical significance, set at $p \leq 0.05$, ** statistical significance, $p < 0.001$; d = Cohen's d, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Countermovement Jump Eccentric Alternative Variables

Descriptive statistics of the CMJ eccentric Alternative Variables are presented in Table 13. There were no significant 3-way interactions for any CMJ Eccentric Alternative Variable, including: Ecc Mean Braking Force (p = 0.825, η_{p2} = 0.005), Ecc Mean Decel Force (p = 0.819, η_{p2} = 0.014), Ecc Mean Force (p = 0.116, η_{p2} = 0.143), Ecc Mean Power (p = 0.912, η_{p2} = 0.007), Ecc Peak Force (p = 0.797, η_{p2} = 0.016) and Force@0V (p = 0.798, η_{p2} = 0.016).

There were no significant Sex × Condition interactions for any CMJ Eccentric Alternative Variable, including: Ecc Mean Braking Force (p = 0.798, η_{p2} = 0.005), Ecc Mean Decel Force (p = 0.532, η_{p2} = 0.030), Ecc Mean Force (p = 0.938, η_{p2} < 0.001), Ecc Mean Power (p = 0.570, η_{p2} = 0.024), Ecc Peak Force (p = 0.864, η_{p2} = 0.002), and Force@0V (p = 0.919, η_{p2} = 0.001).

There were no significant Sex × Time interactions for any CMJ Eccentric Alternative Variable, including: Ecc Mean Braking Force (p = 0.471, η_{p2} = 0.046), Ecc Mean Decel Force (p = 0.070, η_{p2} = 0.173), Ecc Mean Force (p = 0.057, η_{p2} = 0.185), Ecc

Mean Power ($p = 0.054$, $\eta_{p2} = 0.188$), Ecc Peak Force ($p = 0.174$, $\eta_{p2} = 0.117$), and Force@0V ($p = 0.125$, $\eta_{p2} = 0.138$).

As presented in Table 14 and Figure 10, there were significant Condition × Time interactions for Ecc Mean Force ($p = 0.028$, $\eta_{p2} = 0.226$). Post-hoc pairwise comparisons revealed a significant increase in from Pre to Post ($p = 0.032$, $d = 0.06$) during the Low condition, but no difference from Post to 24H-Post ($p = 0.101$, $d = 0.03$) or from Pre to 24H-Post ($p > 0.999$, $d = 0.05$), however all differences were of trivial effect. There were no differences across time points during the High condition ($p > 0.05$). There were no other significant Condition × Time interactions for CMJ Eccentric Alternative Variable, including: Ecc Mean Braking Force ($p = 0.454$, $\eta_{p2} = 0.045$), Ecc Mean Decel Force ($p = 0.700$, $\eta_{p2} = 0.025$), Ecc Mean Power ($p = 0.743$, $\eta_{p2} = 0.021$), and Ecc Peak Force ($p = 0.517$, $\eta_{p2} = 0.046$), and Force@0V ($p = 0.502$, $\eta_{p2} = 0.048$).

Table 13. Countermovement Jump Eccentric Alternative Variables Descriptive Statistic.

		Men (n = 12)			Women (n = 4)			Total (n = 16)		
Variable	*Condition*	Pre	Post	24H-Post	Pre	Post	24H-Post	Pre	Post	24H-Post
Ecc Mean Braking Force (N)	*Low*	1187.6 ± 210.8	1182.8 ± 205.6	1198.5 ± 205.6	1033.4 ± 47.1	1008.6 ± 28.5	997.5 ± 66.0	1149.1 ± 194.4	1139.2 ± 193.0	1148.3 ± 199.9
	High	1175.9 ± 187.9	1157.4 ± 172	1223.8 ± 206.8	994.2 ± 65.7	991.2 ± 37.3	1015.8 ± 47.4	1130.5 ± 182.7	1115.9 ± 165.8	1171.8 ± 201.2
Ecc Mean Decel Force (N)	*Low*	1672.9 ± 413.3	1701.4 ± 383.3	1808.1 ± 371.4	1586.9 ± 199.2	1529.8 ± 157	1537.0 ± 187.4	1651.4 ± 367.0	1658.5 ± 344.4	1740.3 ± 350.5
	High	1741.8 ± 397.5	1657.1 ± 368.2	1802.7 ± 349.1	1558.3 ± 182.5	1482.4 ± 207.8	1506.5 ± 159.6	1695.9 ± 359.6	1613.4 ± 337.9	1728.7 ± 334.7
Ecc Mean Force (N)	*Low*	951.9 ± 98.1	942.4 ± 99.9	949.9 ± 98	799.0 ± 60.3	791.5 ± 64.3	789.5 ± 70.4	913.7 ± 111.6	904.7 ± 112.7	909.8 ± 114.8
	High	952.2 ± 97.3	942 ± 98.3	956.5 ± 104.2	783.5 ± 48.7	799.3 ± 56.0	802.3 ± 55.0	910.0 ± 114.5	906.3 ± 108.6	917.9 ± 115.4
Ecc Mean Power (W)	*Low*	530.3 ± 122.2	525.2 ± 114.9	578.5 ± 108	447.5 ± 70.9	442.8 ± 68.0	449.5 ± 86.6	509.6 ± 115.5	504.6 ± 109.4	546.3 ± 115.7
	High	564.9 ± 118.6	520.8 ± 88.1	584.7 ± 87.1	449.3 ± 86.0	435.3 ± 92.1	434.3 ± 51.5	536.0 ± 120.3	499.4 ± 94.1	547.1 ± 103.0
Ecc Peak Force (N)	*Low*	2258.8 ± 547.4	2324.3 ± 595	2406.0 ± 470.4	2049.0 ± 316.1	1973.3 ± 310.7	1978 ± 255.2	2206.4 ± 498.5	2236.6 ± 550.9	2299.0 ± 460.4
	High	2327.2 ± 539.4	2207.3 ± 547.3	2374.7 ± 419.2	2023.8 ± 259.6	1896.3 ± 307.3	1952 ± 239.2	2251.3 ± 495.2	2129.5 ± 507.8	2269.0 ± 419.6
Force@0V (N)	*Low*	2248.2 ± 546.7	2319.3 ± 597.3	2397.5 ± 473.0	2046.0 ± 316.2	1969.5 ± 312.1	1959.0 ± 252.6	2197.6 ± 497.4	2231.8 ± 552.8	2287.9 ± 464.0
	High	2308.3 ± 536.6	2203.0 ± 547.6	2367.4 ± 418.6	2021.8 ± 261.5	1892.8 ± 307.0	1945.3 ± 240.9	2236.7 ± 491.1	2125.4 ± 507.9	2261.9 ± 419.2

Data presented as Mean ± Standard Deviation. Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; Ecc = Eccentric; Decel = Deceleration; Force@0V = Force at Zero Velocity.

Table 14. Countermovement Jump Eccentric Alternative Variables Condition by Time.

Variable	*Condition*	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Ecc Mean Braking Force (N)	*Low*	1110.5 (54.3)	1095.7 (52.8)	1098.0 (53.3)	0.07	0.01	0.06
	High	1085.1 (48.9)	1074.3 (44.3)	1119.8 (53.3)	0.06	0.23	0.17
Ecc Mean Decel Force (N)	*Low*	1629.9 (109.1)	1615.6 (100.3)	1672.5 (98.3)	0.03	0.14	0.1
	High	1650.1 (104.6)	1569.7 (98.2)	1654.6 (91.8)	0.20	0.22	0.01
Ecc Mean Force (N)	*Low*	875.5 (26.4)	867.0 (27.0)	869.7 (26.8)	0.08	0.03	0.05
	High	867.8 (25.7)	870.6 (26.2)	879.4 (27.7)	0.03	0.08	0.11
Ecc Mean Power (W)	*Low*	488.9 (32.7)	484.0 (30.8)	514.0 (30.0)	0.04	0.25	0.20
	High	507.1 (32.4)	478.0 (25.7)	509.5 (23.3)	0.25	0.32	0.02
Ecc Peak Force (N)	*Low*	2153.9 (146.3)	2148.8 (157.8)	2192.0 (125.1)	0.01	0.08	0.07
	High	2175.5 (142.3)	2051.8 (145.9)	2163.3 (111.9)	0.21	0.21	0.02
Force@0V (N)	*Low*	2147.1 (146.1)	2144.4 (158.4)	2178.3 (125.7)	0.00	0.06	0.06
	High	2165.0 (141.7)	2047.9 (146.0)	2156.3 (111.8)	0.20	0.21	0.02

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; Ecc = Eccentric; Decel = Deceleration; Force@0V = Force at Zero Velocity; * = statistical significance, set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

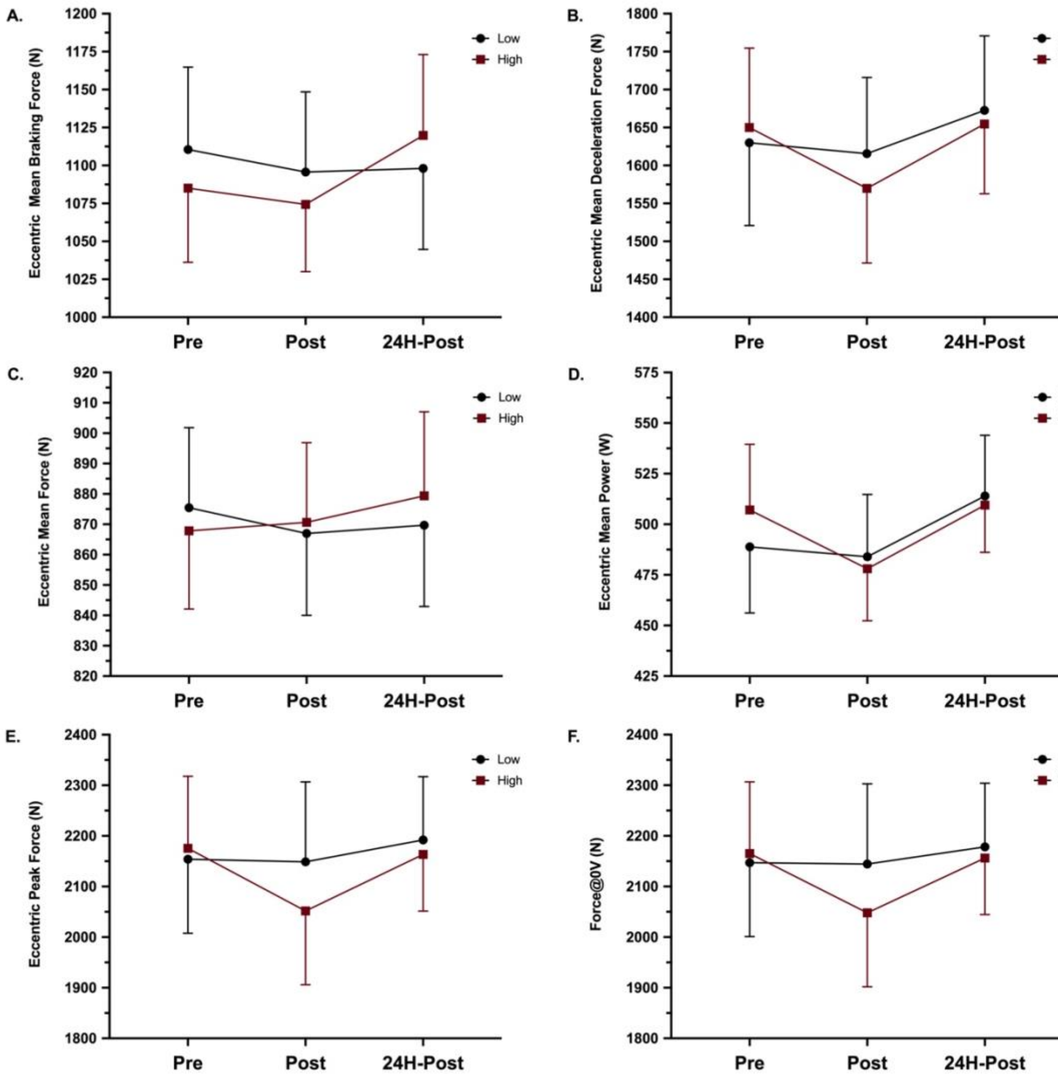


Figure 10. Differences in Countermovement Jump Eccentric Alternative Variables by Condition Across Time

Note: Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load.

There were no significant main effects for Condition for Ecc Mean Braking Force (p = 0.629, *d* = 0.06), Ecc Mean Decel Force (p = 0.657, *d* = 0.05), Ecc Mean Force (p = 0.531, *d* = 0.03), Ecc Mean Power (p = 0.878, *d* = 0.03), Ecc Peak Force (p = 0.464, *d* = 0.09), and Force@0V (p = 0.447, *d* = 0.09).

There was a significant Time main effect for Ecc Mean Power (p = 0.037, η_{p2} = 0.210), with post-hoc pairwise comparisons revealing no significant differences (p > 0.05). There were no significant Time main effects for Ecc Mean Braking Force (p = 0.382, η_{p2} = 0.062), Ecc Mean Decel Force (p = 0.095, η_{p2} = 0.015), Ecc Mean Force (p = 0.156, η_{p2} = 0.124), Ecc Peak Force (p = 0.188, η_{p2} = 0.113) or Force@0V (p = 0.237, η_{p2} = 0.098).

As outlined in Table 15, there was a significant Sex main effect for Ecc Mean Force (p = 0.011, *d* = 1.69), but there were no statistically significant differences detected between sexes for Ecc Mean Braking Force (p = 0.079, *d* = 1.09), Ecc Mean Decel Force (p = 0.316, *d* = 0.60), Ecc Mean Power (p = 0.053, *d* = 1.22), Ecc Peak Force (p = 0.220, *d* = 0.74) or Force@0V (p = 0.225, *d* = 0.73) . However, the differences between sex exhibited a medium to large effect for all CMJ Eccentric Alternative Variables.

Table 15. Sex Differences in Eccentric Alternative Variables

Variable	Men (n = 12)	Women (n = 4)	Effect (*d*)
Ecc Mean Braking Force (N)	1187.7 (47.7)	1006.8 (82.7)*	1.09
Ecc Mean Decel Force (N)	1730.6 (94.9)	1533.5 (164.4)	0.60
Ecc Mean Force (N)	949.2 (26.5)	794.2 (45.9)	1.69
Ecc Mean Power (W)	550.7 (25.5)	443.1 (44.1)	1.22
Ecc Peak Force (N)	2316.4 (131.5)	1978.7 (227.8)	0.74
Force@0V (N)	2307.3 (131.9)	1972.4 (228.4)	0.73

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Ecc = Eccentric; Decel = Deceleration; Force@0V = Force at Zero Velocity; * = statistical significance, set at p ≤ 0.05; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Countermovement Jump Phase Duration Alternative Variables

Descriptive statistics of the CMJ eccentric Alternative Variables are presented in Table 16. There were no significant 3-way interactions for any CMJ Phase Duration Alternative Variable, including: Braking Phase Duration ($p = 0.991$, $\eta_{p2} = 0.001$), Concentric Duration ($p = 0.737$, $\eta_{p2} = 0.014$), Contraction Time ($p = 0.656$, $\eta_{p2} = 0.019$), CT:Ecc Duration ($p = 0.285$, $\eta_{p2} = 0.085$), Ecc Accel Phase Duration ($p = 0.843$, $\eta_{p2} = 0.012$), Ecc Decel Phase Duration ($p = 0.858$, $\eta_{p2} = 0.008$), Ecc Duration ($p = 0.742$, $\eta_{p2} = 0.008$), Flight Time ($p = 0.899$, $\eta_{p2} = 0.008$), and FT:Ecc Duration ($p = 0.885$, $\eta_{p2} = 0.009$).

There were no significant Sex × Condition interactions for any CMJ Eccentric Alternative Variable, including: Braking Phase Duration ($p = 0.637$, $\eta_{p2} = 0.016$), Concentric Duration ($p = 0.427$, $\eta_{p2} = 0.046$), Contraction Time ($p = 0.789$, $\eta_{p2} = 0.005$), CT:Ecc Duration ($p = 0.241$, $\eta_{p2} = 0.097$), Ecc Accel Phase Duration ($p = 0.282$, $\eta_{p2} = 0.082$), Ecc Decel Phase Duration ($p = 0.604$, $\eta_{p2} = 0.020$), Ecc Duration ($p = 0.304$, $\eta_{p2} = 0.075$), Flight Time ($p = 0.139$, $\eta_{p2} = 0.150$), and FT:Ecc Duration ($p = 0.491$, $\eta_{p2} = 0.035$),

There were no significant Sex × Time interactions for any CMJ Eccentric Alternative Variable, including: Braking Phase Duration ($p = 0.470$, $\eta_{p2} = 0.052$), Concentric Duration ($p = 0.641$, $\eta_{p2} = 0.023$), Contraction Time ($p = 0.523$, $\eta_{p2} = 0.041$), CT:Ecc Duration ($p = 0.454$, $\eta_{p2} = 0.044$), Ecc Accel Phase Duration ($p = 0.989$, $\eta_{p2} = 0.001$), Ecc Decel Phase Duration ($p = 0.349$, $\eta_{p2} = 0.072$), Ecc Duration ($p = 0.872$, $\eta_{p2} = 0.010$), Flight Time ($p = 0.943$, $\eta_{p2} = 0.004$), and FT:Ecc Duration ($p = 0.307$, $\eta_{p2} = 0.081$).

Table 16. Countermovement Jump Phase Duration Alternative Variables Descriptive Statistics.

		Men (n = 12)			Women (n = 4)			Total (n = 16)		
Variable	Condition	Pre	Post	24H-Post	Pre	Post	24H-Post	Pre	Post	24H-Post
Braking Phase Duration (s)	Low	0.299 ± 0.091	0.288 ± 0.093	0.289 ± 0.075	0.251 ± 0.082	0.248 ± 0.050	0.264 ± 0.070	0.287 ± 0.089	0.278 ± 0.084	0.282 ± 0.072
	High	0.309 ± 0.070	0.317 ± 0.077	0.286 ± 0.060	0.242 ± 0.048	0.263 ± 0.062	0.246 ± 0.047	0.292 ± 0.070	0.304 ± 0.076	0.276 ± 0.059
Concentric Duration (ms)	Low	315.4 ± 244.2	277.6 ± 148.9	243.5 ± 48.6	218.8 ± 18.7	225.3 ± 22.1	231.5 ± 20.0	291.3 ± 213.7	264.5 ± 130.0	240.5 ± 42.9
	High	250.8 ± 44.6	249 ± 48.1	243.5 ± 47.7	225.0 ± 27.2	233.3 ± 26.2	227.0 ± 25.3	244.4 ± 41.7	245.1 ± 43.4	239.4 ± 43.0
Contraction Time (ms)	Low	810.8 ± 235.8	768.8 ± 155.1	740.7 ± 119.8	638.5 ± 99.1	643.3 ± 71.8	671.0 ± 75.1	767.7 ± 220.6	737.4 ± 147.7	723.3 ± 112.4
	High	774.2 ± 131.9	780.7 ± 123.2	787.4 ± 178.8	612.8 ± 63.5	658.8 ± 95.7	652.0 ± 78.5	733.8 ± 137.0	750.2 ± 126.3	753.6 ± 168.4
CT:Ecc Duration (%)	Low	150.1 ± 8.4	147.6 ± 7.8	149.8 ± 7.8	153.3 ± 6.8	154.3 ± 4.4	153.3 ± 6.2	150.9 ± 7.9	149.3 ± 7.6	150.6 ± 7.4
	High	148.9 ± 8.0	147.6 ± 7.2	148.3 ± 10.5	157.9 ± 3.7	155.4 ± 5.0	154.2 ± 5.0	151.2 ± 8.1	149.6 ± 7.4	149.7 ± 9.6
Ecc Accel Phase Duration (s)	Low	0.328 ± 0.051	0.335 ± 0.062	0.343 ± 0.076	0.285 ± 0.042	0.284 ± 0.025	0.302 ± 0.032	0.317 ± 0.051	0.322 ± 0.059	0.333 ± 0.069
	High	0.361 ± 0.083	0.363 ± 0.085	0.383 ± 0.181	0.262 ± 0.017	0.282 ± 0.035	0.289 ± 0.03	0.336 ± 0.084	0.342 ± 0.083	0.359 ± 0.161
Ecc Decel Phase Duration (s)	Low	0.167 ± 0.050	0.156 ± 0.051	0.154 ± 0.040	0.135 ± 0.044	0.135 ± 0.031	0.138 ± 0.034	0.159 ± 0.049	0.151 ± 0.047	0.150 ± 0.038
	High	0.163 ± 0.037	0.169 ± 0.044	0.161 ± 0.039	0.127 ± 0.023	0.144 ± 0.039	0.136 ± 0.030	0.154 ± 0.037	0.163 ± 0.043	0.155 ± 0.038
Ecc Duration (ms)	Low	495.4 ± 80.8	491.2 ± 98.1	496.9 ± 86.6	420.0 ± 85.2	417.5 ± 54.1	439.5 ± 62.9	476.6 ± 85.9	472.8 ± 93.4	482.6 ± 83.3
	High	523.3 ± 102.8	531.8 ± 91.4	543.9 ± 179.7	388.3 ± 39.1	425.3 ± 72.9	424.8 ± 59.4	489.6 ± 108.2	505.1 ± 97.3	514.1 ± 165.0
Flight Time (ms)	Low	554.7 ± 43.3	551.3 ± 48.3	554.1 ± 50.5	478.5 ± 38.6	472.3 ± 43.3	474.0 ± 43.2	535.6 ± 53.2	531.5 ± 57.8	534.1 ± 59.4
	High	554.8 ± 41.8	539.9 ± 49.0	552.7 ± 42.8	464.8 ± 33.6	445.3 ± 57.2	464.8 ± 34.5	532.3 ± 55.9	516.3 ± 64.9	530.7 ± 55.9
FT:Ecc Duration	Low	1.12 ± 0.22	1.14 ± 0.22	1.16 ± 0.22	1.18 ± 0.18	1.14 ± 0.13	1.10 ± 0.13	1.14 ± 0.21	1.14 ± 0.19	1.14 ± 0.20
	High	1.10 ± 0.21	1.06 ± 0.20	1.10 ± 0.23	1.20 ± 0.08	1.08 ± 0.23	1.12 ± 0.10	1.13 ± 0.19	1.06 ± 0.20	1.11 ± 0.21

Data presented as Mean ± Standard Deviation. Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; CT = Contraction Time; Ecc = Eccentric; Accel = Acceleration; Decel = Deceleration; FT = Flight Time.

As presented in Table 17 and Figures 11 and 12, there were significant Condition × Time interactions for Braking Phase Duration ($p = 0.234$, $\eta_{p2} = 0.099$), Concentric Duration ($p = 0.901$, $\eta_{p2} = 0.007$), Contraction Time ($p = 0.572$, $\eta_{p2} = 0.028$), CT:Ecc Duration ($p = 0.417$, $\eta_{p2} = 0.061$), Ecc Accel Phase Duration ($p = 0.857$, $\eta_{p2} = 0.006$), Ecc Decel Phase Duration ($p = 0.147$, $\eta_{p2} = 0.113$), Ecc Duration ($p = 0.556$, $\eta_{p2} = 0.034$), Flight Time ($p = 0.247$, $\eta_{p2} = 0.096$), or FT:Ecc Duration ($p = 0.433$, $\eta_{p2} = 0.058$).

Table 17. Countermovement Jump Phase Duration Alternative Variables Condition by Time.

Variable	*Condition*	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Braking Phase Duration (s)	*Low*	0.275 (0.026)	0.268 (0.025)	0.276 (0.021)	0.07	0.09	0.01
	High	0.275 (0.019)	0.290 (0.021)	0.266 (0.017)	0.19	0.31	0.12
Concentric Duration (ms)	*Low*	267.1 (62.5)	251.4 (38.2)	237.5 (12.7)	0.08	0.12	0.16
	High	237.9 (12.0)	241.1 (12.8)	235.3 (12.7)	0.06	0.11	0.05
Contraction Time (ms)	*Low*	724.6 (61.8)	706.0 (40.8)	705.8 (32.3)	0.09	0.00	0.10
	High	693.5 (34.8)	719.7 (34.0)	719.7 (46.9)	0.19	0.00	0.16
CT:Ecc Duration (%)	*Low*	151.7 (2.3)	151.0 (2.1)	151.5 (2.2)	0.08	0.06	0.02
	High	153.4 (2.1)	151.5 (2.0)	151.2 (2.8)	0.23	0.03	0.22
Ecc Accel Phase Duration (s)	*Low*	0.307 (0.014)	0.309 (0.016)	0.322 (0.020)	0.03	0.18	0.22
	High	0.311 (0.021)	0.322 (0.022)	0.336 (0.046)	0.13	0.10	0.17
Ecc Decel Phase Duration (s)	*Low*	0.151 (0.014)	0.145 (0.014)	0.146 (0.011)	0.11	0.02	0.10
	High	0.145 (0.010)	0.156 (0.012)	0.148 (0.011)	0.25	0.17	0.07
Ecc Duration (ms)	*Low*	457.7 (23.6)	454.3 (26.1)	468.2 (23.7)	0.03	0.14	0.11
	High	455.8 (26.8)	478.5 (25.3)	484.3 (46.7)	0.22	0.04	0.19
Flight Time (ms)	*Low*	516.6 (12.3)	511.8 (12.7)	514.0 (14.2)	0.09	0.04	0.05
	High	509.75 (11.6)	492.6 (14.7)	508.7 (11.9)	0.32	0.30	0.02
FT:Ecc Duration	*Low*	1.15 (0.06)	1.14 (0.06)	1.13 (0.06)	0.05	0.06	0.10
	High	1.15 (0.06)	1.07 (0.07)	1.11 (0.06)	0.35	0.16	0.18

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load; CT = Contraction Time; Ecc = Eccentric; Accel = Acceleration; Decel = Deceleration; FT = Flight Time; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

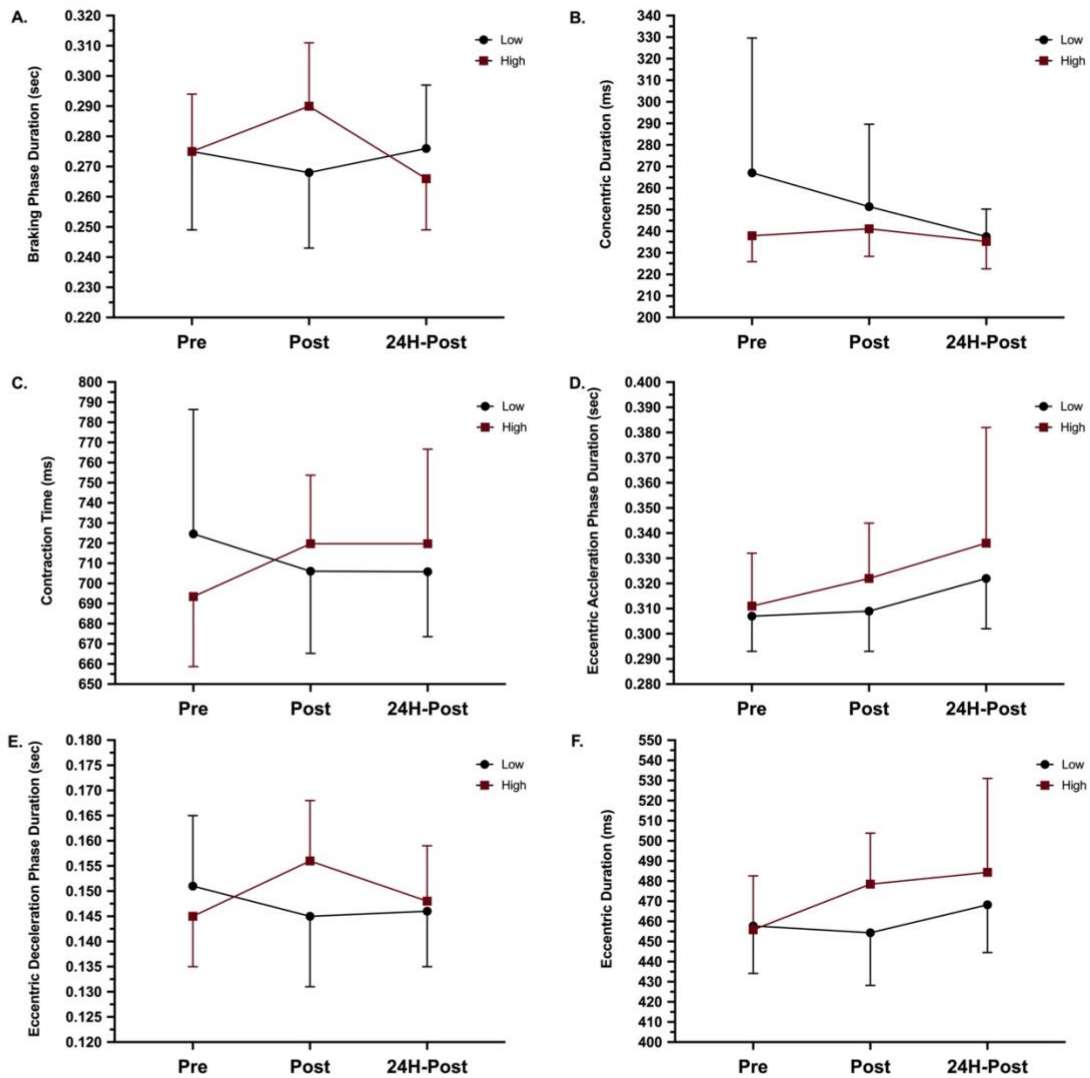


Figure 11. Countermovement Jump Phase Duration Alternative Variables Condition by Time.

Note: Data presented as Mean (Standard Error); Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load.

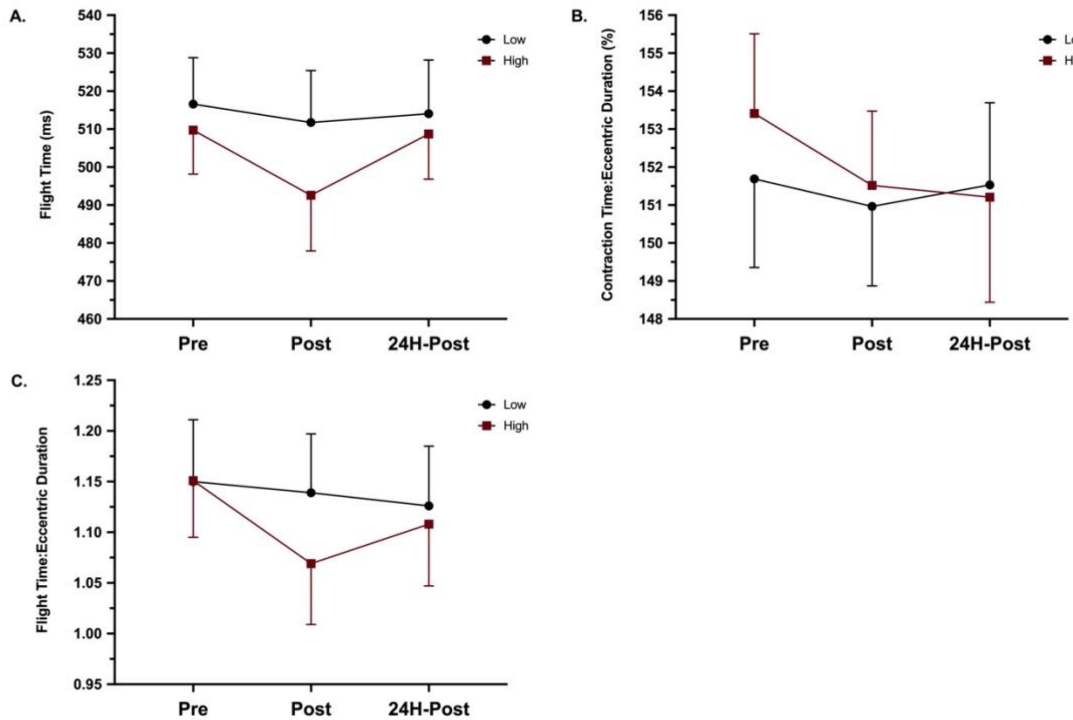


Figure 12. Countermovement Jump Phase Duration Variables Condition by Time

Note: Data presented as Mean (Standard Error); Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low External Training Load; High = High External Training Load.

There was a significant Condition main effect for Flight Time with a decrease in Flight Time during the High = 515.1 (13.0), Low = 503.7 (11.8), p = 0.020, *d* = 0.18). There were no other significant Condition main effect for Braking Phase Duration (p = 0.804, *d* = 0.05), Concentric Duration (p = 0.518, *d* = 0.16), Contraction Time (p = 0.970, *d* = 0.01), CT:Ecc Duration (p = 0.614, *d* = 0.08), Ecc Accel Phase Duration (p = 0.623, *d* = 0.11), Ecc Decel Phase Duration (p = 0.665, *d* = 0.06), Ecc Duration (p = 0.604, *d* = 0.11), or FT:Ecc Duration (p = 0.391, *d* = 0.12).

There were no significant Time main effects for any CMJ Phase Duration Alternative Variables, including: Braking Phase Duration (p = 0.730, η_{p2} = 0.022), Concentric Duration (p = 0.855, η_{p2} = 0.011), Contraction Time (p = 0.989, η_{p2} = 0.001), CT:Ecc Duration (p = 0.438, η_{p2} = 0.057), Ecc Accel Phase Duration (p = 0.387, η_{p2} = 0.056), Ecc Decel Phase Duration (p = 0.721, η_{p2} = 0.023), Ecc Duration (p = 0.491, η_{p2} = 0.041), Flight Time (p = 0.343, η_{p2} = 0.074), or FT:Ecc Duration (p = 0.433, η_{p2} = 0.058).

As presented in Table 18, there was a significant sex difference in Flight Time (p = 0.004, *d* = 1.12) between Sexes. There were no other significant differences observed between Sexes for Jump Phase Duration Alternative Variables, including: Braking Phase Duration (p = 0.233, *d* = 0.51), Concentric Duration (p = 0.315, *d* = 0.41), Contraction Time (p = 0.060, *d* = 0.77), CT:Ecc Duration (p = 0.158, *d* = 0.54), Ecc Accel Phase Duration (p = 0.121, *d* = 0.58), Ecc Decel Phase Duration (p = 0.257, *d* = 0.41), Ecc Duration (p = 0.070, *d* = 0.65), FT:Ecc Duration (p = 0.825, *d* = 0.07), although there was a medium to large effect in most variables between sexes.

Table 18. Sex Differences in CMJ Phase Duration Alternative Variables.

Variables	Men (n = 12)	Women (n = 4)	Effect (*d*)
Braking Phase Duration (s)	0.298 (0.018)	0.252 (0.032)	0.51
Concentric Duration (ms)	263.3 (17.5)	226.8 (30.3)	0.41
Contraction Time (ms)	777.1 (32.1)	646.0 (55.6)	0.77
CT:Ecc Duration (%)	148.7 (2.0)	154.7 (3.5)	0.54
Ecc Accel Phase Duration (s)	0.352 (0.021)	0.284 (0.036)	0.58
Ecc Decel Phase Duration (s)	0.162 (0.011)	0.136 (0.019)	0.41
Ecc Duration (ms)	513.8 (24.1)	419.2 (41.7)	0.65
Flight Time (ms)	551.2 (12.2)	466.6 (21.2)*	1.12
FT:Ecc Duration	1.11 (0.05)	1.14 (0.1)	0.07

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; CT = Contraction Time; Ecc = Eccentric; Accel = Acceleration; Decel = Deceleration; FT = Flight Time; * = statistical significance, set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Endocrine Response Results

Samples from fifteen participants (Men = 12; Women = 3) were included in the endocrine analysis, as one female was excluded due to an inadequate sample provided at the 24H-Post time point. Of the female participants, 1 participant was on an oral contraceptive, while the other 2 participants were in the luteal phase of their menstrual cycle during testing. All male participants provided adequate samples and were included in the analysis. The testosterone assay had an average intra-assay coefficient of variation (CV) of 4.60% and average inter-assay coefficient of variation of 9.85%, while the cortisol assay had an average intra-assay coefficient of variation (CV) of 4.60% and average inter-assay coefficient of variation of 6.00%, additionally all values for testosterone and cortisol among the men and women participants fell within the expected ranges.

There was a significant 3-way Sex × Time × Condition interaction for cortisol ($p = 0.026$, $\eta_{p2} = 0.252$), but not for Testosterone ($p = 0.775$, $\eta_{p2} = 0.013$) or T:C ($p = 0.582$, $\eta_{p2} = 0.041$). Moreover, as depicted in Figure 13, there was a significant Sex × Time interaction for testosterone ($p = 0.048$, $\eta_{p2} = 0.208$). Post-hoc pairwise comparisons revealed significant differences between Sexes at Pre ($p = 0.018$, $d = 1.74$), Post ($p = 0.003$, $d = 2.31$) and at 24H-Post ($p = 0.003$, $d = 2.35$). While no statistically significant Sex × Time differences were revealed in cortisol, differences between sexes at Pre and 24H-Post showed a large effect (Pre: $d = 2.01$; 24-Post: $d = 2.55$), but only a small effect at Post ($d = 0.26$). There were no significant Sex × Condition interactions for testosterone ($p = 0.940$, $\eta_{p2} < 0.001$), cortisol ($p = 0.665$, $\eta_{p2} = 0.015$), or T:C ($p = 0.544$, $\eta_{p2} = 0.029$).

As outlined in and Figure 13, there was a significant main effect for differences in Sex for testosterone ($p = 0.002$, $d = 2.56$), and T:C ($p < 0.000$, $d = 4.56$). In addition, while there were no statistically significant differences in cortisol between sexes, differences between sexes still exhibited a large effect ($p = 0.095$, $d = 1.16$). Therefore, due to the aforementioned sex differences and limited sample size of women, the 3-way model was decomposed into two separate 2-way (Condition × Time) models for analysis within each sex.

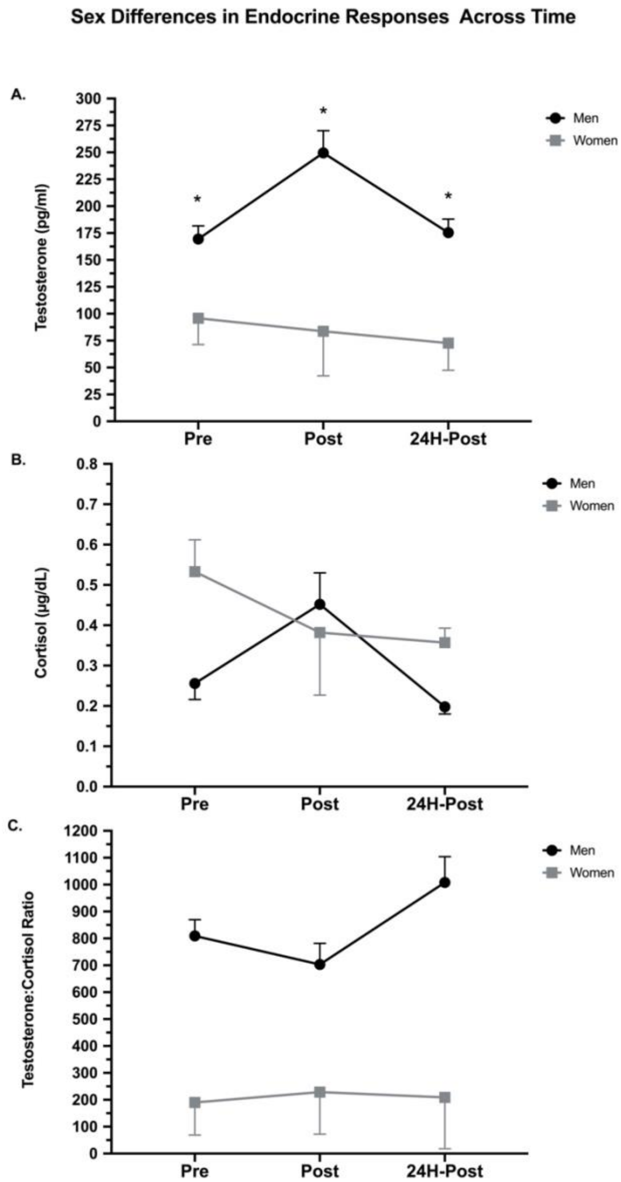


Figure 13. Sex Differences in Endocrine Responses Across Time

Note: Data presented as Mean (Standard Error); Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice.

Endocrine Responses in Men

Testosterone

As presented in Table 19 and illustrated in Figure 14, there were no significant Condition × Time interactions ($p = 0.753$, $\eta_{p2} = 0.025$) for differences in testosterone when examining Men alone. However, as presented in Table 20 and as illustrated in Figure 15, there was a significant Time main effect ($p < 0.001$, $\eta_{p2} = 0.568$) for differences in testosterone, with follow-up pairwise comparisons revealing a significant increases in testosterone from Pre to Post ($p = 0.001$, $d = 1.30$), followed by a significant decrease from Post to 24H-Post ($p = 0.012$, $d = 1.18$), which was not significantly different from baseline (Pre to 24H-Post: $p > 0.999$, $d = 0.14$). There were no significant differences between condition at Pre ($p = 0.908$, $d = 0.04$), Post ($p = 0.881$, $d = 0.05$), or 24H-Post ($p = 0.305$, $d = 0.23$). Also, there was no significant Condition main effect for differences in testosterone between Condition ($p = 0.896$, $\eta_{p2} = 0.002$).

Table 19. Endocrine Response Between Conditions and Across Time in Men.

Variable	*Condition*	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Testosterone (pg/mL)	*Low*	168.5 (11.7)	247.4 (22.8)	181.4 (17.3)	1.26	0.94	0.25
	High	170.3 (16.6)	251.7 (28.8)	169.4 (12.1)	1.00	1.08	0.02
Cortisol (µg/dL)	*Low*	0.197 (0.016)	0.458 (0.066)	0.213 (0.020)	1.57	1.45	0.26
	High	0.314 (0.080)	0.446 (0.108)	0.184 (0.025)	0.40	0.96	0.63
T:C	*Low*	0.088 (0.005)	0.066 (0.009)	0.094 (0.012)	0.87	0.76	0.19
	High	0.073 (0.010)	0.074 (0.009)	0.108 (0.015)	0.03	0.79	0.79

Data Presented as Mean (Standard Error). Low = Low external training load condition; High = High external training load condition; Pre = Pre-Practice; Post = Post=Practice; 24H-Post = 24-Hours Post-Practice; T:C = Testosterone to Cortisol Ratio statistical significance set at $p \leq 0.05$; Effect = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

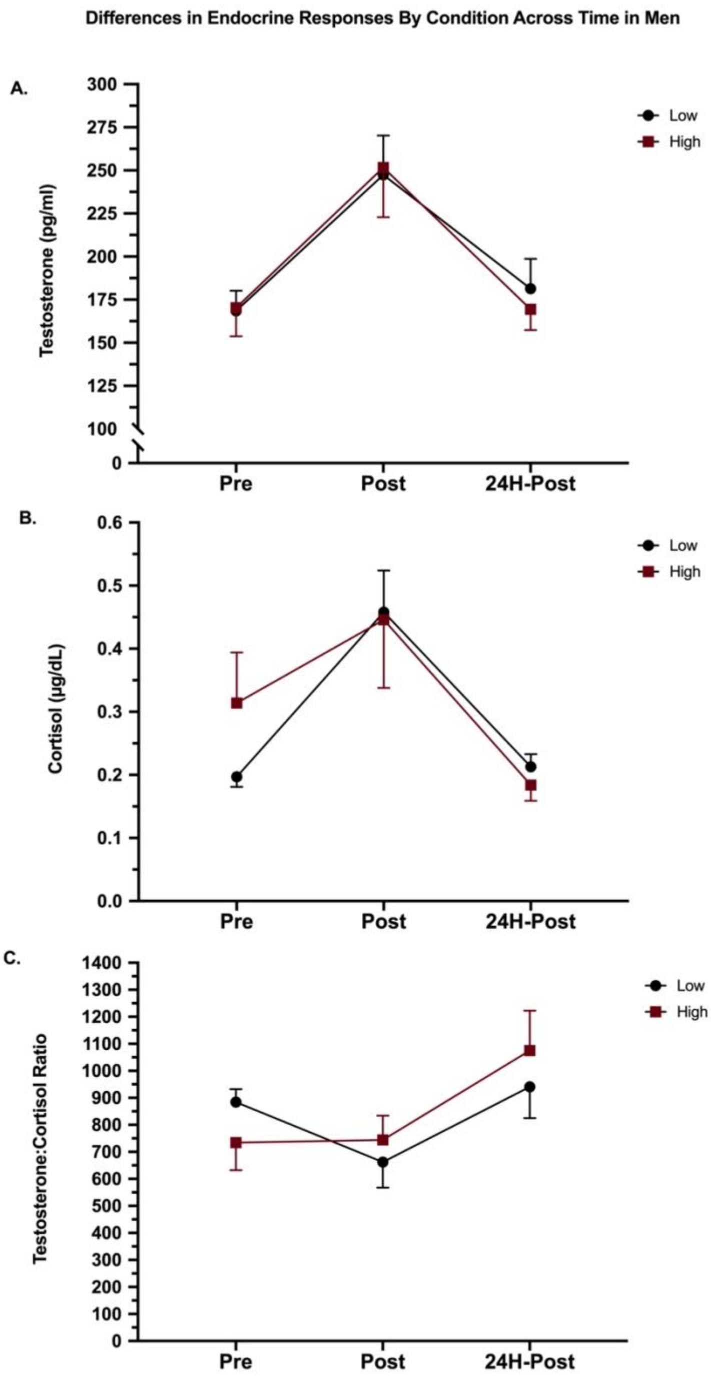


Figure 14. Difference in Endocrine Response by Condition Across Time in Men

Note: Data presented as Mean (Standard Error); Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Low = Low external training load condition; High = High external training load condition.

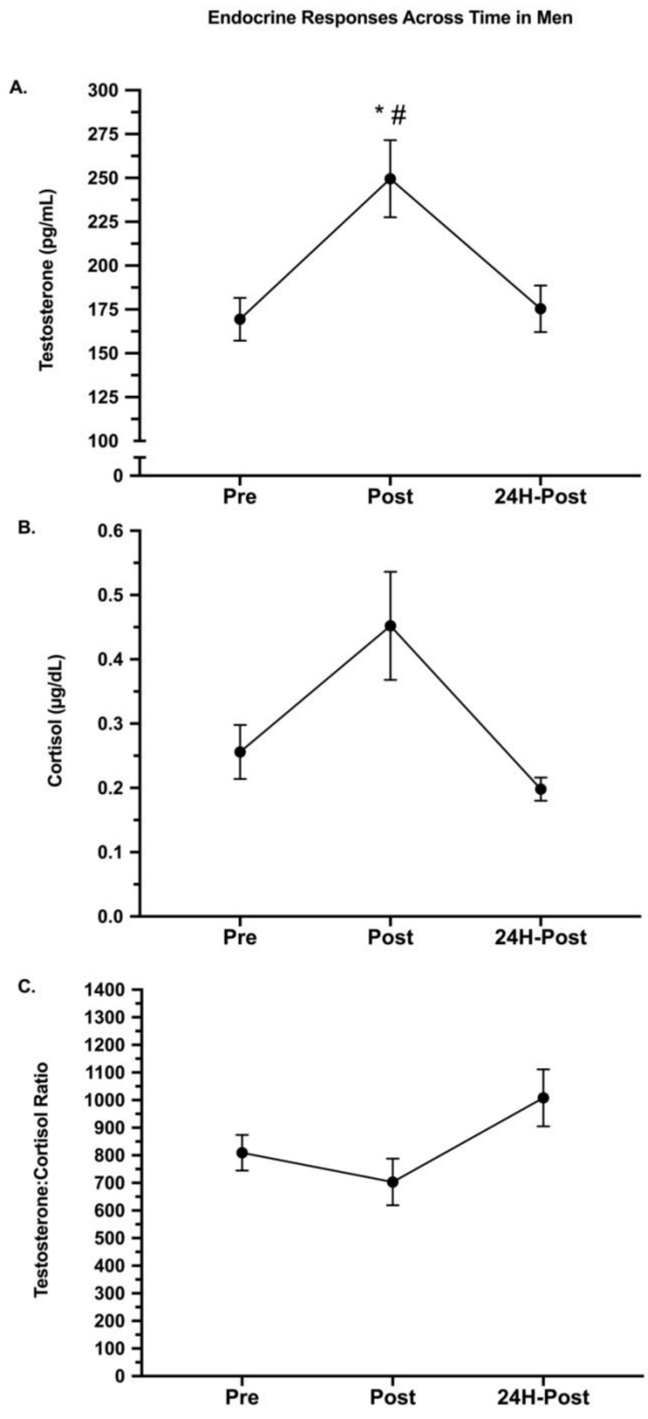


Figure 15. Endocrine Responses Across Time in Men

Note: Data presented as Mean (Standard Error); Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; * = significantly different than Pre; # = significantly different than 24H-Post; statistical significance, set at $p \leq 0.05$.

Descriptive statistics for percent change in testerosterone in men are outlined in Table 21. When examining percent change values, there were no significant Condition × Time interactions ($p = 0.887$, $\eta_{p2} = 0.011$) or significant main effect for Condition (0.620, $\eta_{p2} = 0.023$) for testosterone. However, there was a significant Time main effect for differences in percent change in testosterone ($p < 0.001$, $\eta_{p2} = 0.610$), with follow-up pairwise comparisons revealing a significantly greater positive increase in testosterone from Pre to Post compared to changes from Post to 24H-Post ($p = 0.004$), as well as compared to changes from Pre to 24H-Post ($p = 0.001$). The percent change from Post to 24H-Post was not significantly different from Pre to 24H-Post ($p = 0.085$).

Cortisol

As presented in Table 19 and illustrated in Figure 14, there were no significant Condition × Time interactions ($p = 0.215$, $\eta_{p2} = 0.130$) for differences in cortisol when examining Men alone. In addition, as presented in Figure 15, there was a significant Time main effect ($p = 0.020$, $\eta_{p2} = 0.352$) for differences in cortisol, with follow-up pairwise comparisons revealing no significant differences in Cortisol from Pre to Post ($p = 0.112$, $d = 0.85$), from Post to 24H-Post ($p = 0.062$, $d = 1.21$), or between Pre and 24H-Post ($p = 0.688$, $d = 0.52$). Additionally, there were no significant differences in cortisol between conditions at Pre ($p = 0.163$, $d = 0.59$), Post ($p = 0.856$, $d = 0.04$), 24H-Post ($p = 0.305$, $d = 0.37$). Also, there was no significant Condition main effect for differences in cortisol between Condition between conditions ($p = 0.896$, $\eta_{p2} = 0.002$).

Table 20. Endocrine Results Across Time in Men.

Variable	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Testosterone (pg/mL)	169.4 (12.2)	249.5 (22.0)	175.4 (13.3)*	1.30	1.18	0.14
Cortisol	0.256 (0.042)	0.452 (0.084)	0.198 (0.018)	0.85	1.21	0.52
Cortisol (µg/dL)	809.1 (64.6)	703.3 (84.4)	1008.2 (103.3)	0.45	0.99	0.70

Data Presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post=Practice; 24H-Post = 24-Hours Post-Practice; T:C = Testosterone to Cortisol Ratio; * = significant different from Post, statistical significance set at $p \leq 0.05$; Effect = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Descriptive statistics for percent change in cortisol in men are outlined in Table 21. There was no significant Condition × Time interaction ($p = 0.145$, $\eta_{p2} = 0.170$) or significant Condition main effect ($p = 0.130$, $\eta_{p2} = 0.195$) for percent change in cortisol. However, as presented in Figure 16, there was a significant Time main effect for differences in cortisol. Post-hoc pairwise comparisons revealed a significantly greater positive increase in cortisol from Pre to Post compared to changes from Post to 24H-Post ($p = 0.026$), as well as compared to changes from Pre to 24H-Post ($p = 0.027$). The percent change in cortisol from Post to 24H-Post was not significantly different from Pre to 24H-Post ($p = 0.177$).

Testosterone:Cortisol Ratio

As presented in Table 19 and illustrated in Figure 14, there were no significant Condition × Time interactions ($p = 0.291$, $\eta_{p2} = 0.106$) for differences in T:C when examining Men alone. Additionally, as presented in table 20 and Figure 16, there was no significant Time main effect ($p = 0.078$, $\eta_{p2} = 0.207$) and no Condition main effect ($p = 0.657$, $\eta_{p2} = 0.019$) for differences in T:C.

In parallel, there were no significant Condition × Time interactions (p = 0.280, η_{p2} = 0.109), as well as no significant Condition main effect (p = 0.171, η_{p2} = 0.163) or Time main effect (p = 0.103, η_{p2} = 0.187) for T:C.

Descriptive statistics for percent change in T:C in men are outlined in Table 21. There were no significant Condition × Time interactions (p = 0.280, η_{p2} = 0.109), Condition main effect (p = 0.171, η_{p2} = 0.163), or Time main effect (p = 0.103, η_{p2} = 0.187) for percent change values in T:C.

Table 21. Descriptive Statistics of Percent Change in Endocrine Response in Men.

Variable	*Condition*	Pre	Post	24H-Post
Testosterone (%Δ)	*Low*	46.1 ± 29.1	-21.6 ± 32.5	-0.8 ± 29.5
	High	50.5 ± 49.3	-24.2 ± 27	4.9 ± 26.5
Cortisol (%Δ)	*Low*	151.7 ± 142.6	-35.2 ± 46.1	5.1 ± 51.5
	High	83.8 ± 149.2	-31.9 ± 53.0	-13.0 ± 53.9
T:C Ratio (%Δ)	*Low*	-20.6 ± 47.8	92.0 ± 151.0	17.3 ± 75.0
	High	20.6 ± 71.5	96.0 ± 191.7	111.1 ± 197.2

Data presented as Mean ± Standard Deviation. Low = Low external training load condition; High = High external training load condition; Pre = Pre-Practice; Post = Post=Practice; 24H-Post = 24-Hours Post-Practice; %Δ = percent change; T:C = Testosterone to Cortisol Ratio.

Endocrine Responses in Women

Testosterone

Descriptive statistics of testosterone responses in women are outlined in Table 22. There were no significant Condition × Time interactions (p = 0.458, η_{p2} = 0.323) for differences in testosterone within women. Similarly, there were no significant Condition (p = 0.363, η_{p2} = 0.405) or Time (p = 0.264, η_{p2} = 0.486) main effect for differences in testosterone within women.

Descriptive statistics for percent change in testosterone in women are outlined in Table 23. When examining the percent change, there were no significant Condition × Time interactions (p = 0.590, η_{p2} = 0.232) for differences in percent change in Testosterone in women.

Cortisol

Descriptive statistics of cortisol responses in women are outlined in Table 22. There were no significant Condition × Time interactions (p = 0.093, η_{p2} = 0.819) for differences in cortisol within women. Additionally, there were no significant Condition (p = 0.924, η_{p2} = 0.006), or Time (p = 0.173, η_{p2} = 0.637) main effects for cortisol within women.

Descriptive statistics for percent change in cortisol in women are outlined in Table 23. When examining the percent change, there were no significant Condition × Time interactions (p = 0.105, η_{p2} = 0.780) for differences in percent change in cortisol in women. Additionally, there were no a significant Condition main effect (p = 0.424, η_{p2} = 0.332), or Time main effect (p = 0.591, η_{p2} = 0.231). There was a significant main effect for Condition (p = 0.027, η_{p2} = 0.947), but no main effect for Time (p = 0.238, η_{p2} =

0.581) in cortisol. Follow-up pairwise comparisons revealed greater changes in cortisol during the Low condition compared to the High (p = 0.027).

Testosterone:Cortisol Ratio

Descriptive statistics of T:C responses in women are outlined in Table 22. There were no significant Condition × Time interactions (p = 0.219, η_{p2} = 0.532) for differences in T:C within women. Additionally, there were no significant Condition (p = 0.301, η_{p2} = 0.489), or Time (p = 0.307, η_{p2} = 0.446) main effects for T:C within women.

Descriptive statistics for percent change in T:C in women are outlined in Table 23. When examining percent change in T:C, there were no significant Condition × Time interactions (p = 0.196, η_{p2} = 0.641) for differences in percent change in T:C. Additionally, there were no a significant Condition main effect (p = 0.233, η_{p2} = 0.588), or Time main effect (p = 0.272, η_{p2} = 0.529).

Table 22. Descriptive Statistics for Endocrine Responses in Women.

Variable	*Condition*	Pre	Post	24H-Post
Testosterone (pg/mL)	*Low*	105.1 ± 51.6	74.2 ± 21.7	79.4 ± 33.6
	High	86.5 ± 38.3	93.33 ± 58.0	66.0 ± 22.8
Cortisol (µg/dL)	*Low*	0.64 ± 0.149	0.282 ± 0.052	0.364 ± 0.059
	High	0.425 ± 0.029	0.482 ± 0.216	0.351 ± 0.056
T:C Ratio	*Low*	178.9 ± 103.5	279.8 ± 138.2	229.3 ± 114.8
	High	200.7 ± 82.9	177.8 ± 55.0	188.4 ± 53.6

Data presented as Mean ± Standard Deviation. Low = Low external training load condition; High = High external training load condition; Pre = Pre-Practice; Post = Post=Practice; 24H-Post = 24-Hours Post-Practice; T:C = Testosterone to Cortisol Ratio.

Table 23. Descriptive Statistics of Percent Change in Endocrine Responses in Women.

Variable	*Condition*	Pre	Post	24H-Post
Testosterone (%Δ)	*Low*	-19.7 ± 31	5.7 ± 34.4	29.5 ± 14.6
	High	-1.1 ± 30.7	-2.9 ± 63.8	-16.6 ± 28.3
Cortisol (%Δ)	*Low*	-55.5 ± 5.2	29.2 ± 4.6	75.2 ± 17.6
	High	11.7 ± 46.7	-10.5 ± 56	-17.4 ± 13.2
T:C Ratio (%Δ)	*Low*	87.2 ± 88.8	-17.8 ± 28.9	-25.1 ± 15.6
	High	-7.8 ± 13.9	6.7 ± 6.4	-1.1 ± 20

Data presented as Mean ± Standard Deviation. Low = Low external training load condition; High = High external training load condition; Pre = Pre-Practice; Post = Post=Practice; 24H-Post = 24-Hours Post-Practice; %Δ = percent change; T:C = Testosterone to Cortisol Ratio.

Results-Part II

Participant Anthropometrics

Fifteen NCAA Division I collegiate basketball players (*Male* = 9: age = 19.9 ± 1.2 years, height = 197.8 ± 6.3 cm, mass = 91.6 ± 7.9 kg; *Female* = 6: age = 20.4 ± 0.6 years, height = 179.5 ± 7.3 cm, mass = 81.5 ± 8.4 kg) participated in Part II.

There were no significant Sex × Time interactions for differences in Body Mass during testing (p = 0.951, η_{p2} = 0.004). Similarly, there were no significant differences in Body Mass across Time (Pre = 87.1(2.3) kg; Post = 86.8 (2.3) kg; 24H-Post = 87.0 (2.3) kg, p = 0.365, η_{p2} = 0.075). Additionally, differences in Body Mass between Sexes did not reach the level of statistical significance (Men = 91.5 (2.9) kg; Women = 82.4 (3.5) kg, p = 0.070, *d* = 1.04).

Training Load During Practice

External Training Load

Descriptive statistics of the External Training during Part II are outlined in Table 24 and presented in Figures 16, 17 and 18. There were no significant differences between Sex for any variables, including Total Duration (Men = 134.78 ± 22.6; Women = 118.5 ± 22.2, p = 0.193), PL (Men=584.1±120.8; Women = 555.1 ± 141.9, p = 0.666), PL/Min (Men = 4.43 ± 1.05; Women = 4.8 ± 1.1, p = 0.575), PL_{2D} (Men = 387.6 ± 82.1; Women = 353.5 ± 119.0, p = 0.520), $PL_{1D\text{-}FWD}$ (Men = 238.0 ± 59.9; Women = 230.5 ± 59.9, p = 0.816), $PL_{1D\text{-}SIDE}$ (Men = 255.4 ± 46.9; Women = 212.0 ± 112.7, p = 0.316), $PL_{1D\text{-}UP}$ (Men = 369.1 ± 66.2; Women = 364.4 ± 79.7, p = 0.903), IMA_High (Men = 48.8 ± 20.9; Women = 50.8 ± 30.5, p = 0.885), IMA_Medium (Men = 125.6 ± 48.9; Women = 139.2

± 82.5, p = 0.701), IMA_Low (Men = 549.4 ± 139.3; Women = 533.8 ± 251.5, p = 0.882), Jumps (Men = 135.0 ± 70.0; Women = 131.8 ± 69.6, p = 0.936).

Table 24. Descriptive Statistics of Training Loads for Practice in Part II.

	Men (n = 9)	Women (n = 6)	Total (n = 15)	p-value	Effect *(d)*
Duration (min)	134.8 ± 22.7	118.5 ± 22.2	128.3 ± 23.2	0.193	0.02
PL (au)	584.1 ± 112.2	555.1 ± 141.9	572.5 ± 120.8	0.666	0.23
PL/Minute (au/min)	4.4 ± 1.1	4.7 ± 1.1	4.6 ± 1.0	0.575	0.01
PL_{2D} (au)	387.6 ± 82.1	353.5 ± 118.9	374.0 ± 95.9	0.520	0.36
$PL_{1D\text{-}FWD}$ (au)	238.0 ± 59.9	230.5 ± 59.9	235.0 ± 57.8	0.816	0.00
$PL_{1D\text{-}SIDE}$ (au)	255.4 ± 46.9	212.0 ± 112.7	238.1 ± 79.3	0.316	0.76
$PL_{1D\text{-}UP}$ (au)	369.0 ± 66.2	364.4 ± 79.7	367.2 ± 69.2	0.903	0.19
IMA_High (cts)	48.8 ± 20.9	50.8 ± 30.5	49.5 ± 23.6	0.885	0.37
IMA_Medium (cts)	125.6 ± 48.9	139.2 ± 82.4	130.4 ± 60.1	0.701	0.50
IMA_Low (cts)	549.4 ± 139.3	533.8 ± 251.5	543.86 ± 177.4	0.882	0.55
Jumps (cts)	135.0 ± 70.0	131.8 ± 70.0	133.9 ± 67.2	0.936	0.01
RPE (au)	6.1 ± 1.6	5.3 ± 2.2	5.8 ± 1.8	0.435	0.31
sRPE (au)	822 ± 220	650 ± 320	753 ± 268	0.237	0.36

Data presented Mean ± Standard Deviation. PL = PlayerLoad™; PL_{2D} = 2-Demensional PlayerLoad™; $PL_{1D\text{-}FWD}$ = 1-Demensional PlayerLoad™ Forwards; $PL_{1D\text{-}SIDE}$ = 1-Demensional PlayerLoad™ Side; $PL_{1D\text{-}UP}$ = 1-Demensional PlayerLoad™ Up; IMA_High = High Intensity (>3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; IMA_Medium = Medium Intensity (2.5 to 3.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; IMA_Low = Low Intensity (1.5 to 2.5 $m \cdot s^{-1}$) Inertial Movement Analysis™ events; Jumps = Total number of Jump events (including High, Medium, and Low Intensities); RPE = Rating of Perceived Exertion; sRPE = Session Rating of Perceived Exertion; au = arbitrary units; cts = counts; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

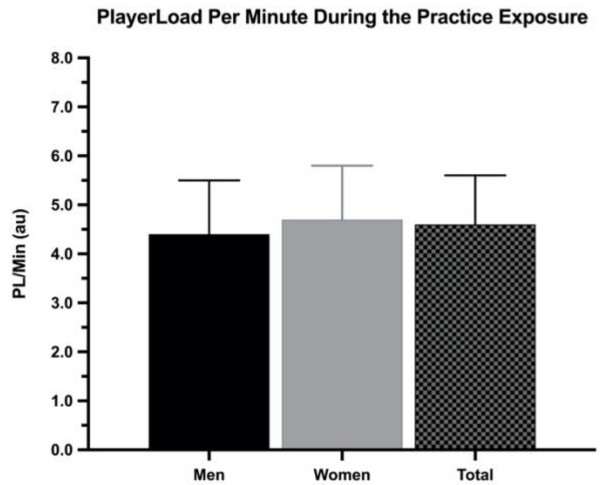


Figure 16. Average PlayerLoad Per Minute During the Practice Exposure.

Note: Data presented as Mean ± Standard Deviation; PL/min = PlayerLoad/minute.

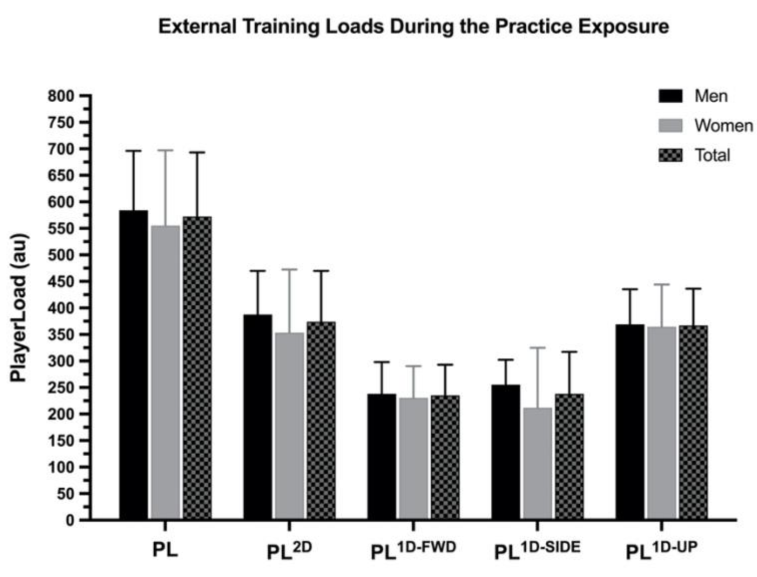


Figure 17. External Training Loads During the Practice Exposure

Note: Data presented Mean ± Standard Deviation. PL = PlayerLoad™; PL2D = 2-Demensional PlayerLoad™; PL1D-FWD = 1-Demensional PlayerLoad™ Forwards; PL1D-SIDE = 1-Demensional PlayerLoad™ Side; PL1D-UP = 1-Demensional PlayerLoad™ Up.

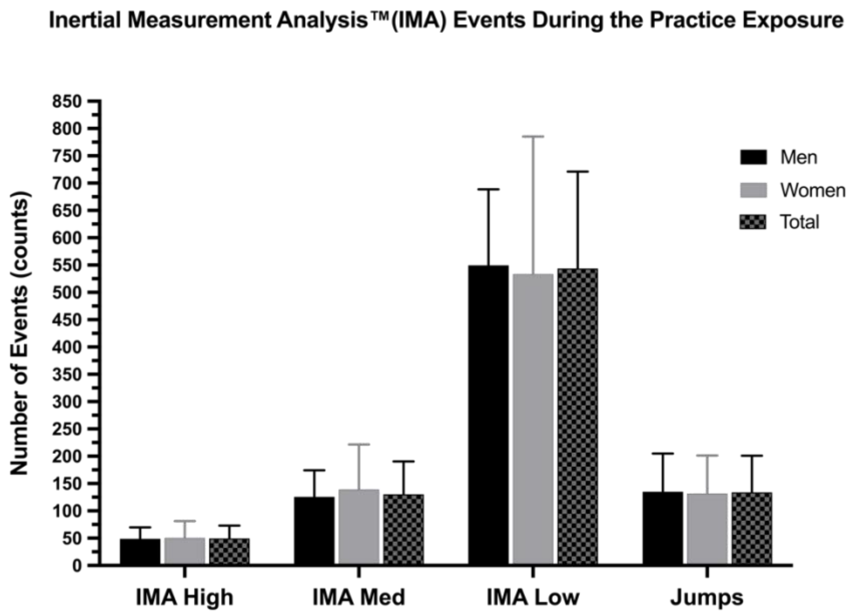


Figure 18. Inertial Measurement Analysis™ Events During the Practice Exposure

Note: Data presented Mean ± Standard Deviation. IMA_High = High Intensity (>3.5 m·s-1) Inertial Movement Analysis™ events; IMA_Medium = Medium Intensity (2.5 to 3.5 m·s-1) Inertial Movement Analysis™ events; IMA_Low = Low Intensity (1.5 to 2.5 m·s-1) Inertial Movement Analysis™ events; Jumps = Total number of Jump events (including High, Medium, and Low Intensities).

Rating of Perceived Exertion

The average RPE of practice was 5.8 ± 1.8 and the average session-RPE (sRPE) was 753 ± 268. There were no sex differences exhibited in RPE (Males = 6.1 ± 1.6; Females = 5.3 ± 2.2, p = 0.435, *d* = 0.31) or sRPE (Males = 822 ± 220; Females = 650 ± 320, p = 0.237, *d* = 0.36).

Subjective Recovery Questionnaire

Results from the Recovery Questionnaire are outlined in Table 25. There were no significant Sex × Time interactions for any variable on the Recover Questionnaire (p > 0.05).There were no significant main effects for differences across Time for the subjective measures of Hours Sleep (Pre = 7.6 ± 1.4; 24H-Post = 7.8 ± 0.9, p = 0.630, *d*

= 0.39), Sleep Quality (Pre = 4.3 ± 0.7; 24H-Post = 3.9 ± 0.9, p = 0.723, *d* = 0.23), Fatigue (Pre = 3.6 ± 0.6; 24H-Post = 3.4 ± 1.0, p = 0.121, *d* = 0.43), Soreness (Pre = 3.6 ± 0.8; 24H-Post = 3.4 ± 1.0, p = 0.121, *d* = 0.19), Stress (Pre = 3.9 ± 0.9; 24H-Post = 4.1 ± 0.8, p = 0.069, *d* = 0.10), or Mood (Pre = 4.5 ± 0.7; 24H-Post = 4.4 ± 0.6, p = 0.112, *d* = 0.3). Although, there was a significant main effect for differences between Sex for Sleep Quality (Men = 7.6 (0.4); Women = 8.0 (0.4), p = 0.024, *d = 1.27*) and Mood (Men = 4.7 (0.2); Women = 4.1 (0.193), p = 0.035, *d = 0.96*), no other significant differences in Hours Sleep (p = 0.495), Fatigue (p = 0.172), Soreness (p = 0.176), or Stress (p = 0.467) between sexes were observed between sexes.

Table 25. Recovery Questionnaire Responses to the Practice Exposure in Part II.

	Men (n = 9)		Women (n = 6)		Total (n = 15)	
Variable	Pre	24H-Post	Pre	24H-Post	Pre	24H-Post
Sleep (hours)	7.4 ± 1.3	7.7 ± 0.4	7.9 ± 1.6	8.0 ± 1.4	7.6 ± 1.4	7.8 ± 0.9
Sleep Quality	4.6 ± 0.5	4.4 ± 0.7	3.8 ± 0.8	3.3 ± 0.8	4.3 ± 0.7	3.9 ± 0.9
Fatigue	3.8 ± 0.5	3.6 ± 1.1	3.33 ± 0.8	3.0 ± 0.9	3.6 ± 0.6	3.4 ± 1.0
Soreness	4.0 ± 0.8	3.6 ± 1.2	3.2 ± 0.8	3.2 ± 0.8	3.6 ± 0.8	3.4 ± 1.0
Stress	4.0 ± 1.1	4.3 ± 0.9	3.8 ± 0.8	3.8 ± 0.8	3.9 ± 0.9	4.1 ± 0.8
Mood	4.8 ± 0.5	4.6 ± 0.5	4.2 ± 0.8	4.0 ± 0.6	4.5 ± 0.7	4.4 ± 0.6

Data presented at Mean ± Standard Deviation. Pre = Pre-Practice; 24H Post = 24 Hours Post-Practice; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Countermovement Jump (CMJ) Results

CMJ Traditional Variables

Overall descriptive statistics of the CMJ Traditional Variables are presented in Table 26. There were no significant Sex × Time interactions for any CMJ Traditional variables, including: Concentric Mean Force ($p = 0.672$, $\eta_{p2} = 0.019$), Concentric Mean Power ($p = 0.740$, $\eta_{p2} = 0.015$), Concentric Peak Force ($p = 0.061$, $\eta_{p2} = 0.194$), FT:CT ($p = 0.368$, $\eta_{p2} = 0.070$), Jump Height (FT) ($p = 0.793$, $\eta_{p2} = 0.015$), Peak Power ($p = 0.700$, $\eta_{p2} = 0.027$), RSI_{Mod} ($p = 0.413$, $\eta_{p2} = 0.059$).

Table 26. Countermovement Jump Traditional Variables Descriptive Statistics.

	Men (n = 9)			Women (n = 6)			Total (n = 15)		
Variable	Pre	Post	24H-Post	Pre	Post	24H-Post	Pre	Post	24H-Post
Concentric Mean Force (N)	1927.6 ± 272.1	1970.7 ± 318.6	1934.6 ± 278.1	1587.3 ± 150.6	1606.0 ± 145.5	1583.0 ± 155.5	1791.5 ± 283.1	1824.8 ± 315.9	1793.9 ± 290.9
Concentric Mean Power (W)	2849.2 ± 550.8	2936.4 ± 661.5	2885.1 ± 541.8	2061.0 ± 152.6	2091.0 ± 183.7	2071.0 ± 195.7	2533.9 ± 584.3	2598.3 ± 667.7	2559.5 ± 593.2
Concentric Peak Force (N)	2512.8 ± 477.8	2608.2 ± 509.3	2505.7 ± 421.9	2026.7 ± 309	2027.7 ± 294	2025.7 ± 272.1	2318.3 ± 474.7	2376.0 ± 515.5	2313.7 ± 432.9
FT:CT	0.76 ± 0.19	0.82 ± 0.26	0.79 ± 0.22	0.69 ± 0.11	0.70 ± 0.09	0.70 ± 0.09	0.73 ± 0.16	0.77 ± 0.21	0.75 ± 0.18
Jump Height (cm)	36.3 ± 4.1	37.4 ± 5.4	37.0 ± 4.1	28.4 ± 4.1	28.8 ± 4.7	28.3 ± 4.0	33.1 ± 5.6	33.9 ± 6.6	33.5 ± 5.9
Peak Power (W)	5197.9 ± 628.8	5354.0 ± 721	5266.8 ± 643.5	3755.8 ± 414.3	3823.8 ± 489.6	3779.2 ± 470.5	4621.1 ± 906.6	4741.9 ± 992.4	4671.7 ± 940.6
RSI_{Mod} (m/s)	0.52 ± 0.15	0.56 ± 0.21	0.53 ± 0.17	0.41 ± 0.06	0.42 ± 0.05	0.41 ± 0.05	0.47 ± 0.13	0.50 ± 0.18	0.49 ± 0.14

Data presented at Mean ± Standard Deviation. Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; FT:CT = Flight Time to Contraction Ratio; FT = Flight Time; Jump Height, computed based off flight time method.

As presented below in Table 27, there were no significant differences detected across Time for any of the CMJ Traditional Variables, including: Concentric Mean Force ($p = 0.165$, $\eta_{p2} = 0.139$), Concentric Mean Power ($p = 0.411$, $\eta_{p2} = 0.060$), Concentric Peak Force ($p = 0.053$, $\eta_{p2} = 0.204$), FT:CT ($p = 0.136$, $\eta_{p2} = 0.156$), Jump Height (FT) ($p = 0.563$, $\eta_{p2} = 0.043$), Peak Power ($p = 0.137$, $\eta_{p2} = 0.154$), or RSI_{Mod} ($p = 0.178$, $\eta_{p2} = 0.132$).

Table 27. CMJ Traditional Variables Across Time.

Variable	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Concentric Mean Force (N)	1757.4 (61.4)	1788.3 (70)	1758.8 (62.9)	0.12	0.11	0.01
Concentric Mean Power (W)	2455.1 (116.6)	2513.7 (140)	2478.1 (116.5)	0.11	0.07	0.05
Concentric Peak Force (N)	2269.7 (110.9)	2317.9 (115.7)	2265.7 (97.9)	0.10	0.12	0.01
FT:CT	0.73 (0.04)	0.76 (0.06)	0.74 (0.05)	0.15	0.06	0.09
Jump Height (cm)	32.3 (1.1)	33.1 (1.4)	32.7 (1.1)	0.14	0.08	0.07
Peak Power (W)	4476.9 (146.6)	4588.9 (169.2)	4523.0 (153.7)	0.16	0.09	0.07
RSI_{Mod} (m/s)	0.46 (0.03)	0.49 (0.04)	0.47 (0.04)	0.16	0.08	0.08

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; FT:CT = Flight Time to Contraction Ratio; FT = Flight Time; Jump Height, computed based off flight time method; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

As outlined in Table 28, several CMJ Traditional Variables exhibited significant differences between sex, including Concentric Mean Force ($p = 0.017$, $d = 1.45$), Concentric Mean Power ($p = 0.005$, $d = 1.76$), Concentric Peak Force ($p = 0.032$, $d = 1.26$), Jump Height ($p = 0.002$, $d = 2.02$), and Peak Power ($p < 0.001$, $d = 2.55$). However, both there were no significant differences in FT:CT ($p = 0.358$, $d = 0.50$) or RSI_{Mod} ($p = 0.106$, $d = 0.92$) between sexes.

Table 28. Sex Differences in CMJ Traditional Variables.

Variable	Men (n = 9)	Women (n = 6)	p-value	Effect (*d*)
Concentric Mean Force (N)	1944.3 (81.1)	1592.1 (99.3)*	0.017	1.45
Concentric Mean Power (W)	2890.3 (154.3)	2074.3 (189.0)*	0.005	1.76
Concentric Peak Force (N)	2542.2 (136.2)	2026.7 (166.8)*	0.032	1.26
FT:CT	0.79 (0.06)	0.70 (0.08)	0.358	0.50
Jump Height (cm)	36.9 (1.4)	28.5 (1.7)*	0.002	2.02
Peak Power (W)	5272.9 (194.6)	3786.3 (238.4)*	< 0.001	2.55
RSI_{Mod} (m/s)	0.54 (0.05)	0.40 (0.06)	0.106	0.92

Data presented as Mean (Standard Error). FT:CT = Flight Time to Contraction Ratio; FT = Flight Time; Jump Height, computed based off flight time method; N = newtons; W = watts; cm = centimeters; * = statistically significant; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

CMJ Concentric Alternative Variables

Overall descriptive statistics of the CMJ Concentric Alternative Variables are presented in Table 29. There were no significant Sex × Time interactions for any Concentric Alternative Variable, including: Concentric Impulse (p = 0.956, η_{p2} = 0.003), Concentric Peak Velocity (p = 0.935, η_{p2} = 0.005), Concentric RPD (p = 0.483, η_{p2} = 0.054), Force@PP (p = 0.409, η_{p2} = 0.031), and Velocity@PP (p = 0.955, η_{p2} = 0.004).

As outlined in Table 30, there was a significant Time main effect for differences in Concentric RPD (p = 0.041, η_{p2} = 0.269) and Force@PP (p = 0.003, η_{p2} = 0.369). Post-Hoc pairwise analysis revealed a significantly higher Concentric RPD at the Post timepoint compared to 24H-Post timepoint (p = 0.001, *d* = 0.10), but no differences between the Pre and Post (p = 0.146, *d* = 0.13) or between Pre and 24H-Post (p > 0.999, *d* = 0.02) timepoints. Similarly, post-hoc pairwise comparison identified a significant increase in Force@PP at the Post timepoint compared to Pre (p = 0.028, d = 0.20), as well as a significant increase at Post compared to 24H-Post (p = 0.002, d = 0.16). However, no significant differences in Force@PP were revealed between the Pre and 24H-Post (p > 0.999, *d* = 0.03) timepoints.

Table 29. Countermovement Jump Concentric Alternative Variables Descriptive Statistics.

	Men (n = 9)			Women (n = 6)			Total (n = 15)		
Variable	Pre	Post	24H-Post	Pre	Post	24H-Post	Pre	Post	24H-Post
Concentric Impulse (Ns)	243.3 ± 21.2	245.0 ± 20.0	245.2 ± 16.3	192.6 ± 21.5	193.0 ± 24.0	193.4 ± 24.4	223.0 ± 32.9	224.2 ± 33.6	224.4 ± 32.5
Concentric Peak Velocity (m/s)	2.80 ± 0.13	2.82 ± 0.18	2.82 ± 0.12	2.46 ± 0.15	2.47 ± 0.18	2.48 ± 0.16	2.66 ± 0.22	2.68 ± 0.25	2.68 ± 0.22
Concentric RPD (W/s)	33192.2 ± 16505.7	35949 ± 18107.1	33979.5 ± 16896.7	21870 ± 7208.4	22989.6 ± 6264.6	21711.6 ± 6537.3	28663.3 ± 14394.5	30765.3 ± 15638.2	29072.3 ± 14734.5
Force at Peak Power (N)	2125.6 ± 230.9	2189.8 ± 261.8	2142.1 ± 253.7	1730.7 ± 208.6	1769.5 ± 199.3	1731.5 ± 215.7	1967.6 ± 293.5	2021.7 ± 314.3	1977.9 ± 311.1
Velocity at Peak Power (m/s)	2.44 ± 0.09	2.44 ± 0.11	2.46 ± 0.04	2.18 ± 0.17	2.17 ± 0.19	2.19 ± 0.18	2.34 ± 0.18	2.33 ± 0.2	2.35 ± 0.18

Data presented as Mean ± Standard Deviation. Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Conc = Concentric; Peak Velociy = Concentric Peak Velocity; RPD = Rate of Power Development; Force@PP = Force at Peak Power; Force@0V = Force at Zero Velocity; Velocity@PP = Velocity at Peak Power.

Additionally, there were no significant differences across Time observed for Concentric Impulse (p = 0.826, η_{p2} = 0.015), Concentric Peak Velocity (p = 0.584, η_{p2} = 0.041), Force@0V (p = 0.674, η_{p2} = 0.030), or Velocity@PP (p = 0.641, η_{p2} = 0.034).

Table 30. CMJ Concentric Alternative Variables Across Time.

Variable	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Conc Impulse (Ns)	218.0 (5.6)	219.0 (5.7)	219.3 (5.2)	0.05	0.01	0.06
Conc Peak Velocity (m/s)	2.63 (0.04)	2.64 (0.05)	2.65 (0.04)	0.09	0.04	0.14
Conc RPD (W/s)	27531.1 (3609.8)	29469.3 (3880.7)*	27845.6 (3652.7)	0.13	0.10	0.02
Force@PP (N)	1928.1 (58.7)	1979.6 (63.2)#*	1936.8 (63.2)	0.20	0.16	0.03
Velocity @PP (m/s)	2.31 (0.03)	2.30 (0.04)	2.32 (0.03)	0.04	0.13	0.09

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Conc = Concentric; Peak Velociy = Concentric Peak Velocity; RPD = Rate of Power Development; Force@PP = Force at Peak Power; Force@0V = Force at Zero Velocity; Velocity@PP = Velocity at Peak Power; # = significantly greater than Pre; * = significantly greater than 24H-Post; statistical significance set at p ≤ 0.05; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Presented in Table 31, the CMJ Concentric Alternative Variables there were significant sex differences in Concentric Impulse (p < 0.001, *d* = 2.53), Concentric Peak Velocity (p = 0.001, *d* = 2.33), Force@PP (p = 0.005, *d* = 1.76), and Velocity@PP (p = 0.001, *d* = 2.19). In contrast, no significant differences were revealed between sexes in Concentric RPD (p = 0.123, *d* = 0.87).

Table 31. Sex Differences in CMJ Concentric Alternative Variables.

Variable	Men (n = 9)	Women (n = 6)	p-value	Effect (*d*)
Conc Impulse (Ns)	244.5 (6.8)	193.0 (8.3)*	< 0.001	2.53
Peak Velocity ($m•s_{-1}$)	2.81 (0.05)	2.47 (0.06)*	0.001*	2.33
Conc RPD ($W•s_{-1}$)	34373.6 (4675.1)	22190. 4 (5725.8)	0.123	0.87
Force@PP (N)	2152.5 (77.4)	1743.9 (94.8)*	0.005	1.76
Velocity@PP ($m•s_{-1}$)	2.45 (0.04)	2.18 (0.05)*	0.001	2.19

Data presented as Mean (Standard Error). Conc = Concentric; Peak Velociy = Concentric Peak Velocity; RPD = Rate of Power Development; Force@PP = Force at Peak Power; Velocity@PP = Velocity at Peak Power; * = statistically significant; statistical significance set at p ≤ 0.05; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

CMJ Eccentric Alternative Variables

Overall descriptive statistics of the CMJ Eccentric Alternative Variables are presented in Table 32. No significant Sex × Time interactions were observed for Ecc Mean Braking Force (p = 0.987, η_{p2} = 0.001), Ecc Mean Decel Force (p = 0.392, η_{p2} = 0.069), Ecc Mean Force (p = 0.727, η_{p2} = 0.024), Ecc Mean Power (p = 0.162, η_{p2} = 0.131), Ecc Peak Force (p = 0.350, η_{p2} = 0.078) or Force@0V (p = 0.424, η_{p2} = 0.064),

As presented in Table 33, there was a significant main effect for differences in Ecc Mean Power (p = 0.009, η_{p2} = .307) across Time. Post-hoc pairwise comparisons identified significantly greater Ecc Mean Power at 24H-Post compared to both Pre (p = 0.021, *d* = 0.22) and Post (p = 0.032, *d* = 0.25).

No differences were observed across Time in Ecc Mean Braking Force (p = 0.153, η_{p2} = 0.134), Ecc Mean Decel Force (p = 0.199, η_{p2} = 0.117), Ecc Mean Force (p = 0.165, η_{p2} = 0.130), Ecc Peak Force (p = 0.750, η_{p2} = 0.022) or Force@0V (p = 0.674, η_{p2} = 0.030).

As presented in Table 34, there were no significant differences in CMJ Eccentric Alternative variables, including: Eccentric Mean Braking Force (p = 0.115, *d* = 0.89), Eccentric Mean Deceleration Force (p = 0.224, *d* = 0.67), Eccentric Mean Force (p = 0.054, *d* = 1.12), Eccentric Mean Power (p = 0.140, *d* = 0.83), Eccentric Peak Force (p = 0.169, *d* = 0.77) and Force@0V (p = 0.169, *d* = 0.77).

Table 32. Countermovement Jump Eccentric Alternative Variables Descriptive Statistics.

	Men (n = 9)			Women (n = 6)			Total (n =15)		
Variables	Pre	Post	24H-Post	Pre	Post	24H-Post	Pre	Post	24H-Post
Ecc Mean Braking Force (N)	1106.8 ± 154.1	1122.3 ± 146.3	1131.7 ± 163.0	991.1 ± 81.2	1003.8 ± 94.6	1017.3 ± 93.2	1060.5 ± 139.2	1074.9 ± 138.0	1086.0 ± 147.1
Ecc Mean Decel Force (N)	1671.2 ± 378.6	1700.9 ± 412.8	1703.6 ± 375.2	1465.7 ± 176.9	1448.3 ± 178.4	1516.1 ± 170.3	1589.0 ± 322.4	1599.9 ± 353.7	1628.6 ± 316.0
Ecc Mean Force (N)	900.1 ± 82.0	895.0 ± 79.2	895.8 ± 79.7	801 ± 94.7	796.5 ± 97.9	800.3 ± 101.6	860.5 ± 97.8	855.6 ± 97.4	857.6 ± 98.3
Ecc Mean Power (W)	536.4 ± 116.2	543.3 ± 113.8	552.9 ± 107.2	461 ± 56.1	448.5 ± 51.3	491.7 ± 62.7	506.3 ± 101.5	505.4 ± 103.2	528.4 ± 94.5
Ecc Peak Force (N)	2276.8 ± 601.5	2337.8 ± 678.7	2285.2 ± 559.0	1899.8 ± 319.2	1887.2 ± 285.1	1938.8 ± 270.5	2126 ± 528.8	2157.5 ± 586.9	2146.7 ± 485.3
Force at Zero Velocity (N)	2262.8 ± 603.0	1889.2 ± 319.4	2113.3 ± 529.2	2328.7 ± 681.2	1881.7 ± 285.8	2149.9 ± 588.0	2280.9 ± 559.3	1925.3 ± 271.6	2138.7 ± 487.4

Data presented as Mean ± Standard Deviation. Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Ecc = Eccentric; Decel = Deceleration.

Table 33. CMJ Eccentric Alternative Variables Across Time.

Variable	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Ecc Mean Braking Force (N)	1049.0 (34.5)	1063.0 (34)	1074.5 (37.0)	0.11	0.08	0.18
Ecc Mean Decel Force (N)	1568.4 (83.4)	1574.6 (90.2)	1609.9 (82.4)	0.02	0.10	0.13
Ecc Mean Force (N)	850.6 (22.9)	845.8 (22.9)	848.1 (23.4)	0.05	0.02	0.03
Ecc Mean Power (W)	498.7 (25.7)	495.9 (25)	522.3 (24.4)*#	0.03	0.25	0.22
Ecc Peak Force (N)	2088.3 (134.8)	2112.5 (147.8)	2112.0 (123.7)	0.04	0.00	0.04
Force@0V (N)	2076.0 (135.1)	2105.2 (148.4)	2103.1 (123.8)	0.05	0.00	0.05

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; Decel = Deceleration; Force@0V = Force at Zero Velocity; * = significantly greater than Pre; # = significantly greater than Post; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Table 34. Sex Differences in CMJ Eccentric Alternative Variables.

Variable	Men (n = 9)	Women (n = 6)	p-value	Effect (*d*)
Ecc Mean Braking Force (N)	1120.3 (43.5)	1004.05 (53.3)	0.115	0.89
Ecc Mean Decel Force (N)	1691.9 (106.6)	1476.7 (130.5)	0.224	0.67
Ecc Mean Force (N)	8967.0 (29.1)	799.3 (35.7)	0.054	1.12
Ecc Mean Power (W)	544.2 (31.1)	467.1 (38.0)	0.140	0.83
Ecc Peak Force (N)	2299.9 (169.8)	1908.6 (207.9)	0.169	0.77
Force@0V (N)	2290.8 (170.2)	1898.7 (208.4)	0.169	0.77

Data presented as Mean (Standard Error). Ecc = Eccentric; Decel = Deceleration; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Countermovement Jump Phase Duration Variables

Overall descriptive statistics of the CMJ Phase Duration Alternative Variables are presented in Table 35. There were no significant Sex × Time interactions for Braking Phase Duration ($p = 0.696$, $\eta_{p2} = 0.018$)**,** Concentric Duration ($p = 0.832$, $\eta_{p2} = 0.006$), Contraction Time ($p = 0.489$, $\eta_{p2} = 0.044$), Contraction Time:Ecc Duration ($p = 0.077$, $\eta_{p2} = 0.179$), Ecc Accel Phase Duration ($p = 0.224$, $\eta_{p2} = 0.109$), Ecc Decel Phase Duration ($p = 0.776$, $\eta_{p2} = 0.011$), Ecc Duration ($p = 0.368$, $\eta_{p2} = 0.074$), Flight Time ($p = 0.865$, $\eta_{p2} = 0.011$), or Flight Time: Ecc Duration ($p = 0.279$, $\eta_{p2} = 0.092$).

As presented in Table 36, there was a significant main effect revealed for a difference in Contraction Time:Ecc Duration ($p = 0.006$, $\eta_{p2} = 0.323$) across Time. Post-hoc pairwise comparisons revealed a significant increase at 24H-Post compared to Post ($p = 0.009$, $d = 0.32$). However, there were no significant differences between Pre and Post ($p > 0.999$, $d = 0.09$) or between Pre and 24H-Post ($p = 0.67$, $d = 0.22$).

No other significant differences were observed in CMJ Phase Duration Alternative Variables across Time, including: Braking Phase Duration ($p = 0.312$, $\eta_{p2} = 0.086$)**,** Concentric Duration ($p = 0.094$, $\eta_{p2} = 0.195$), Contraction Time ($p = 0.411$, $\eta_{p2} =$

0.058), Ecc Accel Phase Duration ($p = 0.169$, $\eta_{p2} = 0.128$), Ecc Decel Phase Duration ($p = 0.875$, $\eta_{p2} = 0.010$), Ecc Duration ($p = 0.344$, $\eta_{p2} = 0.079$), Flight Time ($p = 0.592$, $\eta_{p2} = 0.039$), or Flight Time: Ecc Duration ($p = 0.237$, $\eta_{p2} = 0.106$).

Table 35. Countermovement Jump Phase Duration Variables Descriptive Statistics.

Variable	Men (n = 9)			Women (n = 6)			Total (n = 15)		
	Pre	Post	24H-Post	Pre	Post	24H-Post	Pre	Post	24H-Post
Braking Phase Duration (s)	0.307 ± 0.085	0.296 ± 0.088	0.298 ± 0.092	0.287 ± 0.077	0.276 ± 0.071	0.266 ± 0.05	0.299 ± 0.079	0.288 ± 0.080	0.285 ± 0.077
Concentric Duration (ms)	249.0 ± 61.9	244.1 ± 68.6	251.6 ± 70.0	250.5 ± 44.9	243.0 ± 40.1	251.5 ± 42.2	249.6 ± 53.9	243.7 ± 57.1	251.5 ± 58.6
Contraction Time (ms)	740.2 ± 137.8	724.9 ± 173.3	738.3 ± 161.2	715.5 ± 137.5	704.3 ± 124.5	694.7 ± 111.7	730.3 ± 133.3	716.7 ± 151.0	720.9 ± 140.7
CT:Ecc Duration (%)	150.7 ± 7.9	150.9 ± 7.0	151.6 ± 8.3	154.6 ± 5.9	153.2 ± 5.1	157.1 ± 5.3	152.3 ± 7.2	151.8 ± 6.2	153.8 ± 7.6
Ecc Accel Phase Duration (s)	0.331 ± 0.048	0.318 ± 0.059	0.325 ± 0.054	0.312 ± 0.064	0.309 ± 0.052	0.294 ± 0.041	0.323 ± 0.054	0.314 ± 0.055	0.313 ± 0.05
Ecc Decel Phase Duration (s)	0.16 ± 0.051	0.162 ± 0.06	0.161 ± 0.054	0.153 ± 0.037	0.153 ± 0.04	0.149 ± 0.035	0.157 ± 0.045	0.158 ± 0.052	0.156 ± 0.046
Ecc Duration (ms)	491.3 ± 84.9	480.7 ± 111.2	486.9 ± 99.3	464.8 ± 97.2	461.5 ± 87.7	443.0 ± 73.4	480.7 ± 87.6	473 ± 99.5	469.3 ± 89.7
Flight Time (ms)	543.4 ± 31.3	550.7 ± 40.1	548.8 ± 31.3	479.5 ± 34.8	483.0 ± 39.8	479.3 ± 34.8	517.9 ± 45.2	523.6 ± 51.6	521 ± 47.3
FT:Ecc Duration	1.15 ± 0.27	1.23 ± 0.39	1.18 ± 0.31	1.07 ± 0.18	1.08 ± 0.16	1.11 ± 0.15	1.12 ± 0.23	1.17 ± 0.32	1.15 ± 0.25

Data presented as Mean ± Standard Deviation. Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; CT = Contraction Time; Ecc = Eccentric; Accel = Acceleration; Decel = Deceleration; FT = Flight Time.

Table 36. CMJ Phase Duration Variables Across Time.

Variable	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
Braking Phase Duration (s)	0.297 (0.022)	0.286 (0.022)	0.282 (0.021)	0.13	0.05	0.18
Concentric Duration (ms)	249.8 (14.7)	243.6 (15.6)	251.5 (16)	0.11	0.13	0.03
Contraction Time (ms)	727.9 (36.3)	714.6 (41.2)	716.5 (38)	0.09	0.01	0.08
CT:Ecc Duration (%)	152.7 (1.9)	152.1 (1.7)	154.3 (1.9)*	0.09	0.32	0.22
Ecc Accel Phase Duration (s)	0.322 (0.014)	0.313 (0.015)	0.31 (0.013)	0.16	0.06	0.23
Ecc Decel Phase Duration (s)	0.157 (0.012)	0.158 (0.014)	0.155 (0.013)	0.02	0.06	0.04
Ecc Duration (ms)	478.1 (23.7)	471.1 (27.1)	464.9 (23.8)	0.07	0.06	0.14
Flight Time (ms)	511.5 (8.6)	516.8 (10.5)	514.1 (8.6)	0.14	0.07	0.08
FT:Ecc Duration	1.11 (0.06)	1.15 (0.08)	1.14 (0.07)	0.14	0.03	0.12

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; CT = Contraction Time; Ecc = Eccentric; Accel = Acceleration; Decel = Deceleration; FT = Flight Time; * = significantly greater than Post; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Illuminated in Table 37, the only significant difference identified between sexes in the CMJ Phase Duration Variables was Flight Time (p = 0.002, *d* = 2.01). There were no significant differences between sexes in any other Jump Phase variable including: Braking Phase Duration (p = 0.564, *d* = 0.31), Concentric Duration (p = 0.997, *d* = 0.00), Contraction Time (p = 0.703, *d* = 0.21), Contraction Time: Eccentric Duration (p = 0.297, *d* = 0.57), Eccentric Acceleration Phase Duration (p = 0.484, *d* = 0.39), Eccentric Deceleration Phase Duration (p = 0.702, *d* = 0.21), Eccentric Duration (p = 0.551, *d* = 0.32), or Flight Time: Eccentric Duration (p = 0.474, *d* = 0.39).

Table 37. Sex Differences in CMJ Phase Durations Variables.

Variable	Men (n = 9)	Women (n = 6)	p-value	Effect (*d*)
Braking Phase Duration (s)	0.300 (0.026)	0.276 (0.032)	0.564	0.31
Concentric Duration (ms)	248.2 (19.4)	248.3 (23.8)	0.997	0.00
Contraction Time (ms)	734.5 (48.0)	704.8 (58.8)	0.703	0.21
Contraction Time:Ecc Duration (%)	151.1 (2.3)	155.0 (2.8)	0.297	0.57
Ecc Accel Phase Duration (s)	0.325 (0.017)	0.305 (0.021)	0.484	0.39
Ecc Decel Phase Duration (s)	0.161 (0.016)	0.151 (0.020)	0.702	0.21
Ecc Duration (ms)	486.3 (30.8)	456.4 (37.8)	0.551	0.32
Flight Time (ms)	547.6 (11.1)	480.6 (13.6)*	0.002	2.01
FT:Ecc Duration	1.18 (0.09)	1.08 (0.10)	0.474	0.39

Data presented as mean (standard error). CT = Contraction Time; Ecc = Eccentric; Accel = Acceleration; Decel = Deceleration; FT = Flight Time; * = statistically significant; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Interpolated Twitch Technique Results

Results from the Interpolated Twitch Technique across time are presented in Table 38. There was a significant Time main effect for MVC (p = 0.010, η_{p2} = 0.357), Interpolated Twitch Torque (p = 0.039, η_{p2} = 0.220) and Voluntary Activation (p = 0.038, η_{p2} = 0.222) b. Differences in EMG across time did not reach levels statistical significance (p = 0.054, η_{p2} = 0.201). Results of the post-hoc pairwise comparisons revealed significant increase in MVC from Pre to 24H-Post (p = 0.037, *d* = 0.63), but no significant differences from Pre to Post (p = 0.125, *d* = 1.23) or Post to 24H-Post (p = 0.90, *d* = 0.33). Similarly, significant decrease was observed in Interpolated Twitch Torque from Pre to 24H-Post (p = 0.044, *d* = 1.09), but no significant differences were detected from Pre to Post (p = 0.585, *d* = 2.17) or from Post to 24H-Post (p = 0.653, *d* = 0.43). There was a significant increase in Voluntary activation from Pre to 24H-Post (p = 0.044, *d* = 1.19), but no differences from Pre to Post (p > 0.999, *d* = 1.57) or Post to 24H-Post (p > 0.132, *d* = 0.57). While no significant main effects were observed across time for EMG, differences between Pre to Post demonstrated a medium negative effect (*d* = 0.68), while Post to 24H-Post (*d* = 0.45) and Pre to 24H-Post (*d* = 0.27) both showed small effects.

Table 38. Differences During the Interpolated Twitch Technique Across Time

Variable	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24H-Post (*d*)	Pre to 24H-Post (*d*)
MVC (Nm)	129.8 (7.8)	140 (8.7)	152.5 (10.6)Ψ	1.23	0.33	0.63
Interpolated Twitch (Nm)	10.1 (1.2)	7.5 (1.2)	5.8 (0.8) Ψ	2.17	0.43	1.09
Voluntary Activation (%)	71.9 (2.7)	76.9 (3.6)	83.7 (2.4) Ψ	1.57	0.57	1.19
EMG RMS (mV)	0.342 (0.04)	0.315 (0.04)	0.384 (0.04)	0.68	0.45	0.27

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; MVC = Maximal Voluntary Contraction; EMG RMS = Electromyography Root Mean Square; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80 Ψ = Significantly different from Pre to 24H-Post.

As presented in Table 39, significant Sex differences were revealed in parameters during the Interpolated Twitch Technique, with Men having a greater MVC (Men = 165.3 (10.6); Women = 116.2 (13.0), p = 0.012, *d* = 1.54), Interpolated Twitch (Men = 9.2 (0.7); Women = 6.4 (0.9), p = 0.030, *d* = 1.30), and EMG (Men = 0.431 (0.05); Women = 0.262 (0.06), p = 0.036, *d* = 1.14) compared to women, but no differences were identified in Voluntary Activation (Men = 77.6 (1.9); Women = 77.5 (2.3), p = 0.993, *d* = 0.02).

Table 39. **Sex Differences During the Interpolated Twitch Technique**

Variable	Men (n = 9)	Women (n = 6)	p-value	Effect (*d*)
MVC (Nm)	165.3 (10.6)	116.2 (13.0)	0.012*	1.54
Interpolated Twitch (Nm)	9.2 (0.7)	6.4 (0.9)	0.030*	1.30
Voluntary Activation (%)	77.6 (1.9)	77.5 (2.3)	0.993	0.02
EMG RMS (mV)	0.431 (0.05)	0.262 (0.06)	0.036*	1.14

Data presented as Mean (Standard Error). Pre = Pre-Practice; Post = Post-Practice; 24H-Post = 24-Hours Post-Practice; MVC = Maximal Voluntary Contraction; EMG RMS = Electromyography Root Mean Square; statistical significance set at $p \leq 0.05$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Twitch Characteristic Results

There was a significant Sex × Time interaction for Rate of Torque Development (p = 0.038, η_{p2} = 0.222). Post-hoc pairwise comparisons revealed Men to have a significantly greater Rate of Torque Development at Pre (Men = 324.6 (17.2); Women = 202.2 (18.7), p < 0.001 , *d* = 2.67), Post (Men = 298.2 (12.7); Women = 212.5 (15.5), p = 0.001 , *d* = 2.26), and 24H-Post (Men = 320.2 (17.2); Women = 212.9 (21.0), p = 0.002, *d* = 2.08). As illustrated in Figure 19, the post-hoc pairwise comparisons revealed a significant difference in Men from Pre to Post (p = 0.027, *d* = 0.63), as well as from Post to 24H-Post (p = 0.037, *d* = 0.59), but no significant from Pre to 24H-Post (p > 0.999, *d*

= 0.092). However, in women no differences were detected from Pre to Post ($p > 0.999$, $d = 0.244$), Post to 24H-Post ($p > 0.999$, $d = 0.227$), or Pre to 24H-Post ($p > 0.999$, $d = 0.220$).

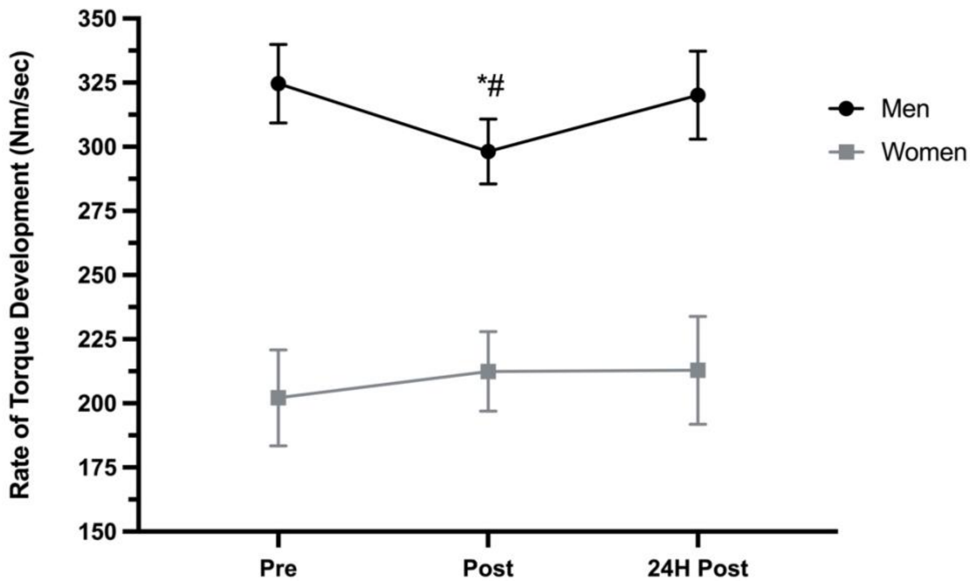


Figure 19. Sex by Time Differences in Rate of Torque Development.

Note: Data presented as Mean (standard Error); * = significant difference from Pre to Post, $d = 0.63$ (Medium); # = significant differences from Post to 24H-Post, $d = 0.59$ (Medium); statistical significance set at $p \leq 0.05$.

There were no other significant Sex × Time interactions for other twitch characteristics, including: Doublet ($p = 0.113$, $\eta_{p2} = 0.154$), Single Twitch ($p = 0.327$, $\eta_{p2} = 0.082$), LFF (0.841, $\eta_{p2} = 0.013$), Rate of Relaxation ($p = 0.311$, $\eta_{p2} = 0.086$), Average Rise Time ($p = .251$, $\eta_{p2} = 0.101$), Time to Peak ($p = .181$, $\eta_{p2} = 0.123$), or Half Relaxation Time ($p = 0.429$, $\eta_{p2} = 0.063$).

Presented in Table 40, there was significant main effect for differences across Time in the Single Twitch (p = 0.011, η_{p2} = 0.293), as well as LFF (p = 0.039, η_{p2} = 0.221), but no significant differences in Doublet (p = 0.075, η_{p2} = 0.181).

Table 40. Differences in Twitch Characteristics Across Time

Variable	Pre	Post	24H-Post	Pre to Post (*d*)	Post to 24-Post (*d*)	Pre to 24-Post (*d*)
Doublet (Nm)	66.8 (3.4)	65.6 (2.7)	69.4 (3.6)	0.39	0.31	0.19
Single Twitch (Nm)	35.9 (2.3)	33.3 (2.2)	36.7 (2.3)*	1.16	0.39	0.09
LFF	0.54 (0.02)	0.51 (0.02)	0.53 (0.01)*	1.50	0.33	0.16
RTD (Nm/sec)	263.4 (12.1)	255.3 (10.0)	266.5 (13.6)	0.73	0.24	0.06
Rate of Relaxation (Nm/sec)	0.78 (0.07)	0.80 (0.05)	0.80 (0.05)	0.33	0.00	0.08
Average Rise Time (ms)	31.5 (1.1)	30.7 (0.7)	31.6 (1.0)	0.87	0.27	0.02
Time to Peak Torque (ms)	255.1 (4.4)	256.8 (1.1)	260.4 (0.7)	0.53	1.01	0.43
Half Relaxation Time (ms)	47.4 (6.1)	42.2 (1.5)	44.3 (1.5)	1.17	0.36	0.18

Data presented as Mean (Standard Error). LFF = Low Frequency Fatigue; RTD = Rate of Torque Development; * = significant difference from Post, significance set at p ≤ 0.05; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Post-Hoc pairwise comparison using a Bonferroni correction identified a significant difference in Single Twitch between Post and 24H-Post (p = 0.009, *d* = 0.39), but differences between Pre and Post did not reach levels of statistical significance (p = 0.159 *d* = 1.16), and no differences were apparent between Pre and 24H-Post (p > 0.999, *d* = 0.09). Similarly, as outlined in Figure 20, there was a significant difference in LFF Post compared to 24H-Post (p = 0.030, *d* = 0.33), but differences between Pre and Post (p = 0.168, *d* = 1.50), as well as differences between Pre and 24H-Post (p > 0.999, *d* = 0.16) failed to reach statistical significance.

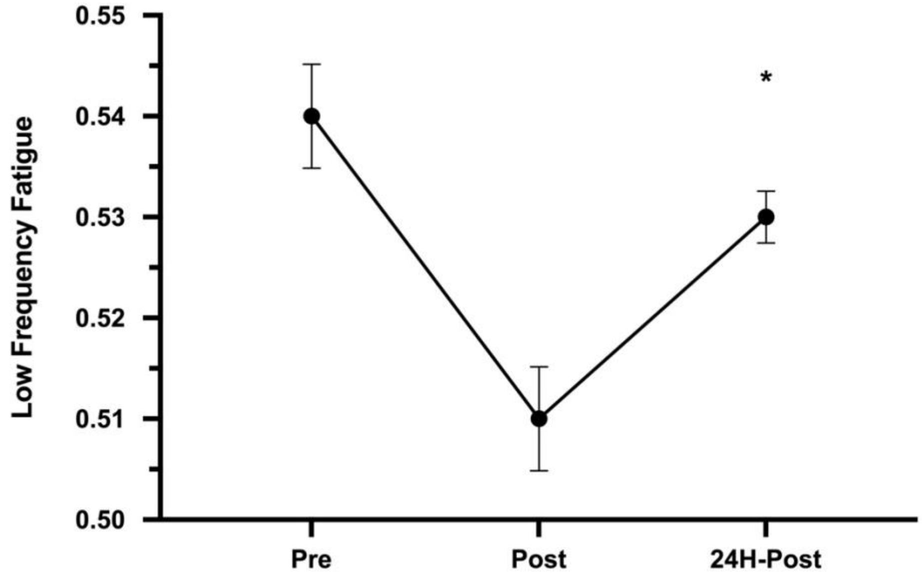


Figure 20. Differences in Low Frequency Fatigue Across Time.

Note: Data presented as Mean (Standard Error); * = significant from Post to 24H-Post, *d* = 0.39 (Small), Post to 24H-Post, p = 0.159, *d* = 1.16 (Large); statistical significance set a $p \leq 0.05$.

In addition, no significant differences in RTD ($p = 0.251$, $\eta_{p2} = 0.101$), Rate of Relaxation ($p = 0.413$, $\eta_{p2} = 0.059$), Average Rise Time ($p = 0.978$, $\eta_{p2} = 0.70$), Time to Peak ($p = 0.314$, $\eta_{p2} = 0.079$), or Half Relaxation Time ($p = 0.415$, $\eta_{p2} = 0.053$) were observed across Time.

As presented in Table 41, men and women demonstrated significant Sex differences in twitch characteristics. Men had a significantly greater Doublet (Men = 80 (4.0); Women = 54.5 (4.8), $p < 0.001$), Single Twitch (Men = 41.8 (2.7); Women = 28.7 (3.3), $p = 0.010$), and Rate of Torque Development (Men = 314.3 (14.3); Women = 209.2 (17.5), $p < 0.001$), as well as a significantly slower Rate of Relaxation (Men = 0.95 (0.07); Women = 0.62 (0.08), $p < 0.007$). No differences between sex were observed in LFF (Men = 0.52 (0.02); Women = 0.53 (0.02), $p = 0.707$), Average Rise Time (Men = 32.2 (1.1); Women = 30.4 (1.3), 0.295), Time to Peak Torque (men = 254.6 (2.0); Women =

260.4 (2.4), p = 0.088), or Half Relaxation Time (Men = 44.9 (3.5); Women = 44.3 (4.3), p = 0.919).

Table 41. Sex Differences in Twitch Characteristics

Variable	Men (n = 9)	Women (n = 6)	p-value	Effect (*d*)
Doublet (Nm)	80.0 (4.0)	54.5 (4.8)**	<0.001	2.15
Single Twitch (Nm)	41.8 (2.7)	28.7 (3.3)*	0.010	1.62
LFF	0.52 (0.02)	0.53 (0.02)	0.707	0.18
RTD (Nm/sec)	314.3 (14.3)	209.2 (17.5)**	<0.001	2.45
Rate of Relaxation (Nm/sec)	0.95 (0.07)	0.62 (0.08)*	0.007	1.63
Average Rise Time (ms)	32.2 (1.1)	30.4 (1.3)	0.295	0.56
Time to Peak Torque (ms)	254.6 (2.0)	260.4 (2.4)	0.088	0.98
Half Relaxation Time (ms)	44.9 (3.5)	44.3 (4.3)	0.919	0.06

Data presented as Mean (Standard Deviation). LFF = Low Frequency Fatigue; RTD = Rate of Torque Development; * = Statistically significant $p \leq 0.05$; ** = statistical significance, $p \leq 0.001$; *d* = Cohen's *d*, interpreted as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (≥0.80).

Discussion

The primary purpose of the present study was to examine the acute neuromuscular function and endocrine responses to High and Low eTL basketball practices in a cohort of collegiate basketball players. A secondary aim sought to examine the central and peripheral contributions to neuromuscular fatigue following sport-specific basketball training session.

The key findings in Part I of this study were 1) there were no significant differences in countermovement jump performance across time, however there appeared to be small effects for some variables during the High condition, which only exhibited trivial to no effect during the Low condition; 2) there were significant sex differences in endocrine responses to eTL; 3) there were no differences in endocrine responses between the high or low eTL conditions; 4) In men, there were significant increases in testosterone from Pre to Post-Practice that returned to baseline at 24-hour following practice. 5) cortisol appeared to increase from pre to post practice, but return to baseline 24-hours following practice, but these changes were not influenced by the condition; and 6) testosterone:cortisol ratio appeared unaffected by condition and across time.

Discussion: *Part I*

Hydration Status

There present investigation observed participants arriving to testing with a sub-optimal hydration status. Utilizing the guidelines provided by the National Athletic Trainers Association (NATA) (Casa et al., 2000; Heishman, Daub, et al., 2018; Thigpen et al., 2014), the USG and urine color scores observed in the present study on average, would characterize athletes as hypohydrated and slight dehydrated, respectively. These findings parallel previous work by Heishman et al., that specifically illuminated the longitudinal dehydration among collegiate basketball players during various training phases (Heishman, Daub, et al., 2018). Similarly, the data in the present study supports the findings of Thigpen et al. that identified the majority of athletes in a cohort of men's and women's collegiate basketball players arriving to training session hypohydrated (Thigpen et al., 2014). Of additional note, while not the primary focus of the present investigation, these data provide more serial evidence of basketball players arriving with suboptimal hydration statuses.

Although the hydration status of participants in the study was suboptimal, the lack of differences in hydration status between conditions and across time provides some added control in the experimental design. Finding no significant differences in hydration status suggests the deleterious effects associated with poor hydration status, such as potentially influencing both physical performance (Cheuvront et al., 2010; Cheuvront & Kenefick, 2014) and endocrine responses (Judelson et al., 2007) should not have confounded the interpretation of the data in the present study. Additionally, the similarities between the poor hydration status in the sample of participants of the present study and the systemic hypohydration reported among athletes in previous literature (Hamouti et al., 2010; Heishman, Daub, et al., 2018; Osterberg et al., 2009; Thigpen et al., 2014; Volpe et al., 2009) may actually bolster the ecological validity and practical application of the observed performance and endocrine outcomes of the present study.

Subjective Questionnaires

There were no differences in responses to the recovery questionnaire between condition or across time. Recovery questionnaires are commonly utilized in applied sport science and are thought to provide reliable subjective fatigue monitoring tool (Bourdon et al., 2017; T. Edwards et al., 2018b; Halson, 2014). Responses are thought to be influences by a variety of factors including the rate of adaptation to previous training and the extend of muscle damage during the training exposure. Previous work has shown a similar pattering in fatigue and overall well-being scores and suggested the simple psychometric tool for supporting the assessment of recovery following training (McLean et al., 2010). Ultimately, the recovery questionnaire was implemented in the presented study to provide additional perspective on the impact of the imposed training conditions, as well as to provide some evidence of control over exogenous factors (i.e.- sleep and outside activity) that could have influenced the interpretation of the resultant performance outcomes variables. No differences in well-being scores on the recovery questionnaire alludes to the overall volume and intensity of training loads experienced, as well as the athlete is ability to cope with the imposed training stimulus in the present study.

External Training Load

Although the intended study design attempted to control for practice duration between conditions, there was a statistically significant Sex × Condition interactions, as well as a significant Condition and Sex main effect for differences in practice Duration. The observed statistically significant differences in Duration, likely do not hold any clinical or practical relevance, as the largest differences were between sexes at approximately 15 minutes, while there were only small differences of an average of 2 minutes revealed between the High and Low conditions that reached levels of statistical significance. These differences became statistically significant due to the limited variability in the observed data. From a practical perspective, these differences could manifest simply by players getting on the court a few minutes early for pre-practice work. Ultimately, while differences in duration were statistically significant, these differences have little to no practical relevance.

As intended, there was a significant difference in PL/min conditions but no differences PL. Additionally, there were also significant differences in practice intensity between sexes within conditions. Placed into perspective with eTL of previous literature, the average PL/min during the High condition was greater than the highest weekly average previously reported in men's collegiate basketball players during the preseason (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020) and similar to other data of reported from collegiate basketball players in the off-season (Heishman, Peak, et al., 2020). Additionally, the reported PL/min of the present study were lower than that previously in elite collegiate women's players, as well as in professional players (Ransdell et al., 2019; Scanlan et al., 2012), but greater than semi-professional players during competition (Fox et al., 2018). With respect to the present study, the women's team had fewer players as a whole, allowing for less substitutions and player-interchanges, which could have increased the average PL/min, compared to men.

As is relates to PL, the present study paralleled training loads reported in collegiate basketball players during the off-season training block (Heishman, Peak, et al., 2020) and during the preseason (Heishman et al., 2017; Heishman, Curtis, et al., 2018), but also lower than other data from the preseason (Heishman, Daub, Miller, Freitas, & Bemben, 2020) and that reported in professional players (Svilar, Castellano, & Jukic, 2018; Svilar, Castellano, Jukic, et al., 2018). Although the literature is absent of data specifically describing the undulation of training loads across various training phases, the primary contributor for the differences in eTL observed in the present study was the training phase of testing, as Part I took place in the off-season training phase. Discrepancies in eTL among training phases are apparent when examining various reports of the off-season block, preseason block, and even the competitive season block (Fox et al., 2018; Heishman, Curtis, et al., 2018; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020; Heishman, Peak, et al., 2020; Ransdell et al., 2019; Svilar, Castellano, Jukic, et al., 2018).

The eTL characteristics of a practice are also related to the types of drills and activities included in the basketball sessions, which is primarily dictated by the sport coaches and their perception of the team's technical and tactical attributes needing improvement. A plethora of factors are thought to influence the training load intensity during practice, including the team's style of play, the skillset of player personnel, the number of players engaged in a drill, the size of the playing area, and even the technical/tactical emphasis of the drill (Fox et al., 2018; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020; Ransdell et al., 2019; Scanlan et al., 2015). Previous literature has also identified differences in eTL demands between competitive games and sport specific training sessions (Fox et al., 2018; Ransdell et al., 2019). While not stratified in the present study, additional factors may influence the eTL experienced during basketball play, including a player's role on the team (i.e.-key player, rotational player, etc.) (Heishman, Daub, Miller, Freitas, & Bemben, 2020), and potentially player position may (Schelling & Torres, 2016; Svilar, Castellano, & Jukic, 2018; Svilar, Castellano, Jukic, et al., 2018) or may not (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Ransdell et al., 2019) be a delineating factor.

The IMU hardware utilized should be considered as another factor that could have potentiated disparities in the observed eTL in comparison to previous literature. The majority of previous research in basketball has used the Catapult Innovations S5 unit, while the present study used the newer Catapult Innovations T6 devices. Although utilizing the same hardware, as well as the same filtering and analysis software, a comparison between the two units has yet to be published. In addition, the methodology of collection may influence several parameters. For example, not interchanging, or "benching" athletes when they are not the primary participant in an activity, as suggested by previous literature (Fox et al., 2018; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020; Narazaki et al., 2009) likely plays a role in both attenuating the intensity (PL/min) and augmenting the total volume (PL) of the work observed in the present study, and may also explain discrepancies among intensities found in the literature.

This study is one of few to offer a comprehensive eTL profile for collegiate basketball players, containing the commonly reported variables of PL and PL/min, but also the inclusion of IMU™ data. This information offers a thorough look at the load profile experienced by collegiate basketball players, as well as potential sex differences in such characteristics. This data may also prove valuable when comparing the findings of the present study with future research. When examining sex differences, men performed significantly more events in each micro-movement category, except for IMA-Low, although these differences still exhibited a large effect. These differences are likely due to using the same predefined intensity thresholds used to categorize the micro-movements between sexes, which therefore likely results in each category falling at a lower relative intensity in men, due men exhibiting higher levels of absolute jump height, power, and speed. Interestingly, there were no main effects for differences between sex differences observed for PL_{2D}, $PL_{1D\text{-}FWD}$, $PL_{1D\text{-}SIDE}$, or $PL_{1D\text{-}UP}$ which are seldomly reported in the literature. These findings may suggest men and women experience similar volumes of movement during practice. When coupled with the results from the IMA™ data, the volumes of movement may be comparable, but the absolute intensities appear to be higher in men.

While the nature of the chosen study design did not allow a parallel in drills and activities during the practice sessions between sexes, the researchers recognize and accept the trade-offs made in the study design when not controlling for specific drills and activities performed by each team during the practices. Although the specific drills and activities were not controlled between the practices of the men's and women's teams, this allowed for an enhanced ecological validity of the study, as the sport-specific coaches implemented necessary drills for their respective teams, which was typical of the training phase and then allowed subsequent neuromuscular and endocrine responses to be evaluated, which were then more relevant to the typical training demands of that team. While this may influence the comparison between sexes, it may also result in greater-team specific observations, thereby enhancing practical significance within each team, including value added specifically for the players committing their time to participant in the study.

Internal Training Load

As expected there was a significant increase in Internal Training Load (iTL) between Conditions, as assessed via heart rate response. With an increase in eTL, there would be an expected concomitant rise in iTL response. Previous literature has documented the association between eTL and subsequent iTL responses in basketball (Heishman, Curtis, et al., 2018; Scanlan et al., 2014; Svilar, Castellano, & Jukic, 2018), as well as other team sports (Casamichana et al., 2013). The significant differences in heart rate intensity between conditions provides evidence that the study design achieved varying training load demands and subsequently a greater internal response.

In comparison with the present study, Heishman et al. (2018) examined a high eTL compared to a low eTL practice during the preseason and observed much higher TRIMP value during the high exposure compared to the lower TRIMP values during the low exposure. More specifically, the high eTL exposure resulted in TRIMP values of approximately 135 (au), almost 1/3 higher than that of the present study, while the low eTL exposure only reached approximately 65 (au) on average.

Although not the recommended method to evaluate heart rate response during basketball due to the extreme fluctuations during the intermittent play of the sport, the average heart rate during both sessions fell within the typical range of 132-165 bpm experienced when taken from the total time of play (Stojanović et al., 2018). While this support participants experiencing practically relevant intensities in the present study, it may reflect a limited effect between conditions, when trying to compare High vs. Low training loads, and subsequently limiting the magnitude of change in the responses of the neuromuscular performance outcome variables.

Interestingly, although there were significant differences between conditions when examining both eTL from the IMU and iTL measure via the heart rate system, there were no significant differences observed between conditions in RPE or sRPE. Moreover, although differences between conditions exhibited a small effect, the effect was likely not practically significant, with both RPE values average 5 on the 1-10 scale. While a strong association between sRPE and other quantitative parameters of training load has been established (Impellizzeri et al., 2004; McLaren et al., 2018), some evidence suggests that sRPE may lack sensitivity to discriminate between basketball training session and competition with clear differences in external training load (Fox et al., 2018), and may also be limited in detecting discrepancies between- and within-game variability in other team sport (McLaren et al., 2016; West et al., 2014; Weston et al., 2015).

Fatigue during human performance may more accurately be understood through the dichotomization of fatigue into the categories of *performance fatigability* and *perceived fatigability* (Enoka & Duchateau, 2016; Kluger et al., 2013), with the latter relating to RPE and sRPE indices. Significant differences in both eTL and iTL, but no differences in perceptual responses may offer more context into the training intensity experienced in both conditions. It appears there were no differences in the perceived fatigability of the participants between conditions.

Countermovement Jump

Overall, no significant differences emerged for any CMJ variable across time, however, 6 of 7 CMJ Tradition Variables, 4 of 6 CMJ Concentric Alternative Variables, 3 of 5 CMJ Eccentric Alternative Variables, and 3 of 7 CMJ Phase Duration Alternative Variables did display a small effect during the High condition from Pre to Post-practice, while none of these effects were observed during the Low condition. Additionally, the majority of these variables that showed an effect following practice during the High condition, revealed trivial to no effect at the 24-hour assessment following practice, signifying a resolved back to baseline. These varying responses between eTL conditions may offer some preliminary support of the CMJ as a valuable tool in understanding the dose-response relationship of external training loads in collegiate basketball athletes.

Countermovement Jump Traditional Variables

While not statistically significant, Conc Mean Force, Conc Mean Power, FT:CT, Jump Height, Peak Power, and RSI_{Mod}, all showed small effects, with decreases from Pre to Post-Practice, but only during the High condition. In contrast, all effects during the Low condition were trivial, at best.

In the present study, there were no significant interaction or main effects for time in the present study, however, JH seemed to be moderated by Condition, with significant declines in JH during the High compare to Low condition. In addition, although not statistically significant, decreases in JH from Pre to Post-practice appeared to have a small affect, which returned to baseline by 24-hours following training, and again, was absent altogether during the Low condition. Jump Height (JH) is one of the most readily utilized and reported metrics of the CMJ, however the sensitivity of JH to detect changes in neuromuscular performance remain controversial. Previous research has used JH as an index of neuromuscular performance to evaluate changes across training phases, which has yielded conflicting results, including reports of JH showing no change (Ferioli et al., 2018; Heishman, Daub, Miller, Freitas, & Bemben, 2020), as well as increasing (Aoki et al., 2017) and decreasing (Cruz et al., 2018; Heishman et al., 2017). Discrepancies associated with acute responses following basketball training exposures remain similarly unclear. Similar to the findings of the present study, Pliauga et al. (2015) observed no difference in JH from pre to post-game. However, in contrast to the present study, previously literature has found a significant decrease in JH to emerge at 24-hours following a competitive and simulated games (Chatzinikolaou et al., 2014; Pinto et al., 2018; Pliauga et al., 2015). Specifically, previous research by Heishman et al. (2018) observed men's basketball players during the preseason and reported a significant decrease in jump height 24-Hours following practices with High eTL compared to Low eTL practices.

When examining the discrepancies reported in literature associated with JH, the variety of methods used to compute jump height should not be overlook as a source of error influencing results. A variety of technology have been utilized to assess JH, which can be easily estimated by the flight time method (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020; Linthorne, 2001), while using tools that are less expensive than a force platform (Claudino et al., 2017; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020; Klavora, 2000; Ziv & Lidor, 2010). The impulse-momentum theorem has been characterized as "gold-standard" estimation of jump height (McMahon et al., 2018), however, misidentifying the instant of take-off by as little as 2-3 milliseconds can result in 2% variables in velocity and displacement (Hara et al., 2008; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020; McMahon et al., 2018). Additionally, threshold used to detect jump initiation in force platform analysis software can also influence the validity of such measurements. Ultimately, the present study used the flight time method for JH estimation due to an increase absolute reliability demonstrated in previous work (Heishman, Brown, et al., 2019; Heishman, Daub, Miller, Freitas, Frantz, et al., 2020).

Again, while not statistically significant, the present study saw a decrease in FT:CT of approximately 6.6%, and a decrease of 8.5% in the associated variable of RSI_{Mod}, but only during the High condition. Nearly identical decreases in FT:CT were observed immediately following a fatiguing protocol in other team sport athletes (Gathercole, Sporer, Stellingwerff, et al., 2015a), which shifted back towards baseline at 24-hours following the exercise bout. Similar decreases in FT:CT of 7.8% have been reported in Australian Rules Football (ARF), however these changes were observed immediately after and 24-hours following the game. Additionally in ARF, Rowell et al. (2017) observed FT:CT as the most sensitive variable to acute training loads, as decreases were apparent 30-minutes after, 18-hours after, and 42- hours after the match. Brownstein et al. (2017) reported a decrease in RSI immediately post and 24-hours following a 90-minute competitive soccer match (Brownstein et al., 2017). The data in the present study support previous work in collegiate basketball players, that observed moderate negative perturbations in FT:CT were associated with weeks that included increases in training load intensity, as assessed by PlayerLoad/min (Heishman, Daub, Miller, Freitas, & Bemben, 2020). With the cohort of participant considered skilled jumper, skilled performers are often capable of adapting and adopting compensatory strategies in effort to achieve gross tasks. Therefore, the observation in movement strategy, represented by FT:CT and RSI_{Mod} may reflect the skilled jumpers modifying movement strategy to achieve their gross performance outcome of jump height. Cumulatively, these data may suggest the sensitivity of both FT:CT and RSI_{Mod} accentuate fatigue by illuminating compensatory movement strategies of the athlete.

Although a paucity of evidence exists in basketball players, alteration in force and power have been observed following other team sport activities. Substantial decrease in absolute and relative mean power, as well as relative mean force immediately following a competitive match, training and fatiguing protocols in team sport athletes (Cormack, Newton, & McGuigan, 2008; Gathercole, Sporer, Stellingwerff, et al., 2015a, 2015b; Hoffman et al., 2003; Sparkes et al., 2018) (Sparkes, 2019), that often remained suppressed 24-hours after the match (Cormack, Newton, & McGuigan, 2008; Hoffman et al., 2003; Kennedy & Drake, 2017; McLellan et al., 2011; Sparkes et al., 2018).

In addition to increases in both force and power, men jumped approximately 28% higher than women on average, similar to the range of approximately 24-27% reported in similar studies (Ebben et al., 2007; Laffaye et al., 2014; Rice et al., 2017). While differences in jump height have been well documented, sex differences in force and power emerge even when resistance training status and jump training is controlled (Ebben et al., 2007; Laffaye et al., 2014; Rice et al., 2017; Riggs & Sheppard, 2009). It should be noted, other studies have reported no sex difference in relative peak force and rate of force development (Rice et al., 2017; Riggs & Sheppard, 2009). In the present study, the CMJ variables were compared on an absolute not a relative basis, which is likely responsible for the variety and magnitude of the sex differences. Understanding sex differences in performance variables of the force-time variables may aid practitioners in implementing optimal training prescription. Interestingly, there were no significant differences in FT:CT and RSI_{Mod}, which is commonly associated with an athletes level of explosiveness (Kipp et al., 2016; Martinez, 2016). Overall, the interplay of variation in muscle mass and strength, as well as differences in muscle-tendon stiffness are all probably contributing factors responsible for apparent sex differences. Also, observed Sex differences may relate to differences in jump strategy, such as increases in lower limb stiffness, evident by less countermovement displacement during the eccentric and concentric phases of the jump (McMahon et al., 2017).

CMJ Concentric Alternative Variables

Although there were no significant differences between Condition for across Time, Conc Impulse Peak Velocity and Velocity@PP each demonstrated a small negative effect from Pre to Post-practice during the High condition, which was not observed in the Low condition that appeared to inflict trivial to no effects. Peak Velocity and Veloctiy@PP appeared to be some of the most affected variables during the High condition, while again show little to no effect during the low exposure. Decrease on peak velocity may suggest a slowing of muscular contraction time, which is often evident with peripheral fatigue (Allen et al., 2008; Kent-Braun et al., 2002b). Gathercole also so a small and moderate effect of decrease in Peak velocity and Velocity@PP, respectively, following a fatigue protocol and in rugby players with increasing training loads (Gathercole, Sporer, & Stellingwerff, 2015; Gathercole, Sporer, Stellingwerff, et al., 2015a). It seems plausible higher intensity training may manipulate jump mechanics (Gathercole, Sporer, Stellingwerff, et al., 2015a; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Kennedy & Drake, 2017; Knicker et al., 2011), but also considering the inverse relationship between force and velocity, it may be speculated that the velocity of movement slowed in an effort to maximize force production in an attempt to achieve of the desired gross output of jump height. The effects observed on Peak Velocity and Velocity@PP may make them a focus for monitoring changes in neuromuscular performance.

Additionally, while rarely reported, especially in basketball players, Concentric Impulse also exhibited a small effect during the high condition. , which would be expected due to the strong relationship between Concentric Impulse and JH (Linthorne, 2001; McMahon et al., 2018). However, it is unclear if this provides additive information than

JH, but JH can likely be articulate to athletes and coaches in a more relatable manner. Finally, both Conc RPD and Force@PP demonstrated trivial to no effect across Time and between Conditions, suggesting a lack of sensitivity in detecting acute changes in neuromuscular performance.

Again, as expected due to the rationale discussed above, there were significant Sex differences between Conc Impulse, Peak Velocity, Force@PP, and Velocity@PP, all showing large effect. Although not reaching levels of statistical significance, sex differences for Force@0V and Conc RPD showed medium and large effect, respectively.

CMJ Eccentric Alternative Variables

Eccentric Alternative Variables displayed no significant differences between condition and across time and additionally had few variables that display a small effect from Pre to Post-Practice, including Ecc Mean Decel Force, Ecc Mean Power, Ecc Peak Force (Rice et al., 2017; Riggs & Sheppard, 2009). As discussed above, previous literature has examined changes in the movement strategy, through the FT:CT and RSImod, which take into consideration the eccentric phase, however, previous work has yet to examine changes in eccentric forces following a team sport. While no data was significant, small effects observed in the FT:CT may be accompanied by a paralleling decrease in force Ecc Mean Decel Force, Ecc Mean Power, Ecc Peak Force during the eccentric phase as these parameter exhibited a small effect. However, the value of these effect should be interpreted with caution due to the variability in some eccentric parameters.

Although Sex differences in eccentric parameters have been identified, less consistency exists in the literature. Previous work has documented no differences between eccentric rate of force development and movement time (Rice et al., 2017; Riggs & Sheppard, 2009). The present study only saw a significant difference in Eccentric Mean Braking Force, but irrespective of the present study using absolute and not relative values. However, all eccentric variables displayed a medium to large effect for differences between sex, which may not have reached levels of statistical significance due to the variability of some eccentric measures, as noted by previous literature (Heishman, Daub, Miller, Freitas, Frantz, et al., 2020; McMahon et al., 2017). These data suggest eccentric characteristics are the least discriminate component of the force- and power-time signatures of the CMJ between sexes. In addition to the above-mentioned factors, sec differences in eccentric characteristics may relate to an increased lower-extremity stiffness (McMahon et al., 2012).

CMJ Phase Duration Variables

Also referred to as the Jump Strategy variables, changes in Phase Duration Alternative Variables are thought to reflect alteration in movement strategy during the CMJ (Cormack, 2008; Gathercole, 2015). There were no significant differences discovered in Phase Duration Alternative Variables in the present study. However, there appeared to be a small effect for the increase or longer duration of the Braking Phase, Eccentric Decel Phase, and overall duration of the Eccentric Phase during the High condition, but an effect during the Low condition was trivial or non-existent. These finding are in agreement with the few previous studies that measured changes Eccentric Phase Duration, also reporting extended duration (Gathercole, Sporer, & Stellingwerff, 2015; Gathercole, Sporer, Stellingwerff, et al., 2015a; Kennedy & Drake, 2017). However, disagreement emerges in the time course associated with eccentric alterations.

The present study supports work by Gathercole et al., with Eccentric Duration increased immediately following the exercise exposure and returning to baseline at 24-hours, while other work has only observed the alteration to emerge 48-hours following the exercise exposure (Kennedy & Drake, 2017). The present study provided added information that has yet to be reported in other work, in that the Eccentric Phase demarcated into the Braking Phase and Eccentric Deceleration Phase, which may provide added information as the Eccentric Decel Phase exhibited a slightly greater effect, although still classified as small. Additionally, these data in the present study would suggest that there was a prolonged eccentric phase of the jump following practice, but any modification in jump strategies resolved to baseline by 24-hours post-practice.

Interestingly, a key finding the present study was a lack of the small to trivial effect associated with the changes in Contraction Time (CT). As previously discussed, prior research has outlined alterations in FT:CT (Gathercole, Sporer, Stellingwerff, et al., 2015a; Heishman, Daub, Miller, Freitas, & Bemben, 2020; Rowell et al., 2018), which was also observed in the preset study and usually is related to the athletes ability to maintain the gross output of flight time, but does so by lengthening contraction time to achieve that goal of jump height. The data in the present study actually shows a greater affect in alteration of the FT, as compared to the CT of the jump. While merely speculative, the basketball players in the present study are skilled jumpers, which may choose a different compensatory pattern when manipulate their movement strategy, such as sacrifice jump height (FT), but still maintain the speed of contraction. This modification may have advantageous sport-specific implications, for example, the quickness and timing of a jump may be more valuable to a basketball player attempting to get a rebound before another player, rather than the absolute vertical displacement. Additionally, little change in CT combined with a lengthening Eccentric Duration resulted in a small effect of a decrease in CT:Ecc Duration percent. Concentric Duration appeared unaffected across time in both conditions.

Endocrine Responses

There were significant differences effects between sex, condition, and across time, which led to the decomposition of the model and analyses for men and women performed independently. While differences in sex hormones played a role, the experimental design led to a limited comparison between sexes, specifically in endocrine responses. Due to each team's practice schedules which was outside the control of the researchers and experimental design, women were tested in the morning (between the hours of 0630 and 0830), while men were tested in the afternoon (between the hours of 1330 and 1530 hours). This presented comparative challenges due to circadian rhythmicity resulting in higher levels of testosterone and cortisol that decrease throughout the day (Hackney, 2006; Hayes et al., 2010). Therefore, large differences in testosterone combined with the limited the number of female subjects made the comparison of responses between sexes challenging.

In men, there were significant increases in testosterone from Pre to Post-practice, but there were no differences between conditions in testosterone responses. These differences resolved back to baseline values within 24-hours following practice. Testosterone responses in team sport show mixed results, including both decreases which may last up to lasting up to 48-hours after the event (Romagnoli et al., 2016; West et al., 2014)as well as remaining unchanged (Cormack, Newton, McGuigan, et al., 2008; D. A.

Edwards et al., 2006; Rowell et al., 2017; Silva et al., 2013; Sparkes et al., 2018). While the findings of the present study conflict with previous literature examine these responses outlined in team sport, other work examining responses in middle-distance runners (Guglielmini et al., 1984), responses to intense exercise regardless of duration (Duclos et al., 1996), responses to increasing duration of exercise with intensity remaining constant (Tremblay et al., 2005), as well as responses to acute bouts of resistance exercise (Kraemer & Ratamess, 2005) have all been shown to increase in testosterone. Moreover, it is generally accepted that a single bout of maximal endurance exercise promotes increases in testosterone (Hackney, 1989; Hackney & Lane, 2015). Therefore, the findings in the present study that appear to conflict with findings in other team sports are probably due to the training intensity and duration experienced. Furthermore, increased training status appears to enhance the response of testosterone after exercise (Pliauga et al., 2015). This study provides evidence that basketball practice of High and Low eTL stimulates increases in testosterone.

In men, there was a significant increase in cortisol from pre to post-practice but there were no differences between conditions in cortisol responses. These differences resolved back to baseline values within 24-hours following practice. In contrast to testosterone, congruent findings demonstrating acute increases in cortisol from Pre to Post-exercise is well document in the literature, including evidence in basketball (Arruda et al., 2014, 2017; Chatzinikolaou et al., 2014; Gonzalez-Bono et al., 1999; Moreira et al., 2012), as well as other sports (Casto & Edwards, 2016a; D. A. Edwards et al., 2006; Elloumi et al., 2003; Filaire et al., 1999; Haneishi et al., 2007; Moreira et al., 2009; Rowell et al., 2018; Sparkes et al., 2018; West et al., 2014), however, the duration of these elevations in cortisol remain less clear, with reports of the increases lasting from 24-hours 48-hours following exercise in these studies. The sublimation of cortisol back to baseline within 24-hours following each practice in the present study likely relates to the intensity and duration of each practice exposures.

Cortisol levels increase at a proportional rate to exercise intensity, with a critical threshold at approximately 60% VO_{2MAX} (Hackney & Lane, 2015; Hill et al., 2008; Viru & Viru, 2004). Although heart rate intensities suggest exercise intensity was clearly above that critical threshold, the significant differences in eTL and iTL were not resultant of varying cortisol responses. The total duration of exercise also regulates the final levels of cortisol reached (C. Davies & Few, 1973; Hackney, 2006; Hackney & Lane, 2015). While duration was controlled in the present study, with no practically relevant differences, duration may play a larger role in other training phases that typically include longer practice durations, such as the during preseason (Heishman, Daub, Miller, Freitas, & Bemben, 2020). Also of note, responses are modulated by an individual training history (C. Davies & Few, 1973), therefore the a greater cortisol response was likely evoked in this cohort of trained collegiate basketball players than would have been their untrained counterparts. In addition, the competitive levels and/or the importance of the competition can modulate these responses and these differences also appear to be influences by sex (Kivlighan et al., 2005).

Previous work has shown acute alteration in the T:C following team sport activity (Cormack, Newton, McGuigan, et al., 2008; Rowell et al., 2018; Silva et al., 2013). However, in the present study, the concomitant rise of both testosterone and cortisol resulted in no significant difference in T:C ratio across time or between condition.

Ultimately, T:C ratio may be more useful in longitudinal analyses, such as across a training phase, to detect undesirable perturbations in the anabolic:catabolic balance that may result in non-functional overreaching and potential overtraining (Andre & Fry, 2018; Kraemer et al., 2013; Martínez et al., 2010; Moore & Fry, 2007; Schelling et al., 2015; J. D. Stone et al., 2017; Viru & Viru, 2004).

In women testosterone, cortisol, and T:C ratio appeared unaffected by condition and across time. While much less data is available, previous work in females soccer players observed increases in testosterone from pre to post competition in women, which was unchanged in men as well as increase in cortisol (D. A. Edwards et al., 2006). The obvious rationale for the lack of responses reported in the present study may be the small sample size, with other 3 participants, as well as increases in resting levels of both testosterone and cortisol due to circadian rhythms that may have masked potential changes. Additionally, it is well established that oral contraceptives decrease serum and salivary testosterone (Crewther et al., 2015; D. A. Edwards & O'Neal, 2009), however much research overlooks these details when measuring testosterone in reproductive age females, especially in applied performance (D. A. Edwards & O'Neal, 2009). While the study design did not permit controlling for oral contraceptives or menstrual cycle, menstrual history questionnaire was administered with results showing 2 athletes were not on contraceptives and both were in the luteal phase during testing, while 1 was one oral contraceptives. Ultimately, endocrine responses in women appeared unaffected across time in both conditions.

Discussion-*Part II*

In Part II, the key findings were 1) no differences in CMJ variables across time, with changes exhibiting trivial to no effect; 2) men experienced a significant decrease in Rate of Torque Development from Pre to Post-practice, which returned to baseline at 24-hours following practice, while women experienced no changes across time; 3) Low frequency fatigue appeared to emerge immediately following practice, but resolved back to baseline at 24H-post practice; and 4) There were significant Sex differences in CMJ variables, MVC, Interpolated Twitch Torque, EMG, and twitch characteristics, but no differences in percent voluntary activation.

Training Load

The duration of practice was nearly double the average practice time in Part I and similar increases in PL were apparent with PL approximately 100 au higher on average than those experienced in Part I. However, the average PL experiences in Part II was 0.4 au/min lower than experiences in the Low condition in Part I. In addition to the aforementioned factor influencing eTL, Part II was performed during the preseason training phase, in contrast to Part I being performed in the off-season training phase, which likely played a major role in the observed discrepancies between Part I and Part II. More specifically, these discrepancies between Part I in Part II in training volume relates to the duration of practice, as league regulatory body (NCAA) allows more time for sport coaches to spend with players in the preseason, as compared to the off-season training phase, leading to increased practice lengths (Heishman, Daub, Miller, Freitas, & Bemben, 2020; Heishman, Peak, et al., 2020).

Differences in PL/min between Part I and Part II may be due to the technical and tactical emphasis of practice shifting from individual skill development work during the off-season to more team-oriented drills and activities during the preseason, as the team prepares for the forthcoming competitive season and playing opponents (Heishman, Daub, Miller, Freitas, & Bemben, 2020). Moreover, more team-oriented drills limit the number of players participating in segments, which may potentially drive down an athlete's PL/min. The off-season training block often focuses more on individualized player development, rather than team development, incorporating more individual skill development work, with the structure of drills during practice including more players at a time, ultimately reducing the amount of time players are not incorporated in drills and activity. In summary, these differences should be considered when interpreting the neuromuscular performance changes evoked.

Countermovement Jump

Despite player undergoing a longer duration of practice and almost double the total player load, no significant differences were observed across time in any CMJ Traditional, Concentric Alternative, Eccentric Alternative, or Phase Duration Variables and differences across time. Moreover, effects were only found to be trivial to no effect at all. Therefore, it may be concluded that discrepancies in CMJ performances between Part I and Part II may relate to the intensity of the basketball training exposures. Specially, Part II had a much lower PL/min than Part I. These findings would support work previously mentioned by Heishman et al., observing significant differences in eTL intensity resulted in concomitant modifications in CMJ performance during the preseason, emphasizing the impact of training intensity rather than training volume on CMJ performance indices (Heishman, Daub, Miller, Freitas, & Bemben, 2020).

Interpolated Twitch Technique and Twitch Characteristics

To the researcher's knowledge, this is the first study to attempt to discern between alteration in central verse peripheral mechanism of fatigue in basketball players. The present study observed no significant differences from Pre to Post-practice in MVC, but significant increases in MVC were revealed from Post to 24H-Post following the practice exposure. These increases were parallel with significant increases in Voluntary Activation from Post to 24H-Post-practice. These data suggest the volume and intensity of exercise experienced during the single practice bout lacked the capacity to evoke significant fatigue. Additionally, at minimum, the eTL in practice did not elicit reductions MVC or Voluntary Activation but may in fact potentiated responses in MVC and Voluntary Activation. While data for comparison is limited, these findings disagree previous literature that has been performed in soccer, where reductions in MVC and voluntary activation have been reported following both simulated and competitive matches. Rampinini et al. (2011) noted reductions in MVC, EMG RMS, and voluntary activation have been identified following a soccer match, which required 48-hours to resolve (Rampinini et al., 2011). Thomas et al. (2017) also found reduction in MVC that persisted for 72-horus following a simulated-match, with central mechanisms, indicated by reductions in voluntary activation, appearing to be the primary site of fatigue manifestation, which was apparent immediately post-exercise and also remained unresolved for 48-hours (Thomas et al., 2017). Brownstein et al. reported competitive soccer matches to elicit neuromuscular fatigue that required 48-72 hours to resolve, with clear reduction in MVC immediately following the match that persisted for 72-hours following, as well as decreases in voluntary activation and potentiated twitch torque immediately post-match, which lasted 48-hours following the match (Brownstein et al., 2017). Difference in findings likely related to the underlying difference in the volume and intensity of exercise required of each sport, with the eTL experienced in the present study were not high enough to cause extensive fatigue.

The present study observed a decrease in Single Twitch Torque from Pre to Post-practice, of large effect, which resolved back to baseline from Post to 24H-Post, which reached levels of statistical significance. However, there were no significant alterations in Doublet Twitch Torque, consequently resulting in a decrease of the Single to Doublet Twitch Torque ratio representing Low Frequency Fatigue (LFF). Rampinini et al. (2011) reported similar findings, with increase in low frequency fatigue following the competitive soccer match, suggesting peripheral mechanisms played a factor (Rampinini et al., 2011). Although LFF is long-lasting, differences observed from Pre to Post-practice resolved back to baseline within 24-hours. Such resolution may allude to the severity of the LFF observed.

There were significant Sex differences in Rate of Torque Development, where men saw a significant reduction from Pre to Post-post practice, which return to baseline at 24-hours, while women remained unaffected across time. There were no other significant Sex × Time interactions and no significant differences in any other twitch characteristics across time.

When these data are interpreted with the CMJ data, it appears the eTL experienced during practice was not great enough to evoke negative impairments in neuromuscular performance. Important to note, in each of the aforementioned studies in soccer examining these central and peripheral changes in neuromuscular fatigue, also reported significant changes in subjective recovery questionnaire metrics, including increases in fatigue, active soreness, and passive soreness. The lack of subjective differences coupled with the eTL information reiterated the limited decrements and fatigue imposed on the athletes. Moreover, small deficits may emerge in peripheral mechanisms, specifically at low firing frequencies, evidence with the apparent LFF. It is possible that the athlete was able to overcome any peripheral deficits, albeit likely small deficits, with the enhancement of voluntary activation, which resulted in no observed changes in MVC or CMJ performance indices.

CHAPTER V: CONCLUSION

The primary purpose of the present study was to examine the acute neuromuscular function and endocrine responses to High and Low eTL basketball practices in a cohort of collegiate basketball players. A secondary aim sought to examine if neuromuscular alteration were primary central or peripheral in origin in response to a sport-specific basketball training session.

Research Questions

Research Questions and Hypotheses: Part I

Research Question 1: Are there significant differences in the countermovement jump traditional and alternative performance variables pre-, immediately-post, and 24-hours following exposures of high and low load sport-specific basketball training?

Hypothesis 1: Significant decreases in CMJ performance would occur from pre- to immediately-post and remain below pre- values at 24-hours following the high training load in parallel with previous literature (Cormack, Newton, & McGuigan, 2008; Ferioli et al., 2018; Heishman, Curtis, et al., 2018). No significant difference in CMJ performance would be present among pre-, immediately post, or 24-hours post measures following the low load training exposure, as previous literature has reported differences in CMJ performance following high compared to low training loads (Heishman, Curtis, et al., 2018).

There were no statistically significant differences in any countermovement jump traditional or alternative CMJ performance variables across time, however 6 of 7 CMJ Tradition Variables, 4 of 6 CMJ Concentric Alternative Variables, 3 of 5 CMJ Eccentric

Alternative Variables, and 3 of 7 CMJ Phase Duration Alternative Variables did display a small effect during the High condition from pre- to immediately-post practice, while none of these effects were observed during the low condition. Additionally, the majority of these variables that showed an effect following practice during the high condition, revealed trivial to no effect at the 24-hour assessment following practice, signifying a resolved back to baseline.

Research Question 2: Are there significant differences in testosterone, cortisol, or the testosterone:cortisol ratio pre-, immediately-post, and 24-hours following exposures of high and low load sport-specific basketball training?

Hypothesis 2: There would be a significant increase in salivary testosterone and decrease in the T:C ratio, while salivary cortisol would significantly increase from pre- to immediately-post measures following the high load training exposures in accordance with prior literature (Arruda et al., 2014; D. A. Edwards et al., 2006; Rowell et al., 2017). Salivary cortisol levels would remain elevated and the T:C ratio would remain suppressed at 24-hours following the high training loads exposure (Cormack, Newton, & McGuigan, 2008; Romagnoli et al., 2016; Silva et al., 2013). No differences would exist between testosterone levels from pre-to immediately-post, or at 24-hours measures following the low intensity exposures (Cormack, Newton, & McGuigan, 2008; McLellan et al., 2010; Silva et al., 2013). In addition, there would be a significant increase in cortisol immediately following the bout of low training load, which would return to baseline by 24-hours post. No significant differences would exist between testosterone or the T:C ratio follow the low load training exposure at pre-, immediately-post, or 24-hours post measures, as previous literature has indicated training intensity plays a vital role in the magnitude and duration of hormonal responses (Hackney, 1989; Hackney & Lane, 2015). There were significant increases in testosterone and cortisol from pre- to immediately-post that resolved back to baseline within 24-hours of the sport-specific training exposure. The concomitant rise in testosterone and cortisol resulted in no significant differences in T:C ratio. Additionally, there were not differences in testosterone, cortisol, or T:C ratio between conditions.

Research Question 3: Are there significant sex differences in countermovement jump traditional and alternative performance variables pre-, immediately-post, and 24-hours following exposures of high and low load sport-specific basketball training?

Hypothesis 3: Significant differences would exist between sexes in CMJ variables, with women having less decrement in performance measures immediately after, or 24-hours following the high load training exposure. No differences would exist between sexes following the low load training exposure.

There were significant sex differences in CMJ variables, however there were no significant differences between sexes across time in any CMJ variable during the high or low condition.

Research Question 4: Are there significant sex differences in testosterone, cortisol, or the testosterone:cortisol ratio pre-, immediately-post, and 24-hours exposures of high and low load sport-specific basketball training?

Hypothesis 4: Significant differences would exist between sexes in testosterone response, with men having greater increases in testosterone immediately following and 24-hours following the high load exposure. No differences between the sexes would exist in cortisol responses following the high training load and no differences in cortisol responses would exist following the low load training exposure. Greater increases in testosterone and similar cortisol responses would results in significant sex differences in T:C ratio, with men experiencing a greater decrease in T:C ratio.

There were significant sex differences in testosterone and cortisol responses, as men exhibited a clear rise in testosterone and cortisol from pre- to immediately-post practice, while no change in T:C ratio across time. However, no differences were detected in testosterone, cortisol or T:C ratio between condition or across time in women.

Research Questions and Hypothesis: Part II

Research Question 5: Are there significant differences in maximal voluntary isometric contraction torque of the knee extensors pre-, immediately-post, and 24-hours following a bout of sport specific basketball training?

Hypothesis 5: There would be a significant decrease in maximal voluntary isometric contraction torque of the knee extensors immediately following and 24-hours following a bout of sport-specific basketball training.

There were actually significant increases in MVC across time, with differences from post- to 24-hours following practice reaching levels of statistical significance.

Research Question 6: Are there significant differences, in peripheral fatigue, measured by twitch torque, pre-, immediately-post, and 24-hours following a single bout of sport-specific basketball training?

Hypothesis 6: There would be a significant increase in peripheral fatigue, measured by twitch torque, before, immediately-post and 24-hours following a single bout of sport-specific basketball training, as previous literature has suggested high-intensity training exacerbates peripheral fatigue.

There were signs of peripheral fatigue evident following practice, with a reduction in Rate of Torque Development in men, but not women from pre- to immediately-post practice, which resolved 24-hours following the sport-specific practice. Additionally, there was a significant decrease in single twitch torque in both men and women from pre- to immediately-post practice, which resolved 24-hours following the sport-specific practice, but no other differences associated with peripheral fatigue emerged.

Research Question 7: Are there significant differences in voluntary activation %, assessed via the twitch interpolation technique, pre-, immediately-post, and 24-hours following a bout of sport specific basketball?

Hypothesis 7: There would be no significant differences in voluntary activation %, assessed via the twitch interpolation technique, before, immediately post, and 24-hours following a bout of sport-specific basketball, as the decrements in torque would be attributed to peripheral mechanisms.

There was actually increase in voluntary activation from pre- to immediately-post practice, and again increase 24-hours following practice which reached levels of statistical significance when compared to pre-practice.

Research Question 8: Are there significant differences in low frequency fatigue, assessed as the ratio of torque from a single twitch to a doublet, immediately after or 24-hours following an exposure of basketball specific practice?

Hypothesis 8: There would be significant increases in low frequency fatigue, assessed as the ratio of torque from a single twitch to a doublet, immediately after or 24-hours following an exposure of basketball specific practice, due to the previous literature suggesting team sport activity increases low frequency fatigue (Fowles, 2006a; Lattier et al., 2004).

Low frequency fatigue appeared from pre- to immediately-post practice, which resolved to baseline 24-hours following the sport-specific practice.

Research Question 9: Are there sex differences in voluntary activation %, peripheral fatigue, or LFF pre-, immediately-post and 24-hours following a bout of sport specific basketball training?

Hypothesis 9: There would be significant sex differences in voluntary activation %, peripheral fatigue, or LFF pre-, immediately-post and 24-hours following a bout of sport-specific basketball training, with men showing greater declines in each variable. `

There was only a significant difference between sexes across time for Rate of Torque Development, which decreased in men from pre- to immediately-post practice and returned to baseline at 24-hours following the sport-specific practice, while reaming unchanged across time in women. There were no differences between sexes across time in voluntary activation, peripheral fatigue, or low frequency fatigue.

Practical Significance

The present study offers several findings of practical significance that can bring value to practitioners and clinicians. The present study identified key CMJ Traditional and Alternative metrics that appear to be influenced by high eTL, which coaches and practitioner can utilize to narrow their focus of key metrics used to assess and monitor their athletes. The present study demonstrated the differences in eTL experienced in within the present study may exert a small impact on neuromuscular performance, while they do not result in different endocrine responses, but will potentiate a rise in testosterone and cortisol that will resolve within 24-hours. While the T:C ratio may provide insights associated with the anabolic to catabolic balance of the athlete, it is like more useful as a long-term monitoring strategy, such as measuring changes across a training phase or training cycle with accumulating training loads, rather than merely examining an acute response to a single bout of training. Additionally, the T:C ratio may not provide much value in monitoring female athletes, due to low resting levels of testosterone. Furthermore, the present study confirmed the presence of low frequency fatigue following basketball sport-specific practice, as well as identified preliminary evidence that athlete's experience an increase voluntary activation following sport-specific team practice, which may allow them to maintain neuromuscular performance when mild signs of peripheral fatigue are present.

Suggestions for Future Research

Future research should explore these same acute changes in countermovement jump performance variables, while using this research as a guideline, during various phases of the training calendar, specifically during the preseason and the competitive season when eTL demands are likely the highest. Moreover, a greater understanding needs to be developed around the impact of competitive games during the competitive training phase compared to practices. Future studies should consider striving to generate a greater difference between eTL intensity, which may further establish the dose-response relationship of eTL in collegiate basketball players, which would include understanding the in peripheral and central factors contributing to neuromuscular performance alterations which may underpin the effects observed in the CMJ performance variables following the high eTL condition in the present study. Additionally, with the interesting dynamic observed in the present study associated with the increase duration and eTL volume but a reduction in eTL intensities which then appeared to result in little no effect in altering CMJ performance variables, future research should attempt to dissect this interplay of duration, volume, and intensity which may better guide coaches and practitioners in developing tactical periodization models.

The present study attempted to isolate the acute responses to one practice exposure, the next progression to build upon these findings would be to discern the implication of accumulating training loads over multiple sessions, weeks, and ultimately training phases. Coupling both laboratory and field based-parameters may provide practices with better strategies to manage players and optimize performance outcomes.

REFERENCES

Abbiss, C. R., & Laursen, P. (2005). Models to explain fatigue during pro- longed endurance cycling. *Sports Medicine*, *35*(10), 865–898.

Achten, J., & Jeukendrup, A. E. (2003). Heart rate monitoring: applications and limitations. *Sports Med*, *33*(7), 517–538. https://doi.org/10.2165/00007256-200333070-00004

Allen, D. G., Lamb, G. D., & Westerblad, H. (2008). Skeletal muscle fatigue: cellular mechanisms. *Physiological Reviews, 88*(1), 287–332. https://doi.org/10.1152/physrev.00015.2007.

Amann, M., & Calbet, J. A. L. (2008). Convective oxygen transport and fatigue. *Journal of Applied Physiology*, *104*(3), 861–870. https://doi.org/10.1152/japplphysiol.01008.2007

Amann, Markus. (2011). Central and peripheral fatigue: Interaction during cycling exercise in humans. *Medicine and Science in Sports and Exercise*, *43*(11), 2039–2045. https://doi.org/10.1249/MSS.0b013e31821f59ab

Amann, Markus. (2012). Significance of Group III and IV muscle afferents for the endurance exercising human. *Clinical and Experimental Pharmacology & Physiology*, *39*(9), 831–835. https://doi.org/10.1111/j.1440-1681.2012.05681.x

Ament, W., & Verkerke, G. (2009). Exercise and fatigue. *Sports Medicine*, *39*(5), 389–422. https://doi.org/10.2165/00007256-200939050-00005

Aminian, K., & Najafi, B. (2004). Capturing human motion using body-fixed sensors: Outdoor measurement and clinical applications. *Computer Animation and Virtual Worlds, 15*(2), 79–94. https://doi.org/10.1002/cav.2

Andersson, H., Raastad, T., Nilsson, J., Paulsen, G., Garthe, I., & Kadi, F. (2008). Neuromuscular fatigue and recovery in elite female soccer: Effects of active recovery. *Medicine and Science in Sports and Exercise*, *40*(2), 372–380. https://doi.org/10.1249/mss.0b013e31815b8497

Andre, M. J., & Fry, A. C. (2018). *Weekly Salivary Biomarkers across a Season for Elite Men Collegiate Basketball Players*. *January*.

Aoki, M. S., Ronda, L. T., Marcelino, P. R., Drago, G., Carling, C., Bradley, P. S., & Moreira, A. (2017). Monitoring training loads in professional basketball players engaged in a periodized training program. *Journal of Strength and Conditioning Research*, *31*(2), 348–358. https://doi.org/10.1519/JSC.0000000000001507

Armstrong, L. E. (2005). Hydration assessment techniques. *Nutrition Reviews*, *63*(6 Pt 2), S40-54. https://doi.org/10.1111/j.1753-4887.2005.tb00150.x

Armstrong, L. E., Pumerantz, A. C., Fiala, K. A., Roti, M. W., Kavouras, S. A., Casa, D. J., & Maresh, C. M. (2010). Human hydration indices: acute and longitudinal reference values. *International Journal of Sport Nutrition and Exercise Metabolism*, *20*(2), 145–153.

Arruda, A. F. S., Aoki, M. S., Freitas, C. G., Drago, G., Oliveira, R., Crewther, B. T., & Moreira, A. (2014). Influence of competition playing venue on the hormonal responses, state anxiety and perception of effort in elite basketball athletes. *Physiology and Behavior*, *130*, 1–5. https://doi.org/10.1016/j.physbeh.2014.03.007

Arruda, A. F. S., Aoki, M. S., Paludo, A. C., & Moreira, A. (2017). Salivary steroid response and competitive anxiety in elite basketball players: Effect of opponent level. *Physiology and Behavior*, *177*(May), 291–296.

https://doi.org/10.1016/j.physbeh.2017.05.017

Baker, L. B., Conroy, D. E., & Kenney, W. L. (2007). Dehydration impairs vigilance-related attention in male basketball players. *Medicine and Science in Sports and Exercise*, *39*(6), 976–983. https://doi.org/10.1097/mss.0b013e3180471ff2

Baker, L. B., Dougherty, K. A., Chow, M., & Kenney, W. L. (2007). Progressive dehydration causes a progressive decline in basketball skill performance. *Medicine and Science in Sports and Exercise*, *39*(7), 1114–1123. https://doi.org/10.1249/mss.0b013e3180574b02

Barrett, S., Midgley, A., & Lovell, R. (2014). PlayerLoadTM: reliability, convergent validity, and influence of unit position during treadmill running. *International Journal of Sports Physiology & Performance*, *9*(6).

Bartlett, J. D., O'Connor, F., Pitchford, N., Torres-Ronda, L., & Robertson, S. J. (2016). Relationships Between Internal and External Training Load in Team Sport Athletes: Evidence for an Individualised Approach. *International Journal of Sports Physiology and Performance*. https://doi.org/2015-0791 [pii]

Baxendale, P. M., Jacobs, H. S., & James, V. H. (1982). Salivary testosterone: relationship to unbound plasma testosterone in normal and hyperandrogenic women. *Clinical Endocrinology*, *16*(6), 595–603. https://doi.org/10.1111/j.1365-2265.1982.tb03176.x

Benedict, F. G., & Benedict, C. G. (1927). The Nature of the Insensible Perspiration. *Proceedings of the National Academy of Sciences of the United States of America*, *13*(6), 364–369. https://doi.org/10.1073/pnas.13.6.364

Benedict, F. G., & Root, H. F. (1926). Insensible Perspiration: Its Relation to Human

Physiology and Pathology. *Archives of Internal Medicine*, *38*(1), 1. https://doi.org/10.1001/archinte.1926.00120250006001

Berkelmans, D. M., Dalbo, V. J., Kean, C. O., Milanović, Z., Stojanović, E., Stojiljković, N., & Scanlan, A. T. (2018). Heart Rate Monitoring in Basketball: Applications, Player Responses, and Practical Recommendations. *Journal of Strength and Conditioning Research*, *32*(8), 2383–2399. https://doi.org/10.1519/JSC.0000000000002194

Bigland-Ritchie, B., & Woods, J. J. (1984). Changes in muscle contractile properties and neural control during human muscular fatigue. *Muscle & Nerve*, *7*(9), 691–699. https://doi.org/10.1002/mus.880070902

Bloom, S. R., Johnson, R. H., Park, D. M., Rennie, M. J., & Sulaiman, W. R. (1976). Differences in the metabolic and hormonal response to exercise between racing cyclists and untrained individuals. *The Journal of Physiology*, *258*(1), 1–18.

Boerio, D., Jubeau, M., Zory, R., & Maffiuletti, N. A. (2005). Central and peripheral fatigue after electrostimulation-induced resistance exercise. *Medicine and Science in Sports and Exercise*, *37*(6), 973–978. https://doi.org/10.1249/01.mss.0000166579.81052.9c

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring Athlete Training Loads: Consensus Statement. *International Journal of Sports Physiology and Performance*, *12*(Suppl 2), S2161–S2170. https://doi.org/10.1123/IJSPP.2017-0208

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *Int J Sports Physiol Perform*, *6*(3), 311–321.

Brisson, G. R., Volle, M. A., Tanaka, M., & Desharnais, M. (1977). A possible submaximal exercise-induced hypothalamo-hypophyseal stress. *Hormone and Metabolic Research = Hormon- Und Stoffwechselforschung = Hormones et Metabolisme*, *9*(6), 520. https://doi.org/10.1055/s-0028-1095581

Brownstein, C. G., Dent, J. P., Parker, P., Hicks, K. M., Howatson, G., Goodall, S., & Thomas, K. (2017). Etiology and recovery of neuromuscular fatigue following competitive soccer match-play. *Frontiers in Physiology*, *8*(OCT). https://doi.org/10.3389/fphys.2017.00831

Burnley, M. (2009). Estimation of critical torque using intermittent isometric maximal voluntary contractions of the quadriceps in humans. *Journal of Applied Physiology (Bethesda, Md. : 1985)*, *106*(3), 975–983. https://doi.org/10.1152/japplphysiol.91474.2008

Cairns, S P, Knicker, A. J., Thompson, M. W., & Sjøgaard, G. (2005). Evaluation of models used to study neuromuscular fatigue. *Exercise and Sport Sciences Reviews*, *33*(1), 9–16.

Cairns, Simeon P. (2013). Holistic approaches to understanding mechanisms of fatigue in high-intensity sport. *Fatigue: Biomedicine, Health & Behavior*, *1*(3), 148–167. https://doi.org/10.1080/21641846.2013.765086

Cairns, Simeon P, Knicker, A. J., Thompson, M. W., & Sjøgaard, G. (2005). Evaluation of models used to study neuromuscular fatigue. *Exercise and Sport Sciences Reviews*, *33*(1), 9–16.

Carling, C., Lacome, M., McCall, A., Dupont, G., Le Gall, F., Simpson, B., & Buchheit, M. (2018). Monitoring of Post-match Fatigue in Professional Soccer: Welcome to the Real World. *Sports Medicine*, 1–8. https://doi.org/10.1007/s40279-018-0935-z

Carlton, A., & Orr, R. M. (2015). The effects of fluid loss on physical performance: A critical review. *Journal of Sport and Health Science*, *4*(4), 357–363.

Casa, D. J., Armstrong, L. E., Hillman, S. K., Montain, S. J., Reiff, R. V, Rich, B. S., Roberts, W. O., & Stone, J. A. (2000). National athletic trainers' association position statement: fluid replacement for athletes. *Journal of Athletic Training*, *35*(2), 212–224. https://doi.org/10.4085/1062-6050-48.2.25

Casa, D. J., Stearns, R. L., Lopez, R. M., Ganio, M. S., McDermott, B. P., Yeargin, S. W., Yamamoto, L. M., Mazerolle, S. M., Roti, M. W., & Armstrong, L. E. (2010). Influence of hydration on physiological function and performance during trail running in the heat. *Journal of Athletic Training*, *45*(2), 147–156.

Casamichana, D., Castellano, J., Calleja-Gonzalez, J., San Roman, J., & Castagna, C. (2013). Relationship between indicators of training load in soccer players. *Journal of Strength and Conditioning Research*, *27*(2), 369–374. https://doi.org/10.1519/JSC.0b013e3182548af1

Casto, K. V., & Edwards, D. A. (2016a). Before, During, and After: How Phases of Competition Differentially Affect Testosterone, Cortisol, and Estradiol Levels in Women Athletes. *Adaptive Human Behavior and Physiology*, *2*(1), 11–25. https://doi.org/10.1007/s40750-015-0028-2

Casto, K. V., & Edwards, D. A. (2016b). Testosterone, cortisol, and human competition. *Hormones and Behavior, 82*, 21–37.

https://doi.org/10.1016/j.yhbeh.2016.04.004

Chambers, R., Gabbett, T. J., Cole, M. H., & Beard, A. (2015). The Use of Wearable Microsensors to Quantify Sport-Specific Movements. *Sports Medicine*, *45*(7), 1065–1081. https://doi.org/10.1007/s40279-015-0332-9

Chatzinikolaou, A., Draganidis, D., Avloniti, A., Karipidis, A., Jamurtas, A. Z., Skevaki, C. L., Tsoukas, D., Sovatzidis, A., Theodorou, A., Kambas, A., Papassotiriou, I., Taxildaris, K., & Fatouros, I. (2014). The microcycle of inflammation and performance changes after a basketball match. *Journal of Sports Sciences*, *32*(9), 870–882. https://doi.org/10.1080/02640414.2013.865251

Cheuvront, S. N., & Kenefick, R. W. (2014). Dehydration: Physiology, assessment, and performance effects. *Comprehensive Physiology*, *4*(1), 257–285. https://doi.org/10.1002/cphy.c130017

Cheuvront, S. N., Kenefick, R. W., Ely, B. R., Harman, E. A., Castellani, J. W., Frykman, P. N., Nindl, B. C., & Sawka, M. N. (2010). Hypohydration reduces vertical ground reaction impulse but not jump height. *European Journal of Applied Physiology*, *109*(6), 1163–1170. https://doi.org/10.1007/s00421-010-1458-y

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport*, *20*(4), 397–402. https://doi.org/10.1016/j.jsams.2016.08.011

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037//0033-2909.112.1.155

Cormack, S. J., Mooney, M., Morgan, W., & McGuigan, M. (2013). Influence of neuromuscular fatigue on accelerometer load in elite Australian football players. *International Journal of Sports Physiology and Performance*, *8*(4), 373–378. https://doi.org/10.1123/ijspp.8.4.373

Cormack, S. J., Newton, R., & McGuigan, M. (2008). Neuromuscular and endocrine responses of elite players to an Australian rules football match. *International Journal of Sports Physiology and Performance*, *3*(3), 359–374.

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Cormie, P. (2008). Neuromuscular and endocrine responses of elite players during an Australian rules football season. *International Journal of Sports Physiology and Performance*, *3*(4), 439–453. https://doi.org/10.1123/ijspp.3.3.359

Cormack, S. J., Newton, R. U., McGulgan, M. R., & Doyle, T. L. A. (2008). Reliability of measures obtained during single and repeated countermovement jumps. *International Journal of Sports Physiology and Performance*, *3*(2), 131–144. https://doi.org/10.1123/ijspp.3.2.131

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport*, *13*(1), 133–135. https://doi.org/10.1016/j.jsams.2008.09.015

Crewther, B. T., Hamilton, D., Casto, K. V., Kilduff, L. P., & Cook, C. J. (2015). Effects of oral contraceptive use on the salivary testosterone and cortisol responses to training sessions and competitions in elite women athletes. *Physiology and Behavior*, *147*, 84–90. https://doi.org/10.1016/j.physbeh.2015.04.017

Crewther, B. T., Lowe, T. E., Ingram, J., & Weatherby, R. P. (2010). Validating the salivary testosterone and cortisol concentration measures in response to short high-intensity exercise. *The Journal of Sports Medicine and Physical Fitness*, *50*(1), 85–92.

Cronin, J., & Hansen, K. (2005). Strength and power predictors of sport speed. *Journal of Strength and Conditioning Research*, *19*(2), 349–357. https://doi.org/10.1519/14323.1

Cruz, I. de F., Pereira, L. A., Kobal, R., Kitamura, K., Cedra, C., Loturco, I., & Cal Abad, C. C. (2018). Perceived training load and jumping responses following nine weeks of a competitive period in young female basketball players. *PeerJ*, *6*(July), e5225. https://doi.org/10.7717/peerj.5225

Cummins, C., Orr, R., O'Connor, H., & West, C. (2013). Global positioning systems (GPS) and microtechnology sensors in team sports: A systematic review. *Sports Medicine*, *43*(10), 1025–1042. https://doi.org/10.1007/s40279-013-0069-2

Davies, C., & Few, J. D. (1973). Effects of exercise on adrenocortical function. *Journal of Applied Physiology*, *35*(6), 887–891. https://doi.org/10.1152/jappl.1973.35.6.887

Davies, M., Young, W., Farrow, D., & Bahnert, A. (2013). Comparison of Small-sided Games on Agility Demands in Elite Australian Football. *International Journal of Sports Physiology and Performance*, *MARCH 2013*, 139–147. https://doi.org/10.1123/ijspp.8.2.139

de Hoyo, M., Cohen, D. D., Sañudo, B., Carrasco, L., Álvarez-Mesa, A., del Ojo, J. J., Domínguez-Cobo, S., Mañas, V., & Otero-Esquina, C. (2016). Influence of football match time–motion parameters on recovery time course of muscle damage and jump ability. *Journal of Sports Sciences*, *34*(14), 1363–1370.

https://doi.org/10.1080/02640414.2016.1150603

Dellaserra, C. L., Gao, Y., & Ransdell, L. B. (2014). Use of integrated technology in team sports: a review of opportunities, challenges, and future directions for athletes. *Journal of Strength and Conditioning Research*, *28*(2), 556–573. https://doi.org/10.1519/JSC.0b013e3182a952fb

Dousset, E., Avela, J., Ishikawa, M., Kallio, J., Kuitunen, S., Kyröláinen, H., Linnamo, V., & Komi, P. V. (2007). Bimodal recovery pattern in human skeletal muscle induced by exhaustive stretch-shortening cycle exercise. *Medicine and Science in Sports and Exercise*, *39*(3), 453–460. https://doi.org/10.1249/mss.0b013e31802dd74e

Drew, M. K., Raysmith, B. P., & Charlton, P. C. (2017). Injuries impair the chance of successful performance by sportspeople: A systematic review. *British Journal of Sports Medicine*, *51*(16), 1209–1214. https://doi.org/10.1136/bjsports-2016-096731

Dubois, R., Lyons, M., Paillard, T., Maurelli, O., & Prioux, J. (2018). Influence of Weekly Workload on Physical, Biochemical and Psychological Characteristics in Professional Rugby Union Players Over a Competitive Season. *Journal of Strength and Conditioning Research*, *00*(00), 1–19. https://doi.org/10.1519/JSC.0000000000002741

Duclos, M., Corcuff, J. B., Rashedi, M., Fougere, V., & Manier, G. (1996). Does functional alteration of the gonadotropic axis occur in endurance trained athletes during and after exercise? A preliminary study. *European Journal of Applied Physiology and Occupational Physiology*, *73*(5), 427–433.

https://doi.org/10.1007/bf00334419

Duffield, R., Reid, M., Baker, J., & Spratford, W. (2010). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of Science and Medicine in Sport*, *13*(5), 523–525. https://doi.org/10.1016/j.jsams.2009.07.003

Dunlop, G., Ardern, C. L., Andersen, T. E., Lewin, C., Dupont, G., Ashworth, B., O'Driscoll, G., Rolls, A., Brown, S., & McCall, A. (2019). Return-to-Play Practices Following Hamstring Injury: A Worldwide Survey of 131 Premier League Football Teams. *Sports Medicine*, *2*. https://doi.org/10.1007/s40279-019-01199-2

Ebben, W. P., Flanagan, E. P., & Jensen, R. L. (2007). Gender similarities in rate of force development and time to takeoff during the countermovement jump. *Journal of Exercise Physiology*, *10*(6), 10–17.

Edwards, D. A., & O'Neal, J. L. (2009). Oral contraceptives decrease saliva testosterone but do not affect the rise in testosterone associated with athletic competition. *Hormones and Behavior*, *56*(2), 195–198. https://doi.org/10.1016/j.yhbeh.2009.01.008

Edwards, D. A., WETZEL, K., & WYNER, D. (2006). Intercollegiate soccer: Saliva cortisol and testosterone are elevated during competition, and testosterone is related to status and social connectedness with teammates. *Physiology & Behavior*, *87*(1), 135–143. https://doi.org/10.1016/j.physbeh.2005.09.007

Edwards, R., Hill, D. K., Jones, D. A., & Merton, P. A. (1977). Fatigue of long duration in human skeletal muscle after exercise. *J Physiol*, *272*(3), 769–778.

https://doi.org/10.1113/jphysiol.1977.sp012072

Edwards, T., Spiteri, T., Piggott, B., Bonhotal, J., Haff, G. G., & Joyce, C. (2018a). Reliability and Sensitivity of Neuromuscular and Perceptual Fatigue Measures in Collegiate Men’s Basketball. *Journal of Strength and Conditioning Research*, *February*, 1. https://doi.org/10.1519/JSC.0000000000002517

Edwards, T., Spiteri, T., Piggott, B., Bonhotal, J., Haff, G. G., & Joyce, C. (2018b). Reliability and Sensitivity of Neuromuscular and Perceptual Fatigue Measures in Collegiate Men’s Basketball. *Journal of Strength and Conditioning Research*, 1. https://doi.org/10.1519/JSC.0000000000002517

Edwards, T., Spiteri, T., Piggott, B., Bonhotal, J., Haff, G. G., & Joyce, C. (2018c). Monitoring and Managing Fatigue in Basketball. *Sports*, *6*(1), 19. https://doi.org/10.3390/sports6010019

Elloumi, M., Maso, F., Michaux, O., Robert, A., & Lac, G. (2003). Behaviour of saliva cortisol [C], testosterone [T] and the T/C ratio during a rugby math and during the post-competition recovery days. *European Journal of Applied Physiology*, *90*(1–2), 23–28. https://doi.org/10.1007/s00421-003-0868-5

Enoka, R. (1995). Mechanisms of muscle fatigue: Central factors and task dependency. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *5*(3), 141–149. https://doi.org/10.1016/1050-6411(95)00010-W

Enoka, R., & Duchateau, J. (2008). Muscle fatigue: What, why and how it influences muscle function. *Journal of Physiology*, *586*(1), 11–23. https://doi.org/10.1113/jphysiol.2007.139477

Enoka, R., & Duchateau, J. (2016). Translating fatigue to human performance. *Medicine and Science in Sports and Exercise*, *48*(11), 2228–2238. https://doi.org/10.1249/MSS.0000000000000929

Enoka, R., & Stuart, D. (1992). Neurobiology of muscle fatigue. *Journal of Applied Physiology*, *72*(5), 1631–1648. https://doi.org/10.1152/jappl.1992.72.5.1631

Ferioli, D., Bosio, A., Bilsborough, J. C., Torre, A. La, Tornaghi, M., & Rampinini, E. (2018). The Preparation Period in Basketball: Training Load and Neuromuscular Adaptations. *International Journal of Sports Physiology and Performance*, *January*, 1–28. https://doi.org/10.1123/ijspp.2017-0434

Filaire, E., Bernain, X., Sagnol, M., & Lac, G. (2001). Preliminary results on mood state, salivary testosterone: Cortisol ratio and team performance in a professional soccer team. *European Journal of Applied Physiology*, *86*(2), 179–184. https://doi.org/10.1007/s004210100512

Filaire, E., Le Scanff, C., Duché, P., & Lac, G. (1999). The relationship between salivary adrenocortical hormones changes and personality in Elite female athletes during handball and volleyball competition. *Research Quarterly for Exercise and Sport*, *70*(3), 297–302. https://doi.org/10.1080/02701367.1999.10608048

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A New Approach to Monitoring Exercise Training. *Journal of Strength and Conditioning Research*, *15*(1), 109–115. https://doi.org/10.1519/1533-4287(2001)015<0109:ANATME>2.0.CO;2

Fowles, J. R. (2006a). Technical issues in quantifying low-frequency fatigue in athletes. *International Journal of Sports Physiology and Performance*, *1*(2), 169–171.

Fowles, J. R. (2006b). Technical issues in quantifying low-frequency fatigue in athletes. *International Journal of Sports Physiology and Performance*, *1*(2), 169–171. https://doi.org/10.1123/ijspp.1.2.169

Fox, J. L., Scanlan, A. T., & Stanton, R. (2017). A Review of Player Monitoring Approaches in Basketball: Current Trends and Future Directions. *Journal of Strength and Conditioning Research*, *31*(7), 2021–2029. https://doi.org/10.1519/JSC.0000000000001964

Fox, J. L., Stanton, R., & Scanlan, A. T. (2018). A Comparison of Training and Competition Demands in Semiprofessional Male Basketball Players. *Research Quarterly for Exercise and Sport*, *89*(1), 103–111. https://doi.org/10.1080/02701367.2017.1410693

Fry, A. C., & Kraemer, W. J. (1997). Resistance exercise overtraining and overreaching. Neuroendocrine responses. *Sports Medicine (Auckland, N.Z.)*, *23*(2), 106–129.

Gabbett, T. J. (2015). Relationship Between Accelerometer Load, Collisions, and Repeated High-Intensity Effort Activity in Rugby League Players. *Journal of Strength and Conditioning Research*, *29*(12), 3424–3431. https://doi.org/10.1519/JSC.0000000000001017

Galbo, H., Hummer, L., Peterson, I. B., Christensen, N. J., & Bie, N. (1977). Thyroid and testicular hormone responses to graded and prolonged exercise in man. *European Journal of Applied Physiology and Occupational Physiology*, *36*(2), 101–106.

Gallo, T., Cormack, S. J., Gabbett, T. J., Williams, M., & Lorenzen, C. (2015).

Characteristics impacting on session rating of perceived exertion training load in Australian footballers. *Journal of Sports Sciences*, *33*(5), 467–475. https://doi.org/10.1080/02640414.2014.947311

Gandevia, S. C. (2001). Spinal and Supraspinal Factors in Human Muscle Fatigue. *Physiological Reviews*, *81*(4), 1725–1789. https://doi.org/10.1152/physrev.2001.81.4.1725

Ganio, M. S., Wingo, J. E., Carroll, C. E., Thomas, M. K., & Cureton, K. J. (2006). Fluid ingestion attenuates the decline in V̇O2peak associated with cardiovascular drift. *Medicine and Science in Sports and Exercise*, *38*(5), 901–909. https://doi.org/10.1249/01.mss.0000218127.14107.08

Gann, J. J., Green, J. M., O'Neal, E. K., Renfroe, L. G., & Andre, T. L. (2016). Effects of Hypohydration on Repeated 40-yd Sprint Performance. *Journal of Strength and Conditioning Research*, *30*(4), 901–909. https://doi.org/10.1519/JSC.0000000000001177

Gathercole, R., Sporer, B., & Stellingwerff, T. (2015). Countermovement Jump Performance with Increased Training Loads in Elite Female Rugby Athletes. *International Journal of Sports Medicine*, *36*(09), 722–728. https://doi.org/10.1055/s-0035-1547262

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015a). Alternative Countermovement-Jump Analysis to Quantify Acute Neuromuscular Fatigue. *International Journal of Sports Physiology and Performance*, *10*(1), 84–92. https://doi.org/10.1123/ijspp.2013-0413

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015b). Comparison of the

Capacity of Different Jump and Sprint Field Tests to Detect Neuromuscular Fatigue. *Journal of Strength and Conditioning Research*, *29*(9), 2522–2531. https://doi.org/10.1519/JSC.0000000000000912

Gathercole, R., Stellingwerff, T., & Sporer, B. (2015). Effect of Acute Fatigue and Training Adaptation on Countermovement Jump Performance in Elite Snowboard Cross Athletes. *Journal of Strength and Conditioning Research*, *29*(1), 37–46. https://doi.org/10.1519/JSC.0000000000000622

Gatti, R., & De Palo, E. F. (2011). An update: salivary hormones and physical exercise. *Scandinavian Journal of Medicine & Science in Sports*, *21*(2), 157–169. https://doi.org/10.1111/j.1600-0838.2010.01252.x

Glencross, D. J. (1966). The nature of the vertical jump test and the standing broad jump. *Research Quarterly of the American Association for Health, Physical Education and Recreation*, *37*(3), 353–359. https://doi.org/10.1080/10671188.1966.10614761

Gollhofer, A., Komi, P. V., Miyashita, M., & Aura, O. (1987). Fatigue during stretch-shortening cycle exercises: changes in mechanical performance of human skeletal muscle. *Int J Sports Med*, *8*(2), 71–78. https://doi.org/10.1055/s-2008-1025644

Gonzalez-Bono, E., Salvador, A., Serrano, M., & Ricarte, J. (1999). Testosterone, cortisol, and mood in a sports team competition. *Hormones and Behavior*, *35*(1), 55–62. https://doi.org/10.1006/hbeh.1998.1496

Gozansky, W. S., Lynn, J. S., Laudenslager, M. L., & Kohrt, W. M. (2005). Salivary cortisol determined by enzyme immunoassay is preferable to serum total cortisol for assessment of dynamic hypothalamic--pituitary--adrenal axis activity. *Clinical*

Endocrinology, *63*(3), 336–341. https://doi.org/10.1111/j.1365-2265.2005.02349.x

Granger, D. A., Weisz, J. R., McCracken, J. T., Kauneckis, D., & Ikeda, S. (2005). Testosterone and conduct problems. *Journal of the American Academy of Child and Adolescent Psychiatry, 33*(6), 908. https://doi.org/10.1097/00004583-199407000-00020

Gruet, M., Temesi, J., Rupp, T., Levy, P., Verges, S., & Millet, G. (2014). Dynamics of corticospinal changes during and after high-intensity quadriceps exercise. *Experimental Physiology*, *99*(8), 1053–1064. https://doi.org/10.1113/expphysiol.2014.078840

Guglielmini, C., Paolini, A., & Conconi, F. (1984). Variations of Serum Testosterone Concentrations after Physical Exercises of Different Duration. *International Journal of Sports Medicine*, *05*(05), 246–249. https://doi.org/10.1055/s-2008-1025914

Hackney, A. (1989). Endurance training and testosterone levels. *Sports Medicine*, *8*(2), 117–127.

Hackney, A. (2006). Stress and the neuroendocrine system: the role of exercise as a stressor and modifier of stress. *Expert Review of Endocrinology & Metabolism*, *1*(6), 783–792. https://doi.org/10.1586/17446651.1.6.783

Hackney, A., & Lane, A. (2015). Exercise and the Regulation of Endocrine Hormones. In *Progress in Molecular Biology and Translational Science* (1st ed., Vol. 135). Elsevier Inc. https://doi.org/10.1016/bs.pmbts.2015.07.001

Haddad, M., Stylianides, G., Djaoui, L., Dellal, A., & Chamari, K. (2017). Session-RPE method for training load monitoring: Validity, ecological usefulness, and influencing factors. *Frontiers in Neuroscience*, *11*(NOV), 612. https://doi.org/10.3389/fnins.2017.00612

Haff, G. G., & Triplett, N. (2015). *Essentials of strength tranining and conditioning* (4th ed.).

Hägglund, M., Waldén, M., Magnusson, H., Kristenson, K., Bengtsson, H., & Ekstrand, J. (2013). Injuries affect team performance negatively in professional football: An 11-year follow-up of the UEFA Champions League injury study. *British Journal of Sports Medicine*, *47*(12), 738–742. https://doi.org/10.1136/bjsports-2013-092215

Häkkinen, K., Pakarinen, A., Alén, M., Kauhanen, H., & Komi, P. V. (1988). Neuromuscular and hormonal responses in elite athletes to two successive strength training sessions in one day. *European Journal of Applied Physiology and Occupational Physiology*, *57*(2), 133–139. https://doi.org/10.1152/jappl.1988.65.6.2406

Häkkinen, K., Pakarinen, A., Kyröläinen, H., Cheng, S., Kim, D., & Komi, P. V. (1990). Neuromuscular adaptations and serum hormones in females during prolonged power training. *International Journal of Sports Medicine*, *11*(2), 91–98. https://doi.org/10.1055/s-2007-1024769

Häkkinen, K., Pakarinen, A., Newton, R. U., & Kraemer, W. J. (1998). Acute hormone responses to heavy resistance lower and upper extremity exercise in young versus old men. *European Journal of Applied Physiology and Occupational Physiology*, *77*(4), 312–319. https://doi.org/10.1007/s004210050339

Halson, S. L. (2014). Monitoring Training Load to Understand Fatigue in Athletes. *Sports Medicine*, *44*(S2), 139–147. https://doi.org/10.1007/s40279-014-0253-z

Halson, S. L., & Jeukendrup, A. (2004). Does overtraining exist? An analysis of overreaching and overtraining research. *Sports Medicine*, *34*(14), 967–981. https://doi.org/10.2165/00007256-200434140-00003

Hamouti, N., Coso, J. Del, Estevez, E., & Mora-Rodriguez, R. (2010). Dehydration and sodium deficit during indoor practice in elite European male team players. *European Journal of Sport Science*, *10*(5), 329–336.

Hamouti, N., Coso, J. Del, Ortega, J. F., & Mora-Rodriguez, R. (2011). Sweat sodium concentration during exercise in the heat in aerobically trained and untrained humans. *European Journal of Applied Physiology*, *111*(11), 2873–2881. https://doi.org/10.1007/s00421-011-1911-6

Haneishi, K., Fry, A. C., Moore, C. A., Schilling, B. K., Li, Y., & Fry, M. D. (2007). Cortisol and stress responses during a game and practice in female collegiate soccer players. *Journal of Strength and Conditioning Research*, *21*(2), 583–588. https://doi.org/10.1519/R-20496.1

Hara, M., Shibayama, A., Takeshita, D., Hay, D. C., & Fukashiro, S. (2008). A comparison of the mechanical effect of arm swing and countermovement on the lower extremities in vertical jumping. *Human Movement Science*, *27*(4), 636–648. https://doi.org/10.1016/j.humov.2008.04.001

Hargreaves, M. (2008). Fatigue mechanisms determining exercise performance: integrative physiology is systems biology. *Journal of Applied Physiology*, *104*(5), 1541–1542. https://doi.org/10.1152/japplphysiol.00088.2008

Hayes, L. D., Bickerstaff, G. F., & Baker, J. S. (2010). Interactions of cortisol, testosterone, and resistance training: Influence of circadian rhythms.

Chronobiology International, *27*(4), 675–705. https://doi.org/10.3109/07420521003778773

He, C. S., Tsai, M. L., Ko, M. H., Chang, C. K., & Fang, S. H. (2010). Relationships among salivary immunoglobulin A, lactoferrin and cortisol in basketball players during a basketball season. *European Journal of Applied Physiology*, *110*(5), 989–995. https://doi.org/10.1007/s00421-010-1574-8

Heishman, A. D., Brown, B. S., Daub, B. D., Miller, R. M., Freitas, E. D. S., & Bemben, M. G. (2019). The Influence of Countermovement Jump Protocol on Reactive Strength Index Modified and Flight Time: Contraction Time in Collegiate Basketball Players. *Sports*, *7*(2), 37. https://doi.org/10.3390/sports7020037

Heishman, A. D., Curtis, M. A., Saliba, E., Hornett, R. J., Malin, S. K., & Weltman, A. L. (2018). Noninvasive Assessment of Internal and External Player Load: Implications for Optimizing Athletic Performance. *Journal of Strength and Conditioning Research*, *32*(5), 1280–1287. https://doi.org/10.1519/JSC.0000000000002413

Heishman, A. D., Curtis, M. A., Saliba, E. N., Hornett, R. J., Malin, S. K., & Weltman, A. L. (2017). Comparing performance during morning vs. afternoon training sessions in intercollediate basketball players. *Journal of Strength and Conditioning Research*, *31*(6), 1557–1562. https://doi.org/10.1519/JSC.0000000000001882

Heishman, A. D., Daub, B. D., Miller, R. M., Brown, B. S., Freitas, E. D. S., & Bemben, M. G. (2019). Countermovement Jump Inter-Limb Asymmetries in Collegiate Basketball Players. *Sports (Basel, Switzerland)*, *7*(5), 1–15. https://doi.org/10.3390/sports7050103

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., & Bemben, M. G. (2018). Longitudinal Hydration Assessment in Collegiate Basketball Players Over Various Training Phases. *Journal of Strength and Conditioning Research*, *00*(00), 1–6. https://doi.org/10.1519/JSC.0000000000002845

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., & Bemben, M. G. (2020). Monitoring External Training Loads and Neuromuscular Performance for Division I Basketball Players over the Preseason. *Journal of Sports Science & Medicine*, *19*(1), 204–212.

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., Frantz, B. A., & Bemben, M. G. (2020). Countermovement Jump Reliability Performed With and Without an Arm Swing in NCAA Division 1 Intercollegiate Basketball Players. *Journal of Strength and Conditioning Research*, *34*(2), 546–558. https://doi.org/10.1519/JSC.0000000000002812

Heishman, A. D., Peak, K., Miller, R. M., Brown, B. S., Daub, B. D., Freitas, E. D. S., & Bemben, M. G. (2020). Associations Between Two Athlete Monitoring Systems Used to Quantify External Training Loads in Basketball Players. *Sports (Basel, Switzerland)*, *8*(3), 204–212. https://doi.org/10.3390/sports8030033

Hill-Haas, S., Dawson, B., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small sided-games training in football: A systematic review. *Sports Med*, *41*(3), 199–220. https://doi.org/10.2165/11539740-000000000-00000

Hill, E. E., Zack, E., Battaglini, C., Viru, M., Viru, A., & Hackney, A. (2008). Exercise and circulating Cortisol levels: The intensity threshold effect. *Journal of Endocrinological Investigation*, *31*(7), 587–591.

https://doi.org/10.1007/BF03345606

Hoffman, J. R., Epstein, S., Yarom, Y., Zigel, L., & Einbinder, M. (1999). Hormonal and Biochemical Changes in Elite Basketball Players during a 4-Week Training Camp. *Journal of Strength and Conditioning Research*, *13*(3), 280–285. https://doi.org/10.1519/1533-4287(1999)013<0280:HABCIE>2.0.CO;2

Hoffman, J. R., Kang, J., Ratamess, N. A., & Faigenbaum, A. D. (2005). Biochemical and hormonal responses during an intercollegiate football season. *Medicine and Science in Sports and Exercise*, *37*(7), 1237–1241. https://doi.org/10.1249/01.mss.0000170068.97498.26

Hoffman, J. R., Maresh, C. M., Newton, R. U., Rubin, M. R., French, D. N., Volek, J. S., Sutherland, J., Robertson, M., Gómez, A. L., Ratamess, N. A., Kang, J., & Kraemer, W. J. (2002). Performance, biochemical, and endocrine changes during a competitive football game. *Medicine and Science in Sports and Exercise*, *34*(11), 1845–1853. https://doi.org/10.1097/00005768-200211000-00023

Hoffman, J. R., Nusse, V., & Kang, J. (2003). The Effect of an Intercollegiate Soccer Game on Maximal Power Performance. *Canadian Journal of Applied Physiology*, *28*(6), 807–817. https://doi.org/10.1139/h03-060

Hoffman, J. R., Williams, D., Emerson, N., Hoffman, M., Wells, A., McVeigh, D., McCormack, W., Mangine, G., Gonzalez, A., & Fragala, M. (2012). L-alanyl-L-glutamine ingestion maintains performance during a competitive basketball game. *Journal of the International Society of Sports Nutrition, 9*, 1–8. https://doi.org/10.1186/1550-2783-9-4

Holme, B. (2015). *Wearable microsensor technology to measure physical activity* *demands in handball*. Norwegian School of Sport Sciences, Olso.

Howe, S. T., Aughey, R. J., Hopkins, W. G., Stewart, A. M., & Cavanagh, B. P. (2017). Quantifying important differences in athlete movement during collision-based team sports: Accelerometers outperform Global Positioning Systems. *4th IEEE International Symposium on Inertial Sensors and Systems, INERTIAL 2017 - Proceedings*, 1–4. https://doi.org/10.1109/ISISS.2017.7935655

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine and Science in Sports and Exercise*, *36*(6), 1042–1047. https://doi.org/10.1249/01.MSS.0000128199.23901.2F

Jacobsson, J., & Timpka, T. (2015). Classification of Prevention in Sports Medicine and Epidemiology. *Sports Medicine*, *45*(11), 1483–1487. https://doi.org/10.1007/s40279-015-0368-x

Jennings, D., Cormack, S. J., Coutts, A. J., Boyd, L. J., & Aughey, R. J. (2010). The validity and reliability of GPS units in team sport specific running patterns. *International Journal of Sports Physiology and Performance*, *5*(3), 328–341. https://doi.org/10.1249/MSS.0b013e3181ef9d6b.10.

Johnson, S. G., Joplin, G. F., & Burrin, J. M. (1987). Direct assay for testosterone in saliva: Relationship with a direct serum free testosterone assay. *Clinica Chimica Acta*, *163*(3), 309–318. https://doi.org/10.1016/0009-8981(87)90249-X

Johnston, R. D., Gibson, N. V, Twist, C., Gabbett, T. J., MacNay, S. A., & MacFarlane, N. G. (2013). Physiological responses to an intensified period of rugby league competition. *Journal of Strength and Conditioning Research*, *27*(3), 643–654.

https://doi.org/10.1519/JSC.0b013e31825bb469

Jones, D. (1996). High- and low-frequency fatigue revisited. *Acta Physiologica Scandinavica*, *156*(3), 265–270. https://doi.org/10.1046/j.1365-201X.1996.192000.x

Judelson, D. A., Maresh, C. M., Farrell, M. J., Yamamoto, L. M., Armstrong, L. E., Kraemer, W. J., Volek, J. S., Spiering, B. A., Casa, D. J., & Anderson, J. M. (2007). Effect of hydration state on strength, power, and resistance exercise performance. *Medicine and Science in Sports and Exercise*, *39*(10), 1817–1824. https://doi.org/10.1249/mss.0b013e3180de5f22

Keeton, R. B., & Binder-Macleod, S. A. (2006). Low-frequency fatigue. *Physical Therapy*, *86*(8), 1146–1150. https://doi.org/https://doi.org/10.1093/ptj/86.8.1146

Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scandinavian Journal of Medicine and Science in Sports*, *20*(SUPPL. 2), 95–102. https://doi.org/10.1111/j.1600-0838.2010.01192.x

Kellmann, Michael, Bertollo, M., Bosquet, L., Brink, M., Coutts, A. J., Duffield, R., Erlacher, D., Halson, S. L., Hecksteden, A., Heidari, J., Wolfgang Kallus, K., Meeusen, R., Mujika, I., Robazza, C., Skorski, S., Venter, R., & Beckmann, J. (2018). Recovery and performance in sport: {Consensus} statement. *International Journal of Sports Physiology and Performance*, *13*(2), 240–245. https://doi.org/10.1123/ijspp.2017-0759

Kennedy, R. A., & Drake, D. (2017). The effect of acute fatigue on countermovement jump performance in rugby union players during preseason. *The Journal of Sports Medicine and Physical Fitness*, *57*(10), 1261.

Kent-Braun, J. A. (1999). Central and peripheral contributions to muscle fatigue in humans during sustained maximal effort. *European Journal of Applied Physiology and Occupational Physiology*, *80*(1), 57–63.

Kent-Braun, J. A., Fitts, R. H., & Christie, A. (2012). Skeletal muscle fatigue. *Comprehensive Physiology*, *2*(2), 997–1044. https://doi.org/10.1002/cphy.c110029

Kent-Braun, J. A., Ng, A., Doyle, J., & Towse, T. (2002a). Human skeletal muscle responses vary with age and gender during fatigue due to incremental isometric exercise. *Journal of Applied Physiology*, *93*, 1813–1823.

Kent-Braun, J. A., Ng, A. V., Doyle, J. W., & Towse, T. F. (2002b). Human skeletal muscle responses vary with age and gender during fatigue due to incremental isometric exercise. *Journal of Applied Physiology*, *93*(5), 1813–1823. https://doi.org/10.1152/japplphysiol.00091.2002

Kent-Braun, J. A., & Ng, A. V. (1999). Specific strength and voluntary muscle activation in young and elderly women and men. *Journal of Applied Physiology (Bethesda, Md. : 1985)*, *87*(1), 22–29. https://doi.org/10.1152/jappl.1999.87.1.22

Kindermann, W., Schnabel, A., Schmitt, W. M., Biro, G., Cassens, J., & Weber, F. (1982). Catecholamines, growth hormone, cortisol, insulin, and sex hormones in anaerobic and aerobic exercise. *European Journal of Applied Physiology and Occupational Physiology*, *49*(3), 389–399.

Kipp, K., Kiely, M. T., & Geiser, C. F. (2016). Reactive strength index modified is a valid measure of explosiveness in collegiate female volleyball players. *Journal of Strength and Conditioning Research*, *30*(5), 1341–1347. https://doi.org/10.1519/JSC.0000000000001226

Kivlighan, K. T., Granger, D. A., & Booth, A. (2005). Gender differences in testosterone and cortisol response to competition. *Psychoneuroendocrinology*, *30*(1), 58–71. https://doi.org/10.1016/j.psyneuen.2004.05.009

Klavora, P. (2000). Vertical-jump tests: A critical review. *Strength and Conditioning Journal*, *22*(5), 70–75.

Kluger, B. M., Krupp, L. B., & Enoka, R. (2013). Fatigue and fatigability in neurologic inllnesses. *Neurology*, *80*, 409–416.

Knicker, A., Renshaw, I., Oldham, A., & Cairns, S. (2011). Interactive processes link the multiple symptoms of fatigue in sport competition. *Sports Medicine*, *41*(4), 307–328. https://doi.org/10.2165/11586070-000000000-00000

Komi, P. V. (1984). Physiological and biomechanical correlates of muscle function: effects of muscle structure and stretch-shortening cycle on force and speed. *Exercise and Sport Sciences Reviews*, *12*, 81–121.

Komi, P. V. (2000). Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *Journal of Biomechanics*, *33*(10), 1197–1206.

Kraemer, W. J., Looney, D. P., Martin, G. J., Ratamess, N. A., Vingren, J. L., French, D. N., Hatfield, D. L., Fragala, M. S., Spiering, B. A., Howard, R. L., Cortis, C., Szivak, T. K., Comstock, B. A., Dunn-Lewis, C., Hooper, D. R., Flanagan, S. D., Volek, J. S., Anderson, J. M., Maresh, C. M., & Fleck, S. J. (2013). Changes in creatine kinase and cortisol in National Collegiate Athletic Association Division I American football players during a season. *Journal of Strength and Conditioning Research*, *27*(2), 434–441. https://doi.org/10.1519/JSC.0b013e318281d1b0

Kraemer, W. J., Marchitelli, L., Gordon, S. E., Harman, E., Dziados, J. E., Mello, R., Frykman, P., McCurry, D., & Fleck, S. J. (1990). Hormonal and growth factor responses to heavy resistance exercise protocols. *Journal of Applied Physiology (Bethesda, Md. : 1985)*, *69*(4), 1442–1450. https://doi.org/10.1152/jappl.1990.69.4.1442

Kraemer, W. J., & Ratamess, N. A. (2005). Hormonal Responses and Adaptations to Resistance Exercise and Training. *Sports Medicine*, *35*(4), 339–361. https://doi.org/10.2165/00007256-200535040-00004

Kraemer, W. J., Spiering, B. A., Volek, J. S., Martin, G. J., Howard, R. L., Ratamess, N. A., Hatfield, D. L., Vingren, J. L., Ho, J. Y., Fragala, M. S., Thomas, G. A., French, D. N., Anderson, J. M., Häkkinen, K., & Maresh, C. M. (2009). Recovery from a national collegiate athletic association division I football game: muscle damage and hormonal status. *Journal of Strength and Conditioning Research*, *23*(1), 2–10. https://doi.org/10.1519/JSC.0b013e31819306f2

Kraemer, W. J., Staron, R. S., Hagerman, F. C., Hikida, R. S., Fry, A. C., Gordon, S. E., Nindl, B. C., Gothshalk, L. a, Volek, J. S., Marx, J. O., Newton, R. U., & Häkkinen, K. (1998). The effects of short-term resistance training on endocrine function in men and women. *European Journal of Applied Physiology and Occupational Physiology*, *78*(1), 69–76. https://doi.org/10.1007/s004210050389

Laffaye, G., Wagner, P. P., & Tombleson, T. I. L. (2014). Countermovement jump height: gender and sport-specific differences in the force-time variables. *Journal of Strength and Conditioning Research*, *28*(4), 1096–1105. https://doi.org/10.1519/JSC.0b013e3182a1db03

Lattier, G., Millet, G. Y., Martin, A., & Martin, V. (2004). Fatigue and recovery after high-intensity exercise part I: neuromuscular fatigue. *International Journal of Sports Medicine*, *25*(6), 450–456.

Linthorne, N. P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics*, *69*(11), 1198–1204. https://doi.org/10.1119/1.1397460

Luinge, H. J., & Veltink, P. H. (2005). Measuring orientation of human body segments using miniature gyroscopes and accelerometers. *Medical and Biological Engineering and Computing*, *43*(2), 273–282. https://doi.org/10.1007/BF02345966

Luteberget, L. S., & Spencer, M. (2017). High-Intensity Events in International Women's Team Handball Matches. *International Journal of Sports Physiology and Performance*, *12*(1), 56–61. https://doi.org/10.1123/ijspp.2015-0641

Macintosh, B. R., & Rassier, D. E. (2002). What Is Fatigue? *Canadian Journal of Applied Physiology*, *27*(1), 42–55. https://doi.org/10.1139/h02-003

MacLeod, H., & Sunderland, C. (2012). Previous-day hypohydration impairs skill performance in elite female field hockey players. *Scandinavian Journal of Medicine and Science in Sports*, *22*(3), 430–438. https://doi.org/10.1111/j.1600-0838.2010.01230.x

Malone, J. J., Lovell, R., Varley, M. C., & Coutts, A. J. (2017). Unpacking the Black Box: Applications and Considerations for Using GPS Devices in Sport. *International Journal of Sports Physiology and Performance*, *12*(Suppl 2), S218–S226. https://doi.org/10.1123/ijspp.2016-0236

Martin, V., Millet, G. Y., Martin, A., Deley, G., & Lattier, G. (2004). Assessment of low-frequency fatigue with two methods of electrical stimulation. *J Appl Physiol*, *97*, 1923–1929. https://doi.org/10.1152/japplphysiol.00376.2004.

Martínez, A. C., Seco Calvo, J., Tur Marí, J. A., Abecia Inchaurregui, L. C., Orella, E. E., & Biescas, A. P. (2010). Testosterone and cortisol changes in professional basketball players through a season competition. *Journal of Strength and Conditioning Research*, *24*(4), 1102–1108. https://doi.org/10.1519/JSC.0b013e3181ce2423

Martinez, D. B. (2016). The use of Reactive Strength Index, Reactive Strength Index Modified, and flight time:contraction time as monitoring tools. *Journal of Australian Strength and Conditioning*, *24*(5), 37–41.

Maughan, R. J., & Shirreffs, S. M. (2010). Dehydration and rehydration in competitive sport. *Scandinavian Journal of Medicine & Science in Sports*, *20 Suppl 3*, 40–47. https://doi.org/10.1111/j.1600-0838.2010.01207.x

McDermott, B. P., Anderson, S. A., Armstrong, L. E., Casa, D. J., Cheuvront, S. N., Cooper, L., Kenney, W. L., O’Connor, F. G., & Roberts, W. O. (2017). National Athletic Trainers’ Association Position Statement: Fluid Replacement for the Physically Active. *Journal of Athletic Training*, *52*(9), 877–895.

McLaren, S. J., Macpherson, T. W., Coutts, A. J., Hurst, C., Spears, I. R., & Weston, M. (2018). The Relationships Between Internal and External Measures of Training Load and Intensity in Team Sports: A Meta-Analysis. *Sports Medicine (Auckland, N.Z.)*, *48*(3), 641–658. https://doi.org/10.1007/s40279-017-0830-z

McLaren, S. J., Weston, M., Smith, A., Cramb, R., & Portas, M. D. (2016). Variability of physical performance and player match loads in professional rugby union. *Journal of Science and Medicine in Sport*, *19*(6), 493–497.

https://doi.org/10.1016/j.jsams.2015.05.010

McLean, B. D., Coutts, A. J., Kelly, V., McGuigan, M. R., & Cormack, S. J. (2010). Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance*, *5*(3), 367–383.

McLean, B. D., Cummins, C., Conlan, G., Duthie, G., & Coutts, A. J. (2018). The Fit Matters: Influence of Accelerometer Fitting and Training Drill Demands on Load Measures in Rugby League Players. *International Journal of Sports Physiology and Performance*, *Epub*(Epub), 1–24. https://doi.org/10.1123/ijspp.2017-0729

Mclellan, C. P., Lovell, D. I., & Gass, G. C. (2011). The role of rate of force development on vertical jump performance. *Journal of Strength and Conditioning Research*, *25*(2), 379–385. https://doi.org/10.1519/JSC.0b013e3181be305c

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2010). Creatine kinase and endocrine responses of elite players pre, during, and post rugby league match play. *Journal of Strength and Conditioning Research*, *24*(11), 2908–2919. https://doi.org/10.1519/JSC.0b013e3181c1fcb1

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). Markers of postmatch fatigue in professional Rugby League players. *Journal of Strength and Conditioning Research*, *25*(4), 1030–1039. https://doi.org/10.1519/JSC.0b013e3181cc22cc

McMahon, J. J., Comfort, P., & Pearson, S. (2012). Lower limb stiffness: Considerations for female athletes. *Strength and Conditioning Journal*, *34*(5), 70–73. https://doi.org/10.1519/SSC.0b013e318268131f

McMahon, J. J., Rej, S., & Comfort, P. (2017). Sex Differences in Countermovement

Jump Phase Characteristics. *Sports*, *5*(1), 8. https://doi.org/10.3390/sports5010008

McMahon, J. J., Suchomel, T. J., Lake, J. P., & Comfort, P. (2018). Understanding the Key Phases of the Countermovement Jump Force-Time Curve. *Strength and Conditioning Journal*, *January*, 1. https://doi.org/10.1519/SSC.0000000000000375

Meeusen, R., Piacentini, M. F., Busschaert, B., Buyse, L., De Schutter, G., & Stray-Gundersen, J. (2004). Hormonal responses in athletes: The use of a two bout exercise protocol to detect subtle differences in (over)training status. *European Journal of Applied Physiology*, *91*(2–3), 140–146. https://doi.org/10.1007/s00421-003-0940-1

Mendez-Villanueva, A., Fernandez-Fernandez, J., & Bishop, D. (2007). Exercise-induced homeostatic perturbations provoked by singles tennis match play with reference to development of fatigue. *British Journal of Sports Medicine*, *41*(11), 717–722. https://doi.org/10.1136/bjsm.2007.037259

Merton, P. (1954). Voluntary strength and fatigue. *The Journal of Physiology*, *123*(3), 553–564.

Messersmith, L. L., & Bucher, C. C. (1939). The distance traversed by big ten basketball players. *Research Quarterly of the American Association for Health, Physical Education and Recreation*, *10*(3), 61–62. https://doi.org/10.1080/10671188.1939.10622495

Meylan, C., Trewin, J., & McKean, K. (2017). Quantifying Explosive Actions in International Women's Soccer. *International Journal of Sports Physiology and Performance*, *12*(3), 310–315. https://doi.org/10.1123/ijspp.2015-0520

Minshull, C., & James, L. (2013). The effects of hypohydration and fatigue on neuromuscular activation performance. *Applied Physiology, Nutrition, and Metabolism*, *38*(1), 21–26. https://doi.org/10.1139/apnm-2012-0189

Minton, D. M., O'Neal, E. K., & Torres-McGehee, T. M. (2015). Agreement of urine specific gravity measurements between manual and digital refractometers. *Journal of Athletic Training*, *50*(1), 59–64.

Montgomery, P. G., Pyne, D. B., & Minahan, C. L. (2010a). The Physical and Physiological Demands of Basketball Training and Competition. *International Journal of Sports Physiology and Performance*, *5*, 75–86. https://doi.org/10.1123/ijspp.5.1.75

Montgomery, P. G., Pyne, D. B., & Minahan, C. L. (2010b). The Physical and Physiological Demands of Basketball Training and Competition. *International Journal of Sports Physiology and Performance*, *5*(1), 75–86. https://doi.org/10.1123/ijspp.5.1.75

Mooney, M., Cormack, S. J., O'Brien, B. J., Morgan, W. M., & McGuigan, M. (2013). Impact of neuromuscular fatigue on match exercise intensity and performance in elite Australian football. *J Strength Cond Res*, *27*(1), 166–173. https://doi.org/10.1519/JSC.0b013e3182514683 10.1519/JSC.0b013e3182514683.

Moore, C. A., & Fry, A. C. (2007). Nonfunctional overreaching during off-season training for skill position players in collegiate American football. *Journal of Strength and Conditioning Research*, *21*(3), 793–800. https://doi.org/10.1519/R-20906.1

Moreira, A., Arsati, F., de Oliveira Lima Arsati, Y. B., da Silva, D. A., & de Araújo, V. C. (2009). Salivary cortisol in top-level professional soccer players. *European*

Journal of Applied Physiology, *106*(1), 25–30. https://doi.org/10.1007/s00421-009-0984-y

Moreira, A., Crewther, B. T., Freitas, C. G., Arruda, A. F. S., Costa, E. C., & Aoki, M. S. (2012). Session RPE and salivary immune-endocrine responses to simulated and official basketball matches in elite young male athletes. *The Journal of Sports Medicine and Physical Fitness*, *52*(6), 682–687.

Moreira, A., Nosaka, K., Nunes, J. A., Viveiros, L., Jamurtas, A. Z., & Aoki, M. S. (2014). Changes in muscle damage markers in female basketball players. *Biology of Sport*, *31*(1), 3–7. https://doi.org/10.5604/20831862.1083272

Morton, R. H., Fitz-Clarke, J. R., & Banister, E. W. (1990). Modeling human performance in running. *Journal of Applied Physiology (Bethesda, Md. : 1985)*, *69*(3), 1171–1177.

Murray, R. (1996). Dehydration, hyperthermia, and athletes: Science and practice. *Journal of Athletic Training*, *31*(3), 248–252.

Nagahara, R., Mizutani, M., Matsuo, A., Kanehisa, H., & Fukunaga, T. (2018). Association of Sprint Performance With Ground Reaction Forces During Acceleration and Maximal Speed Phases in a Single Sprint. *Journal of Applied Biomechanics*, *34*(2), 104–110. https://doi.org/10.1123/jab.2016-0356

Narazaki, K., Berg, K., Stergiou, N., & Chen, B. (2009). Physiological demands of competitive basketball. *Scandinavian Journal of Medicine and Science in Sports*, *19*(3), 425–432. https://doi.org/10.1111/j.1600-0838.2008.00789.x

Nicol, C., Avela, J., & Komi, P. V. (2006). The stretch-shortening cycle. *Sports Medicine*, *36*(11), 977–999.

Nicolella, D. P., Torres-Ronda, L., Saylor, K. J., & Schelling, X. (2018). Validity and reliability of an accelerometer-based player tracking device. *PLoS ONE*, *13*(2). https://doi.org/10.1371/journal.pone.0191823

Noon, M., James, R., Clarke, N., Taylor, R., & Thake, C. (2018). Next Day Subjective and Objective Recovery Indices Following Acute Low and High Training Loads in Academy Rugby Union Players. *Sports*, *6*(2), 56. https://doi.org/10.3390/sports6020056

O'Connor, P. J., & Corrigan, D. L. (1987). Influence of short-term cycling on salivary cortisol levels. *Medicine and Science in Sports and Exercise*, *19*(3), 224–228.

Osterberg, K. L., Horswill, C. A., & Baker, L. B. (2009). Pregame urine specific gravity and fluid intake by National Basketball Association players during competition. *Journal of Athletic Training*, *44*(1), 53–57.

Page, R. M., Marrin, K., Brogden, C. M., & Greig, M. (2015). Biomechanical and Physiological Response to a Contemporary Soccer Match-Play Simulation. *Journal of Strength and Conditioning Research*, *29*(10), 2860–2866. https://doi.org/10.1519/JSC.0000000000000949

Pallarés, J. G., Martínez-Abellán, A., López-Gullón, J. M., Morán-Navarro, R., De la Cruz-Sánchez, E., & Mora-Rodríguez, R. (2016). Muscle contraction velocity, strength and power output changes following different degrees of hypohydration in competitive olympic combat sports. *Journal of the International Society of Sports Nutrition*, *13*, 10. https://doi.org/10.1186/s12970-016-0121-3

Papacosta, E., & Nassis, G. P. (2011). Saliva as a tool for monitoring steroid, peptide and immune markers in sport and exercise science. *Journal of Science and*

Medicine in Sport, *14*(5), 424–434. https://doi.org/10.1016/j.jsams.2011.03.004

Peterson, K. D., & Quiggle, G. T. (2017). Tensiomyographical responses to accelerometer loads in female collegiate basketball players. *Journal of Sports Sciences*, *35*(23), 2334–2341. https://doi.org/10.1080/02640414.2016.1266378

Pinto, J. C. B. D. L., Menezes, T. C. B., Fortes, L. D. S., & Mortatti, A. L. (2018). Monitoring stress, mood and recovery during successive basketball matches. *Journal of Physical Education and Sport*, *18*(2), 677–685. https://doi.org/10.7752/jpes.2018.02099

Pliauga, V., Kamandulis, S., Dargevičiute, G., Jaszczanin, J., Kliziene, I., Stanislovaitiene, J., & Stanislovaitis, A. (2015). The Effect of a Simulated Basketball Game on Players' Sprint and Jump Performance, Temperature and Muscle Damage. *Journal of Human Kinetics*, *46*(1), 167–175. https://doi.org/10.1515/hukin-2015-0045

Polgaze, T., Dawson, B., Hiscock, D., & Peeling, P. (2015). A comparative analysis of acceleromter and time motion data in elite mens hockey training and competition. *International Journal of Sports Physiology and Performance*, *2*, 1–44. https://doi.org/10.1123/ijspp.2014-0233

Rampinini, E., Bosio, A., Ferraresi, I., Petruolo, A., Morelli, A., & Sassi, A. (2011). Match-related fatigue in soccer players. *Medicine and Science in Sports and Exercise*, *43*(11), 2161–2170. https://doi.org/10.1249/MSS.0b013e31821e9c5c

Ransdell, L. B., Murray, T., Gao, Y., Jones, P., & Bycura, D. (2019). A 4-Year Profile of Game Demands in Elite Women's Division I College Basketball. *Journal of Strength and Conditioning Research*, *50*(18), 794–795.

https://doi.org/10.1519/JSC.0000000000003425

Reilly, T., Drust, B., & Clarke, N. (2008). Muscle fatigue during football match-play. *Sports Medicine (Auckland, N.Z.)*, *38*(5), 357–367. https://doi.org/10.2165/00007256-200838050-00001

Rhea, M. R. (2004). Determining the Magnitude of Treatment Effects in Strength Training Research Through the Use of the Effect Size. *The Journal of Strength and Conditioning Research*, *18*(4), 918. https://doi.org/10.1519/14403.1

Rice, P. E., Goodman, C. L., Capps, C. R., Triplett, N. T., Erickson, T. M., & McBride, J. M. (2017). Force- and power-time curve comparison during jumping between strength-matched male and female basketball players. *European Journal of Sport Science*, *17*(3), 286–293. https://doi.org/10.1080/17461391.2016.1236840

Richardson, J. T. E. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review*, *6*(2), 135–147. https://doi.org/10.1016/j.edurev.2010.12.001

Riggs, M. P., & Sheppard, J. M. (2009). The relative importance of strength and power qualities to vertical jump height of elite beach volleyball players during the counter-movement and squat jump. *Journal of Human Sport and Exercise*, *4*(3), 221–236. https://doi.org/10.4100/jhse.2009.43.04

Roell, M., Roecker, K., Gehring, D., Mahler, H., & Gollhofer, A. (2018). Player monitoring in indoor team sports: Concurrent validity of inertial measurement units to quantify average and peak acceleration values. *Frontiers in Physiology*, *9*(FEB), 1–13. https://doi.org/10.3389/fphys.2018.00141

Romagnoli, M., Sanchis-Gomar, F., Alis, R., Risso-Ballester, J., Bosio, A., Graziani, R.

L., & Rampinini, E. (2016). Changes in muscle damage, inflammation, and fatigue-related parameters in young elite soccer players after a match. *Journal of Sports Medicine and Physical Fitness*, *56*(10), 1198–1205.

Ronglan, L. T., Raastad, T., & Børgesen, A. (2006). Neuromuscular fatigue and recovery in elite female handball players. *Scandinavian Journal of Medicine and Science in Sports*, *16*(4), 267–273. https://doi.org/10.1111/j.1600-0838.2005.00474.x

Ross, E. Z., Middleton, N., Shave, R., George, K., & Nowicky, A. (2007). Corticomotor excitability contributes to neuromuscular fatigue following marathon running in man. *Experimental Physiology*, *92*(2), 417–426. https://doi.org/10.1113/expphysiol.2006.035972

Rowell, A. E., Aughey, R. J., Hopkins, W. G., Esmaeili, A., Lazarus, B. H., & Cormack, S. J. (2018). Effects of training and competition load on neuromuscular recovery, testosterone, cortisol, and match performance during a season of professional football. *Frontiers in Physiology*, *9*(JUN), 1–11. https://doi.org/10.3389/fphys.2018.00668

Rowell, A. E., Aughey, R. J., Hopkins, W. G., Stewart, A. M., & Cormack, S. J. (2017). Identification of Sensitive Measures of Recovery After External Load From Football Match Play. *International Journal of Sports Physiology and Performance*, *12*(7), 969–976.

Sannikka, E., Terho, P., Suominen, J., & Santti, R. (1983). Testosterone concentrations in human seminal plasma and saliva and its correlation with non-protein-bound and total testosterone levels in serum. *International Journal of Andrology*, *6*(4), 319–330.

Scanlan, A. T., Dascombe, B. J., Reaburn, P., & Dalbo, V. J. (2012). The physiological and activity demands experienced by Australian female basketball players during competition. *Journal of Science and Medicine in Sport*, *15*(4), 341–347. https://doi.org/10.1016/j.jsams.2011.12.008

Scanlan, A. T., Fox, J. L., Borges, N. R., Tucker, P. S., & Dalbo, V. J. (2015). Temporal changes in physiological and performance responses across game-specific simulated basketball activity. *Journal of Sport and Health Science*, *May*. https://doi.org/10.1016/j.jshs.2016.05.002

Scanlan, A. T., Wen, N., Tucker, P. S., & Dalbo, V. J. (2014). The relationship between internal and external training load models during basketball training. *Journal of Strength and Conditioning Research*, *28*(9), 2397–2405. https://doi.org/10.1080/02640414.2016.1266378

Schelling, X., Calleja-González, J., Torres-Ronda, L., & Terrados, N. (2015). Using testosterone and cortisol as biomarker for training individualization in elite basketball: a 4-year follow-up study. *Journal of Strength and Conditioning Research*, *29*(2), 368–378. https://doi.org/10.1519/JSC.0000000000000642

Schelling, X., & Torres-Ronda, L. (2013). Conditioning for basketball: Quality and quantity of training. *Strength & Conditioning Journal*, *35*(6), 89–94.

Schelling, X., & Torres, L. (2016). Accelerometer load profiles for basketball-specific drills in elite players. *Journal of Sports Science and Medicine*, *15*(4), 585–591. https://doi.org/10.1249/01.mss.0000487540.00343

Scott, M. T. U., Scott, T. J., & Kelly, V. G. (2016). The Validity and Reliability of

Global Positioning Systems in Team Sport: A Brief Review. *Journal of Strength and Conditioning Research*, *30*(5), 1470–1490. https://doi.org/10.1519/JSC.0000000000001221

Selye, H. (1946). The general adaptation syndrome and the diseases of adaptation. *The Journal of Allergy*, *17*(6), 231; 289; 358. https://doi.org/10.1108/eb037744

Selye, H. (1950). Stress and the general adaptation syndrome. *British Medical Journal*, *1*(4667), 1383–1392. https://doi.org/10.1159/000227975

Shield, A. J., & Zhou, S. (2004). Activation with the Twitch Interpolation Technique. *Sports Medicine*, *34*(4), 253–267.

Silva, J. R., Ascensão, A., Marques, F., Seabra, A., Rebelo, A., & Magalhães, J. (2013). Neuromuscular function, hormonal and redox status and muscle damage of professional soccer players after a high-level competitive match. *European Journal of Applied Physiology*, *113*(9), 2193–2201. https://doi.org/10.1007/s00421-013-2633-8

Smith, D. J. (2003). A Framework for Understanding the Training Process Leading to Elite Performance. *Sports Medicine*, *33*(15), 1103–1126. https://doi.org/10.2165/00007256-200333150-00003

Spangler, R., Rantalainen, T., Gastin, P. B., & Wundersitz, D. (2018). Inertial Sensors are a Valid Tool to Detect and Consistently Quantify Jumping. *International Journal of Sports Medicine*. https://doi.org/10.1055/s-0044-100793

Sparkes, W., Turner, A., Weston, M., Russell, M., Johnston, M., & Kilduff, L. (2018). Neuromuscular, Biochemical, Endocrine, and Mood Responses to Small-Sided Games' Training in Professional Soccer. *Journal of Strength and Conditioning*

Research, *32*(9), 2569–2576. https://doi.org/10.1519/JSC.0000000000002424

Spiteri, T., Nimphius, S., Wolski, A., & Bird, S. P. (2013). Monitoring Neuromuscular Fatigue in Female Basketball Players Across Training and Game Performance. *J Aust Strength Conditioning*, *21*, 73–74.

St. Clair Gibson, A., & Noakes, T. D. (2004). Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. *British Journal of Sports Medicine*, *38*(6), 797–806. https://doi.org/10.1136/bjsm.2003.009852

Staunton, C., Wundersitz, D., Gordon, B., & Kingsley, M. (2017). Construct Validity of Accelerometry-Derived Force to Quantify Basketball Movement Patterns. *International Journal of Sports Medicine*, *38*(14), 1090–1096. https://doi.org/10.1055/s-0043-119224

Stojanović, E., Stojiljković, N., Scanlan, A. T., Dalbo, V. J., Berkelmans, D. M., & Milanović, Z. (2018). The Activity Demands and Physiological Responses Encountered During Basketball Match-Play: A Systematic Review. *Sports Medicine*, *48*(1), 111–135. https://doi.org/10.1007/s40279-017-0794-z

Stone, J. D., Kreutzer, A., Mata, J. D., Nystrom, M. G., Jagim, A. R., Jones, M. T., & Oliver, J. M. (2017). Changes in Creatine Kinase and Hormones over the Course of an American Football Season. *Journal of Strength and Conditioning Research*, 1. https://doi.org/10.1519/JSC.0000000000001920

Stone, M. H., Keith, R. E., Kearney, J. T., Fleck, S. J., Wilson, G. D., & Triplett, N. T. (1991). Overtraining- A Review of the Signs, Symptoms and Possible Causes. *Journal of Applied Sports Science*, *5*(1), 35–50.

Strazdins, L., Meyerkort, S., Brent, V., D'Souza, R. M., Broom, D. H., & Kyd, J. M. (2005). Impact of saliva collection methods on sIgA and cortisol assays and acceptability to participants. *Journal of Immunological Methods*, *307*(1–2), 167–171. https://doi.org/10.1016/j.jim.2005.09.010

Strojnik, V., & Komi, P. V. (2000). Fatigue after submaximal intensive stretch-shortening cycle exercise. *Medicine and Science in Sports and Exercise*, *32*(7), 1314–1319.

Svilar, L., Castellano, J., & Jukic, I. (2018). Load Monitoring System in Top-Level Basketball Team: Relationship Between External and Internal Training Load. *Kinesiology, 501*, 25–33. https://doi.org/10.26582/k.50.1.4

Svilar, L., Castellano, J., Jukic, I., & Casamichana, D. (2018). Positional Differences in Elite Basketball: Selecting Appropriate Training-Load Measures. *International Journal of Sports Physiology and Performance*, *13*(7), 947–952. https://doi.org/10.1123/ijspp.2017-0534

Szczyglowski, M. K., Ade, C. J., Campbell, J. A., & Black, C. D. (2017). The effects of exercise-induced muscle damage on critical torque. *European Journal of Applied Physiology*, *117*(11), 2225–2236. https://doi.org/10.1007/s00421-017-3710-1

Tabata, I., Atomi, Y., & Miyashita, M. (1984). Blood glucose concentration dependent ACTH and cortisol responses to prolonged exercise. *Clinical Physiology*, *4,* 299–307. https://doi.org/10.1111/j.1475-097X.1984.tb00805.x

Taberner, M., Allen, T., & Cohen, D. D. (2019). Progressing rehabilitation after injury: consider the "control-chaos continuum". *British Journal of Sports Medicine*, *53*(18), 1132–1136. https://doi.org/10.1136/bjsports-2018-100157

Taylor, K.-L., Chapman, D. W., Cronin, J. B., Newton, M. J., & Gill, N. (2012). Fatigue Monitoring in High Performance Sport: A Survey of Current Trends. *J. Aust. Strength Cond*, *20*(1), 12–23.

Thigpen, L. K., Green, J. M., & O'Neal, E. K. (2014). Hydration profile and sweat loss perception of male and female Division II basketball players during practice. *Journal of Strength and Conditioning Research*, *28*(12), 3425–3431. https://doi.org/10.1519/JSC.0000000000000549

Thomas, K., Dent, J., Howatson, G., & Goodall, S. (2017). Etiology and Recovery of Neuromuscular Fatigue after Simulated Soccer Match Play. *Medicine and Science in Sports and Exercise*, *49*(5), 955–964. https://doi.org/10.1249/MSS.0000000000001196

Tremblay, M. S., Copeland, J. L., & Van Helder, W. (2005). Influence of exercise duration on post-exercise steroid hormone responses in trained males. *European Journal of Applied Physiology*, *94*(5–6), 505–513. https://doi.org/10.1007/s00421-005-1380-x

Twist, C., & Highton, J. (2013). Monitoring fatigue and recovery in rugby league players. *Int J Sports Physiol Perform*, *8*(5), 467–474.

Urhausen, A., Gabriel, H., & Kindermann, W. (1995). Blood hormones as markers of training stress and overtraining. *Sports Medicine (Auckland, N.Z.)*, *20*(4), 251–276.

Urhausen, A., & Kindermann, W. (2002). Diagnosis of overtraining: what tools do we have? *Sports Medicine (Auckland, N.Z.)*, *32*(2), 95–102.

Van Iterson, E. H., Fitzgerald, J. S., Dietz, C. C., Snyder, E. M., & Peterson, B. J. (2017). Reliability of Triaxial Accelerometry for Measuring Load in Men's

Collegiate Ice Hockey. *Journal of Strength and Conditioning Research*, *31*(5), 1305–1312. https://doi.org/10.1519/JSC.0000000000001611

Viru, A., & Viru, M. (2004). Cortisol - Essential adaptation hormone in exercise. *International Journal of Sports Medicine*, *25*(6), 461–464. https://doi.org/10.1055/s-2004-821068

Vittek, J., L'Hommedieu, D. G., Gordon, G. G., Rappaport, S. C., & Southren, A. L. (1985). Direct radioimmunoassay (RIA) of salivary testosterone: correlation with free and total serum testosterone. *Life Sciences*, *37*(8), 711–716.

Volpe, S. L., Poule, K. A., & Bland, E. G. (2009). Estimation of prepractice hydration status of National Collegiate Athletic Association Division I athletes. *Journal of Athletic Training*, *44*(6), 624–629. https://doi.org/10.4085/1062-6050-44.6.624

Wang, C., Plymate, S., Nieschlag, E., & Paulsen, C. A. (1981). Salivary testosterone in men: further evidence of a direct correlation with free serum testosterone. *The Journal of Clinical Endocrinology and Metabolism*, *53*(5), 1021–1024. https://doi.org/10.1210/jcem-53-5-1021

Ward, P. A., Ramsden, S., Coutts, A. J., Hulton, A. T., & Drust, B. (2018). Positional Differences in Running and Nonrunning Activities During Elite American Football Training. *Journal of Strength and Conditioning Research*, *32*(7), 2072–2084. https://doi.org/10.1519/JSC.0000000000002294

Watkins, C. M., Barillas, S. R., Wong, M. A., Archer, D. C., Dobbs, I. J., Lockie, R. G., Coburn, J. W., Tran, T. T., & Brown, L. E. (2017). Determination of vertical jump as a measure of neuromuscular readiness and fatigue. *Journal of Strength and Conditioning Research*, *31*(12), 3305–3310.

https://doi.org/10.1519/JSC.0000000000002231

West, D. J., Finn, C. V., Cunningham, D. J., Shearer, D. A., Jones, M. R., Harrington, B. J., Crewther, B. T., Cook, C. J., & Kilduff, L. P. (2014). Neuromuscular function, hormonal, and mood responses to a professional rugby union match. *Journal of Strength and Conditioning Research*, *28*(1), 194–200. https://doi.org/10.1519/JSC.0b013e318291b726

Weston, M., Siegler, J., Bahnert, A., McBrien, J., & Lovell, R. (2015). The application of differential ratings of perceived exertion to Australian Football League matches. *Journal of Science and Medicine in Sport*, *18*(6), 704–708. https://doi.org/10.1016/j.jsams.2014.09.001

Wilcoxson, M. C. S., Johnson, S. L., Pribyslavska, V., Green, J. M., & O'Neal, E. K. (2017). Fluid retention and utility of practical hydration markers to detect three levels of recovery fluid intake in male Runners. *International Journal of Sport Nutrition and Exercise Metabolism*, *27*(2), 178–185. https://doi.org/10.1123/ijsnem.2015-0362

Williams, S., Trewartha, G., Kemp, S. P. T., Brooks, J. H. M., Fuller, C. W., Taylor, A. E., Cross, M. J., & Stokes, K. A. (2016). Time loss injuries compromise team success in Elite Rugby Union: A 7-year prospective study. *British Journal of Sports Medicine*, *50*(11), 651–656. https://doi.org/10.1136/bjsports-2015-094798

Windt, J., Ekstrand, J., Khan, K. M., McCall, A., & Zumbo, B. D. (2018). Does player unavailability affect football teams' match physical outputs? A two-season study of the UEFA champions league. *Journal of Science and Medicine in Sport*, *21*(5), 525–532. https://doi.org/10.1016/j.jsams.2017.08.007

Yang, C. C., & Hsu, Y. L. (2010). A review of accelerometry-based wearable motion detectors for physical activity monitoring. *Sensors*, *10*(8), 7772–7788. https://doi.org/10.3390/s100807772

Yi, T. C., & Moochhala, S. (2013). Current opinion on salivary biomarkers as a measurement for stress and fatigue. *Open Biomarkers Journal*, *6*(1), 9–14.

Young, W. B., Pryor, J. F., & Wilson, G. J. (1995). Effects of Instructions on Charicteristics of Countermovement and Drop Jump Performance. *Journal of Strength and Conditioning Research*, *9*(4), 232–236. https://doi.org/10.1519/1533-4287(1995)009<0232

Ziv, G., & Lidor, R. (2010). Vertical jump in female and male basketball players-A review of observational and experimental studies. *Journal of Science and Medicine in Sport*, *13*(3), 332–339. https://doi.org/10.1016/j.jsams.2009.02.009

APPENDICES

Appendix A: IRB Approval Letter

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Approval of Initial Submission – Expedited Review – AP01

Date: May 21, 2019 **IRB#:** 10752

Principal Investigator: Michael G Bemben, PhD

Approval Date: 05/20/2019

Status Report Due: 04/30/2020

Study Title: Acute Neuromuscular and Endocrine Responses Following High and Low External Training Loads in Collegiate Basketball Players

Expedited Category: 4

Collection/Use of PHI: No

On behalf of the Institutional Review Board (IRB), I have reviewed and granted expedited approval of the above-referenced research study. To view the documents approved for this submission, open this study from the *My Studies* option, go to *Submission History*, go to *Completed Submissions* tab and then click the *Details* icon.

Requirements under the Common Rule have changed. The above-referenced research meets one or more of the circumstances for which continuing review is not required. However, as Principal Investigator of this research, you will be required to submit an annual status report to the IRB.

As principal investigator of this research study, you are responsible to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorization using the currently approved, stamped forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
- Maintain accurate and complete study records for evaluation by the HRPP Quality Improvement Program and, if applicable, inspection by regulatory agencies and/or the study sponsor.
- **Submit an annual status report to the IRB to provide the study/recruitment status and report all harms and deviations that may have occurred.**
- **Submit a final closure report at the completion of the project.**

If you have questions about this notification or using iRIS, contact the IRB @ 405-325-8110 or irb@ou.edu.

Cordially,

Lara Mayeux, Ph.D.
Chair, Institutional Review Board

Appendix B: Informed Consent

701-A-1

CONSENT FORM
University of Oklahoma – Norman Campus

Acute Neuromuscular and Endocrine Responses following High and Low External Training Loads in Collegiate Basketball Players

Principal Investigator: Michael Bemben, PhD.
University of Oklahoma
405-325-2717

This is a research study. Research studies involve only individuals who choose to participate. Please take your time to make your decision. Discuss this with your family and friends.

Would you like to be involved in research at the University of Oklahoma?

I am Michael Bemben, PhD, from the Department of Health and Exercise Science and I invite you to participate in my research project entitled Acute Neuromuscular and Endocrine Responses following High and Low External Training Loads in Collegiate Basketball Players. This research is being conducted at The Lloyd Noble Center and Griffin Family Performance Center. You were selected as a possible participant because of your engagement in the varsity basketball program at the University of Oklahoma. You must be at least 18 years of age to participate in this study.

What is the purpose of this research? The purpose of this research is to examine time course of fatigue and recovery following different training loads during basketball practice.

How many participants will be in this research? About 40 collegiate basketball players, including 20 male collegiate basketball players and 20 female collegiate basketball players, between the ages of 18 and 26 will take part in this research.

What will I be asked to do? If you agree to participate in this research, you will partake in a total of 12 visits, divided into 2 parts, with *Part 1* consisting of 9 visits and *Part 2* consisting of 3 visits. Part 1 and Part 2 can be completed in any order as long as the order of subsequent visits in each part remains the same.

In ***Part 1***; Visit 1 will consist of a study protocol and testing familiarization, consent, privacy forms, and questionnaires including: Sport Health Status Questionnaire, Physical Activity Readiness Questionnaire (PAR-Q), and Menstrual History Questionnaire (women only) (approximately 60 minutes).

Part 1; Visit 2 will take place on a day of regularly scheduled team basketball practice and will include the following activities (approximately 150 minutes):

- *Pre-practice assessments:* Prior to the start of practice, you will provide a salivary sample, a urine sample for hydration assessment, and fill out a recovery questionnaire. Following a standardized warm-up, you will then perform 3 countermovement jumps on dual-cell force platform to assess neuromuscular performance.
- *During Practice:* You will participate in your regularly scheduled basketball practice of either high or low external load intensity, where you will be wearing your external training load monitor and heart rate monitor, throughout the duration of practice as you normally

would. This information will be utilized to characterize the movement quantity and intensity performed during practice.

- *Post-practice Assessments:* Following the conclusion of the regularly scheduled practice, you will perform 3 more countermovement jumps on the dual-cell force platform, followed by filling out the recovery questionnaire, provide your Rating of Perceived Exertion (RPE) of the practice intensity, and finally provide a salivary sample.

Part 1; Visit 3 will take place 24-hours following the conclusion of the sport-specific basketball practice (approximately 45 minutes). You will provide a salivary sample, fill out the recovery questionnaire, and perform 3 countermovement jumps following a standardized warmup.

Part 1; Visit 4 will take place 48-hours following the conclusion of the sport-specific basketball practice (approximately 45 minutes). You will provide a salivary sample, fill out the recovery questionnaire, and perform 3 countermovement jumps following a standardized warmup.

Part 1; Visit 5 will take place 72-hours following the conclusion of the sport-specific basketball practice (approximately 45 minutes). You will provide a salivary sample, fill out the recovery questionnaire, and perform 3 countermovement jumps following a standardized warmup.

Following at least one week, you will return for *Part 1; Visit 6*. This visit will take place on another day of regularly scheduled team basketball practice and will include the same activities as *Part 1; Visit 2* as follows (approximately 150 minutes):

- *Pre-practice assessments:* Prior to the start of practice, you will provide a salivary sample, a urine sample for hydration assessment, and fill out a recovery questionnaire. Following a standardized warm-up, you will then perform 3 countermovement jumps on dual-cell force platform to assess neuromuscular performance.

- *During Practice:* You will participate in your regularly scheduled basketball practice of either high or low external load intensity, where you will be wearing your external training load monitor and heart rate monitor, throughout the duration of practice as you normally would. This information will be utilized to characterize the movement quantity and intensity performed during practice.

- *Post-practice Assessments:* Following the conclusion of the regularly scheduled practice, you will perform 3 more countermovement jumps on the dual-cell force platform, followed by filling out the recovery questionnaire, provide your Rating of Perceived Exertion (RPE) of the practice intensity, and finally provide a salivary sample.

Part 1; Visit 7 will take place 24-hours following the conclusion of the sport-specific basketball practice, in the same manner as *Part 1; Visit 3* (approximately 45 minutes). You will provide a salivary sample, fill out the recovery questionnaire, and perform 3 countermovement jumps following a standardized warmup.

Part 1; Visit 8 will take place 48-hours following the conclusion of the sport-specific basketball practice, in the same manner as *Part 1; Visit 4* (approximately 45 minutes). You will provide a salivary sample, fill out the recovery questionnaire, and perform 3 countermovement jumps following a standardized warmup.

unforeseeable risks with participation. You should discuss these with the researcher prior to providing your consent.

Your participation in the present study may yield direct benefits to you, as the findings of the present study could provide information that will allow the Oklahoma Basketball Performance Staff to better guide and direct your training.

What do I do if I am injured? If you are injured during your participation, report this to a researcher immediately. Emergency medical treatment is available. However, you or your insurance company will be expected to pay the usual charge from this treatment. The University of Oklahoma Norman Campus has set aside no funds to compensate you in the event of injury.

Will I be compensated for participating? You will not be reimbursed for your time and participation in this research.

Who will see my information? In research reports, there will be no information that will make it possible to identify you. Research records will be stored securely and only approved researchers and the OU Institution Review Board will have access to the records. In addition, the faculty members and graduate students appointed to this protocol from the Department of Health & Exercise Science at the University of Oklahoma will have access to the research records.

You have the right to access the research data that has been collected about you as a part of this research. However, you may not have access to this information until the entire research has completely finished and you consent to this temporary restriction.

Do I have to participate? No. If you do not participate, you will not be penalized or lose benefits or services unrelated to the research. If you decide to participate, you don't have to answer any question and can stop participating at any time.

Will my identity be anonymous or confidential? Your name will not be retained or linked with your responses. The data you provide will be retained in anonymous form unless you specifically agree for data retention or retention of contact information at the end of the research.

What will happen to my data in the future? After removing all identifiers, we might share your data with other researchers or use it in future research without obtaining additional consent from you.

I agree for the researcher to use my data in future studies. ___Yes ___ No

Who do I contact with questions, concerns or complaints? If you have questions, concerns or complaints about the research or have experienced a research-related injury, contact Dr. Michael Bemben at 405-325-5211 or 306-3619 (cell) or mgbemben@ou.edu, 24 hours per day.

You can also contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu if you have questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than the researcher(s) or if you cannot reach the researcher(s).

You will be given a copy of this document for your records. By providing information to the researcher(s), I am agreeing to participate in this research.

Participant Signature	Print Name	Date
Signature of Researcher Obtaining Consent	Print Name	Date

Appendix C: HIPPA

University of Oklahoma Health Sciences CenterResearch Privacy Form 1
PHI Research Authorization

AUTHORIZATION TO USE or SHARE
HEALTH INFORMATION[1] THAT IDENTIFIES YOU FOR RESEARCH
An Informed Consent Document for Research Participation may also be required.
Form 2 must be used for research involving psychotherapy notes.

Title of Research Project: **Acute Neuromuscular and Endocrine Responses Following High and Low External Training Loads in Collegiate Basketball Players**

Leader of Research Team: **Michael G. Bemben, PhD**

Address: **1401 Asp Avenue, Norman, OK, 73019**

Phone Number: **405-325-2717**

If you decide to sign this document, University of Oklahoma Health Sciences Center (OUHSC) researchers may use or share information that identifies you (protected health information) for their research. Protected health information will be called PHI in this document.

PHI To Be Used or Shared. Federal law requires that researchers get your permission (authorization) to use or share your PHI. If you give permission, the researchers may use or share with the people identified in this Authorization any PHI related to this research from your medical records and from any test results. Information used or shared may include all information relating to any tests, procedures, surveys, or interviews as outlined in the consent form; medical records and charts; name, address, telephone number, date of birth, race, government-issued identification numbers, and weight, height, salviary cortisol and testosterone results, and answer to questionnaires.

Purposes for Using or Sharing PHI. If you give permission, the researchers may use your PHI to evaluate the acute neuromuscular and endocrine responses to high and low external training loads in collegiate basketball players.

Other Use and Sharing of PHI. If you give permission, the researchers may also use your PHI to develop new procedures or commercial products. They may share your PHI with other researchers, the research sponsor and its agents, the OUHSC Institutional Review Board, auditors and inspectors who check the research, and government agencies such as the Food and Drug Administration (FDA) and the Department of Health and Human Services (HHS), and when required by law. The researchers may also share your PHI with no one else.

[1] Protected Health Information includes all identifiable information relating to any aspect of an individual's health whether past, present or future, created or maintained by a Covered Entity.

IRB Office Use Only
Version 01/06/2016

IRB NUMBER: 10752
IRB APPROVAL DATE: 05/20/2019

Confidentiality. Although the researchers may report their findings in scientific journals or meetings, they will not identify you in their reports. The researchers will try to keep your information confidential, but confidentiality is not guaranteed. The law does not require everyone receiving the information covered by this document to keep it confidential, so they could release it to others, and federal law may no longer protect it.

YOU UNDERSTAND THAT YOUR PROTECTED HEALTH INFORMATION MAY INCLUDE INFORMATION REGARDING A COMMUNICABLE OR NONCOMMUNICABLE DISEASE.

Voluntary Choice. The choice to give OUHSC researchers permission to use or share your PHI for their research is voluntary. It is completely up to you. No one can force you to give permission. However, you must give permission for OUHSC researchers to use or share your PHI if you want to participate in the research and, if you cancel your authorization, you can no longer participate in this study.

Refusing to give permission will not affect your ability to get routine treatment or health care unrelated to this study from OUHSC.

Canceling Permission. If you give the OUHSC researchers permission to use or share your PHI, you have a right to cancel your permission whenever you want. However, canceling your permission will not apply to information that the researchers have already used, relied on, or shared or to information necessary to maintain the reliability or integrity of this research.

End of Permission. Unless you cancel it, permission for OUHSC researchers to use or share your PHI for their research will never end.

Contacting OUHSC: You may find out if your PHI has been shared, get a copy of your PHI, or cancel your permission at any time by writing to:

Privacy Official
University of Oklahoma Health Sciences Center
PO Box 26901
Oklahoma City, OK 73190

or

Privacy Board
University of Oklahoma Health Sciences Center
PO Box 26901
Oklahoma City, OK 73190

If you have questions, call: (405) 271-2511 or (405) 271-2045.

Access to Information. You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study is completely finished. You consent to this temporary restriction.

Giving Permission. By signing this form, you give OUHSC and OUHSC's researchers led by the Research Team Leader permission to share your PHI for the research project listed at the top of this form.

University of Oklahoma Health Sciences CenterResearch Privacy Form 1
PHI Research Authorization

Patient/Participant Name (Print): ______________________________

____ _______________
Signature of Patient-Participant Date
or Parent if Participant is a minor

Or

____ _______________
Signature of Legal Representative** Date

**If signed by a Legal Representative of the Patient-Participant, provide a description of the relationship to the Patient-Participant and the authority to act as Legal Representative:

____
OUHSC may ask you to produce evidence of your relationship.

A signed copy of this form must be given to the Patient-Participant or the Legal Representative at the time this signed form is provided to the researcher or his representative.

Appendix D: Physical Activity Readiness Questionnaire (PAR-Q)

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ________________________________

SIGNATURE ________________________________ DATE ________________________________

SIGNATURE OF PARENT ________________________________ WITNESS ________________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

continued on other side...

Appendix E: Sport Specific Health Questionnaire

Neuromuscular Research Laboratory
OU Department of Health and Exercise Science
Sport Specific Health Status Questionnaire

Instructions Complete each question accurately. All information provided is confidential.

PART 1. INFORMATION ABOUT INDIVIDUAL

1. ____
Date

2. ____
Legal name Preferred Name

3. ____
Mailing address

4. ____
Home Phone Cell Phone

5. Sex (circle one): Female Male

6. Year of birth: ______________________ Age ________

7. What is your dominant foot? (What foot would you kick a soccer ball with?)

Right Foot Left Foot

PART 2. MEDICAL HISTORY

7. Date of last medical physical exam: ________________
Year

8. Date of last physical fitness test: ________________
Year

9. Circle operations you have had:

Back	Heart	Kidney	Eyes	Joint	Neck
Ears	Hernia	Lung	Other________________		

NONE

10. Circle all medicine taken in last 6 months:
Asthma (list type) ________________
High-blood-pressure medication (list type) ________________

Blood thinner	Epilepsy medication	Thyroid
Corticosteroids	Estrogen	Other ________________
Depression	Heart-rhythm medication	
Diabetic pill	Insulin	**NONE**
Digitalis	Nitroglycerin	
Diuretic		

11. Any of these health symptoms that occurs frequently is the basis for medical attention.

Circle the number indicating how often you have each of the following:

1 = Practically never 2 = Infrequently 3 = Sometimes 4 = Fairly often 5 = Very often

a. Cough up blood
1 2 3 4 5
b. Abdominal pain
1 2 3 4 5
c. Low back pain
1 2 3 4 5
d. Leg pain
1 2 3 4 5
e. Arm or shoulder pain
1 2 3 4 5
f. Chest pain
1 2 3 4 5
g. Swollen joints
1 2 3 4 5
h. Feel faint
1 2 3 4 5
I. Dizziness (MC)
1 2 3 4 5
j. Breathless with slight exertion
1 2 3 4 5

PART 3. INJURY HISTORY

Please fill-out the chart indicating previous injury history.

Past Injury	Year	L or R	Diagnosis if Known	Other Comments/Description
Hand				
Wrist				
Forearm				
Elbow				
Upper Arm				
Shoulder				
Collarbone				
Neck				
Ribs/Chest				
Back Upper/Lower				
Hip				
Thigh				
Knee				
Ankle				

Foot				

PART 4. SPORT-RELATED ACTVIITY

12. How many hours on average per week do you participate in basketball activity when a coach is present?

    a. Strength Training _____ hours

    b. Conditioning _____ hours

    c. Team Basketball Practice _____ hours

13. How many hours do you participate in individual training on your own when a coach is **NOT** present?

    ___________ hours

Appendix F: Menstrual History Questionnaire

Subject ID: _____________ Date: __________________

Neuromuscular Research Laboratory
Department of Health and Exercise Science
University of Oklahoma

MENSTRUAL HISTORY QUESTIONNAIRE

We are asking you to give us as complete a menstrual history as possible. All information is strictly confidential.

Are you pregnant? (circle your response)

YES- Do not complete the rest of this form

NO- Continue to section A.

SECTION A: CURRENT MENSTRUAL STATUS

1. Approximately how many menstrual periods have you had during the past 12 months?
   (please circle what months you have had a period. This means from this time last year to the present month)

   Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

2. What is the usual length of your menstrual cycle (first day of your period to the next onset of your period)?

   ___________days. Today is day __________ of your present menstrual cycle.

3. What was the date of the onset of your last period?

4. When do you expect you next period?

5. What is the average length (number of days) of your menstrual flow? ______________ days

   How many of these days do you consider "heavy"? ________________days

6. Do you experience cramps during menstruation (dysmenorrheal)? If yes, how many days does this last?

7. Do you experience symptoms of premenstrual syndrome (i.e., weight gain, increased eating, depression, headaches, anxiety, breast tenderness)? If yes, please list the symptoms.

IRB NUMBER: 10752
IRB APPROVAL DATE: 05/20/2019

8. Do you take oral contraceptives or any other medication that includes estrogen and/or progesterone?

    If yes, how long have you been taking this medication? ________________________

    What is the brand name and dosage of this mediation? ________________________

Has this medication affected your menstrual cycle (regularity, length and amount of flow)? If yes, indicate changes.

9. Have you taken oral contraceptives in the past? If no, skip to SECTION B.

    If yes, what was the brand name and dosage? _____________________

    When did you start taking the pill; for how long; and when did you stop taking it?

10. If you answered yes to 9 or 10, did you experience a weight gain and/or a change in appetite as a result of oral contraceptive use? If so, please indicate amount of weight gained. ___________lbs

SECTION B: PAST MENSTRUAL HISTORY

1. At what age did you experience your first menstrual period?

2. Were your periods regular (occurring monthly) during the first two years after menstruation began? If not, at what age did your period become regular?

3. Has there been any time in the past where your periods were irregular or absent? If no, skip to question 4. If yes, did these periods coincide with unusual bouts of training, or with a period of stress?

4. If you have had an irregular period due to training please describe (i.e., you have a period in the offseason but only irregular menstruation during preseason and season)?

5. Have you ever consulted a doctor about menstrual problems (specifically, about irregular or missing periods)? If no, skip to question 6.

    Have you ever been diagnosed as having a shortened luteal phase (the time in between periods)?

6. Have you ever consulted a doctor about any problems relating to your hormonal system? If so, please explain.

Appendix G: Recovery Questionnaire

Participant ID: ______________ Date ____________

Recovery Questionnaire

Study Part: *Part 1 or Part 2*

Time Point: *Pre- 24-Hours Post 48-Hours Post 72- Hours Post*

1. How many hours of sleep did you get last night? __________ hours
2. How many hours did you participate in basketball or training outside of mandatory team activity (Playing, shooting, conditioning, etc.)? ___________ hours
3. In reference to Question 2: How strenuous was that exercise (1-10) _____________

	5	4	3	2	1	Record Score
Sleep Quality	Very restful	Good	Difficulty Falling Asleep	Restless Sleep	Insomnia	
Fatigue	Very Fresh	Fresh	Normal	More tired than normal	Always tired	
General Muscle Soreness	Feeling great	Feeling good	Norman	Increase in soreness/tightness	Very sore	
Stress Levels	Very Relaxed	Relaxed	Normal	Feeling Stressed	Highly Stressed	
Mood	Very positive mood	Generally good mood	Less interested in others&/or activities than usual	Snappiness at teammates, family, and co-workers	Highly annoyed/irritable/down	

Appendix H: Oklahoma Men's Basketball Letter of Support

THE UNIVERSITY OF
OKLAHOMA

Lloyd Noble Center
2900 South Jenkins, Room P240
Norman, OK 73019

Phone: 405.325.4732
Fax: 405.325.7562

SoonerSports.com

FINAL FOUR
1939, 1947, 1988, 2002

ELITE EIGHT
1985, 2003, 2009

SWEET 16
1979, 1987, 1989, 1999, 2015

BIG 12 CHAMPION
2005

BIG 12 TOURNEY CHAMPION
2001, 2002, 2003

BIG EIGHT CHAMPION
1979, 1984, 1985, 1988, 1989

BIG EIGHT TOURNEY CHAMPION
1979, 1985, 1988, 1990

BIG SEVEN CHAMPION
1949

BIG SIX CHAMPION
1929, 1939, 1940, 1942, 1944, 1947

MISSOURI VALLEY CHAMPION
1928

31
ALL-AMERICANS

75
FIRST-TEAM ALL-CONFERENCE HONOREES

30
POSTSEASON TRIPS IN LAST 34 YEARS

OKLAHOMA
MEN'S BASKETBALL

Institutional Support Letter

To the University of Oklahoma Institutional Review Board:

I am familiar and fully supportive of Dr. Mike Bemben's research project entitled "*Acute Neuromuscular and Endocrine Responses following High and Low External Training Loads in Collegiate Basketball Players.*" I understand the involvement of Dr. Bemben and his research team's to be recruiting potential participants from our team, as well as using the Griffin Family Performance Center and Lloyd Noble Center Basketball Facilities to execute the testing protocol.

I understand that this research will be carried out following sound ethical principles and that participant involved in this research study is strictly voluntary and provides confidentiality of research data, as described in the research protocol.

Therefore, as a representative of the University of Oklahoma Men's Basketball Program, I agree that Dr. Mike Bemben's research project may be conducted at our program/facilities.

Sincerely,

Mike Shepherd
Men's Basketball Director of Operation
University of Oklahoma

INSPIRING CHAMPIONS TODAY...PREPARING LEADERS FOR TOMORROW

IRB NUMBER: 10752
IRB APPROVAL DATE: 05/20/2019

Appendix I: Oklahoma Women's Basketball Letter of Support

OKLAHOMA
WOMEN'S BASKETBALL

3
FINAL FOURS

9
SWEET 16 APPEARANCES

19
CONSECUTIVE NCAA TOURNAMENT APPEARANCES

8
ASSOCIATED PRESS ALL-AMERICANS

1
ASSOCIATED PRESS PLAYER OF THE YEAR

10
BIG 12 CHAMPIONSHIPS

6
BIG 12 PLAYER OF THE YEAR

7
BIG 12 FRESHMAN OF THE YEAR

Institutional Support Letter

To the University of Oklahoma Institutional Review Board:

I am familiar and fully supportive of Dr. Mike Bemben's research project entitled "*Acute Neuromuscular and Endocrine Responses following High and Low External Training Loads in Collegiate Basketball Players.*" I understand the involvement of Dr. Bemben and his research team's to be recruiting potential participants from our team, as well as using the Griffin Family Performance Center and Lloyd Noble Center Basketball Facilities to execute the testing protocol.

I understand that this research will be carried out following sound ethical principles and that participant involved in this research study is strictly voluntary and provides confidentiality of research data, as described in the research protocol.

Therefore, as a representative of the University of Oklahoma Women's Basketball Program, I agree that Dr. Mike Bemben's research project may be conducted at our program/facilities.

Sincerely,

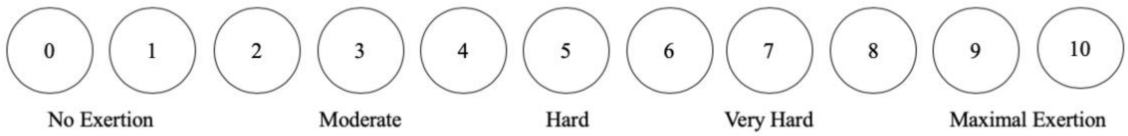
Sherri Coale
Head Women's Basketball Coach
University of Oklahoma

THE UNIVERSITY OF OKLAHOMA | LLOYD NOBLE CENTER
2900 S. JENKINS | NORMAN, OK 73019
SOONERSPORTS.COM | @OU_WBBALL

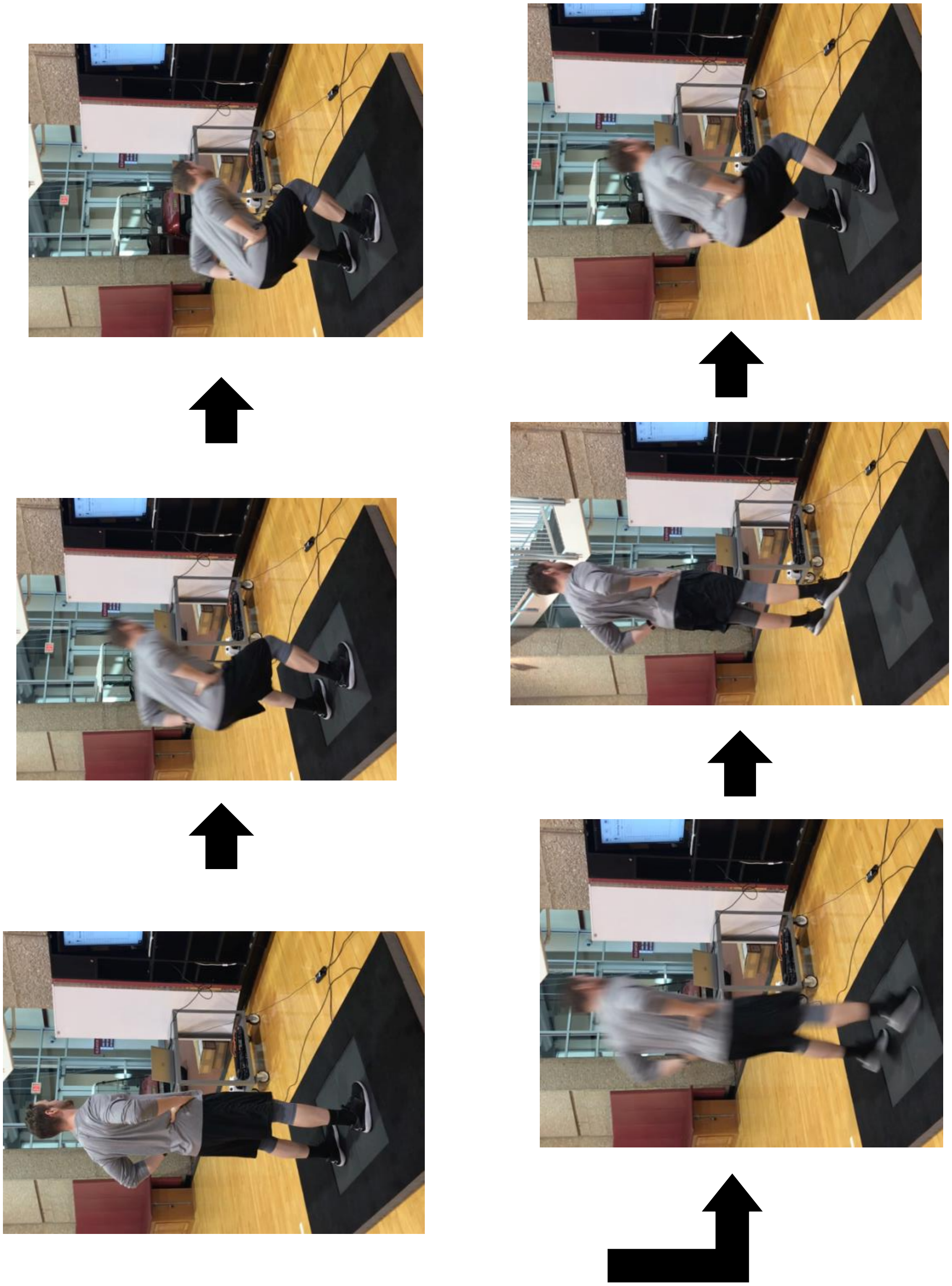
IRB NUMBER: 10752
IRB APPROVAL DATE: 05/20/2019

Appendix J: Rating of Perceived Exertion Chart

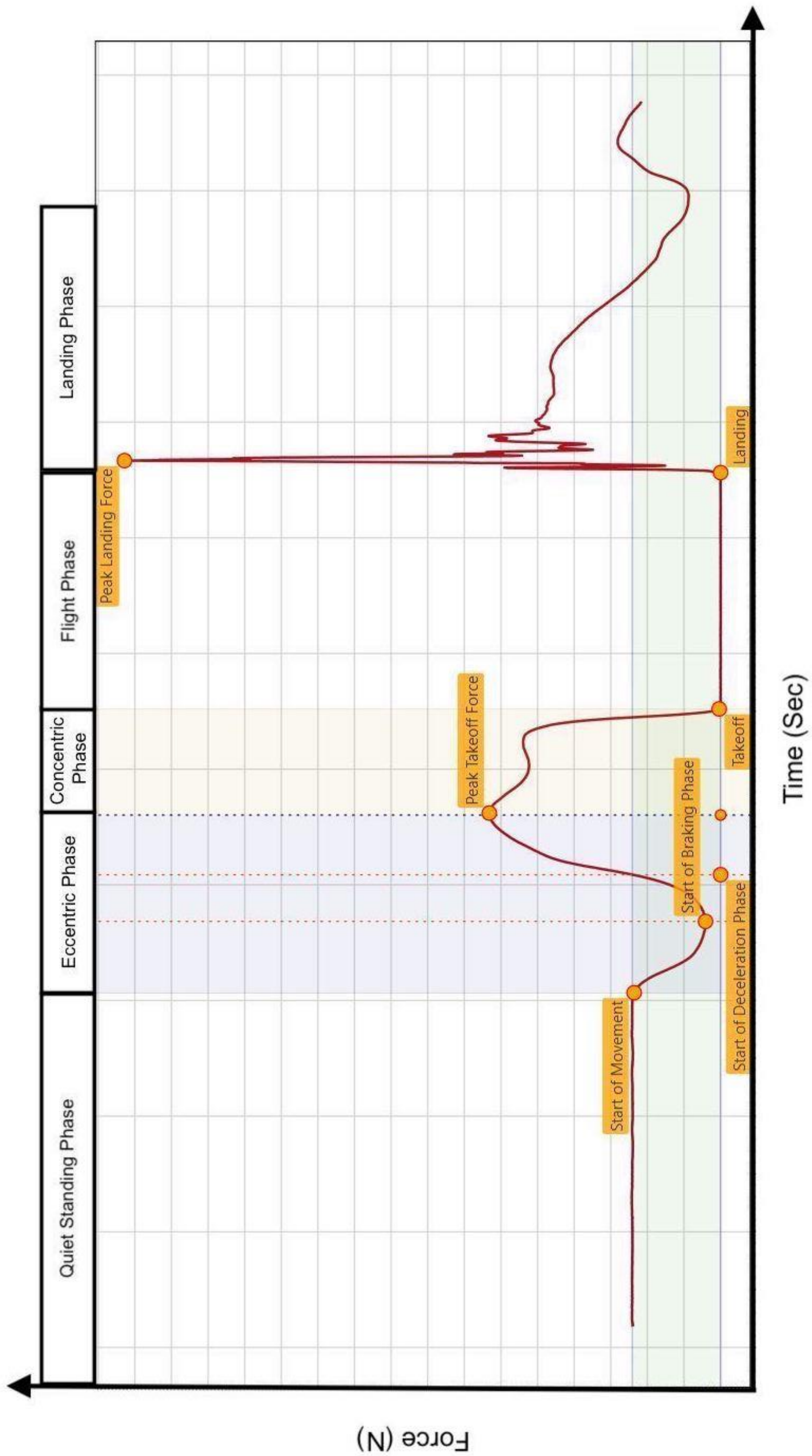
"How hard do you think practice was today?"



Appendix K: Countermovement Jump Testing Procedure

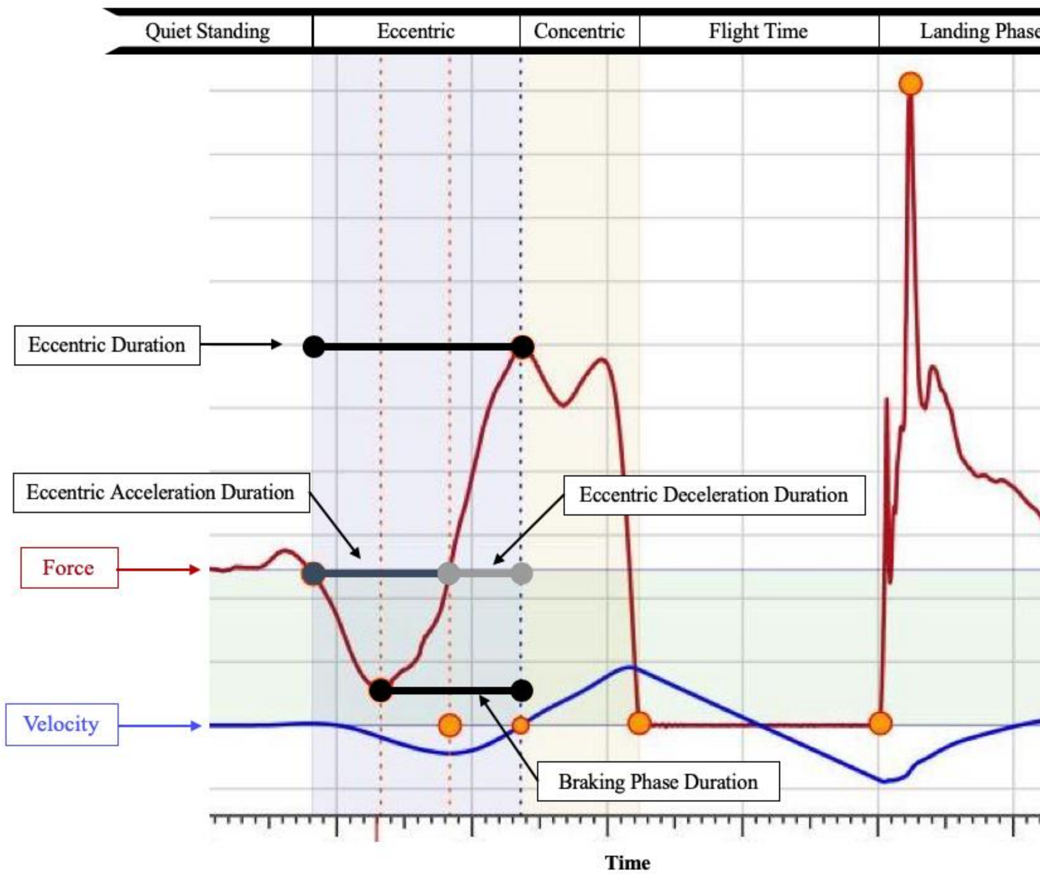


Appendix L: Countermovement Jump Force-Time Signature



The Countermovement Force-Time signature depicting the Quiet Standing Phase, the Eccentric Phase, the Concentric Phase, Flight Phase, and the Landing Phase.

Appendix M: Countermovement Eccentric Phase and Braking Phase Duration



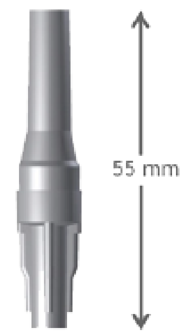
Appendix N: Salivary Collection

CS-5016.02 | Rev. 5, 05Mar18

Collection Methods: Passive Drool using the Saliva Collection Aid

Introduction: Whole saliva collected by passive drool is the gold standard when collecting oral fluid for biological testing. It avoids localized secretions of specific salivary glands providing a more consistent specimen. Whole saliva can be easily evaluated for volume collected and for salivary flow rate. Free from being compromised by absorbing materials used with other collection methods, whole saliva can be assayed for all analytes of interest.

The Saliva Collection Aid (SCA) is an ideal collection tool for collecting whole saliva (passive drool). Its ease of use reduces participant burden and improves compliance for collecting whole saliva.



Patent No. US9498191B

The Saliva Collection Aid offers the following benefits:

- ✓ Simple and easy to use, single use
- ✓ Individually packaged in a clean, foil pouch *(non-sterile)*
- ✓ Ready-to-go instructions
- ✓ Comfortable, no-mess collection
- ✓ Universal fit with external threaded cryovials
- ✓ Vented design reduces sample foaming
- ✓ Collection directly into cryovials, reducing freezer storage space
- ✓ Use for participants 6 years of age and older*
- ✓ Constructed of polypropylene
- ✓ Eliminates time and material needed to transfer specimen to storage vials in the lab

*NOTE: Sample collection with passive drool is designed for saliva donors who can follow simple instructions. For children younger than approximately 4 years of age, there may be wide ranging individual differences in their capability of collecting whole saliva. Thus, we encourage pilot study.

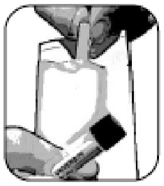
Passive Drool Cautions:

1. Use only as directed; Use each Saliva Collection Aid only once.
2. Do not use this device for children under the age of three (3), or without adult supervision
3. Do not disassemble or pull apart device; discard if disassembled.

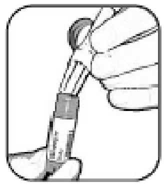
Materials Needed:

- Cryovials (Salimetrics Item No. 5004.01-06)
- Saliva Collection Aid (Item No. 5016.02)
- Bar-coded labels (Item No. 5009.07)
- 2" swab storage tubes boxes (Item No. 5023.05)

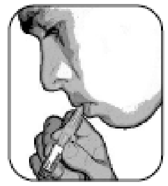
Instructions for Use:



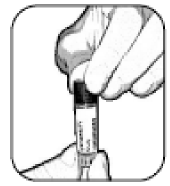
Step 1:
Open foil pouch and remove the Saliva Collection Aid (SCA).



Step 2:
Place ribbed-end of the SCA securely into a pre-labeled collection vial *(see Caution 3 above)*.



Step 3:
Allow saliva to pool in mouth. Then, with head tilted forward, gently guide saliva through the SCA into the vial. Fill to the required volume.*



Step 4:
Remove and discard SCA. Attach cap to collection vial and tighten.

*NOTE: Reserve a small amount of air space in the vial to accommodate liquid expansion during freezing.

Sample Handling and Processing *(As described in the Saliva Collection Handbook)*:

- Immediately after collection, freeze samples at or below -20°C. If freezing is not possible, refrigerate immediately at 4°C and maintain at this temperature for no longer than necessary (ideally less than 2 hours) before freezing at or below -20°C (temperature of a regular household freezer).
- Samples stored for more than 4 months should be frozen at -80°C.
- Freeze-thaw cycles should be minimized for some analytes. It is critical that storage conditions are researched prior to initiation of sample collection.
- It is recommended that tubes be organized into cryostorage boxes (9x9 grids, 81 tubes) before storing or shipping.

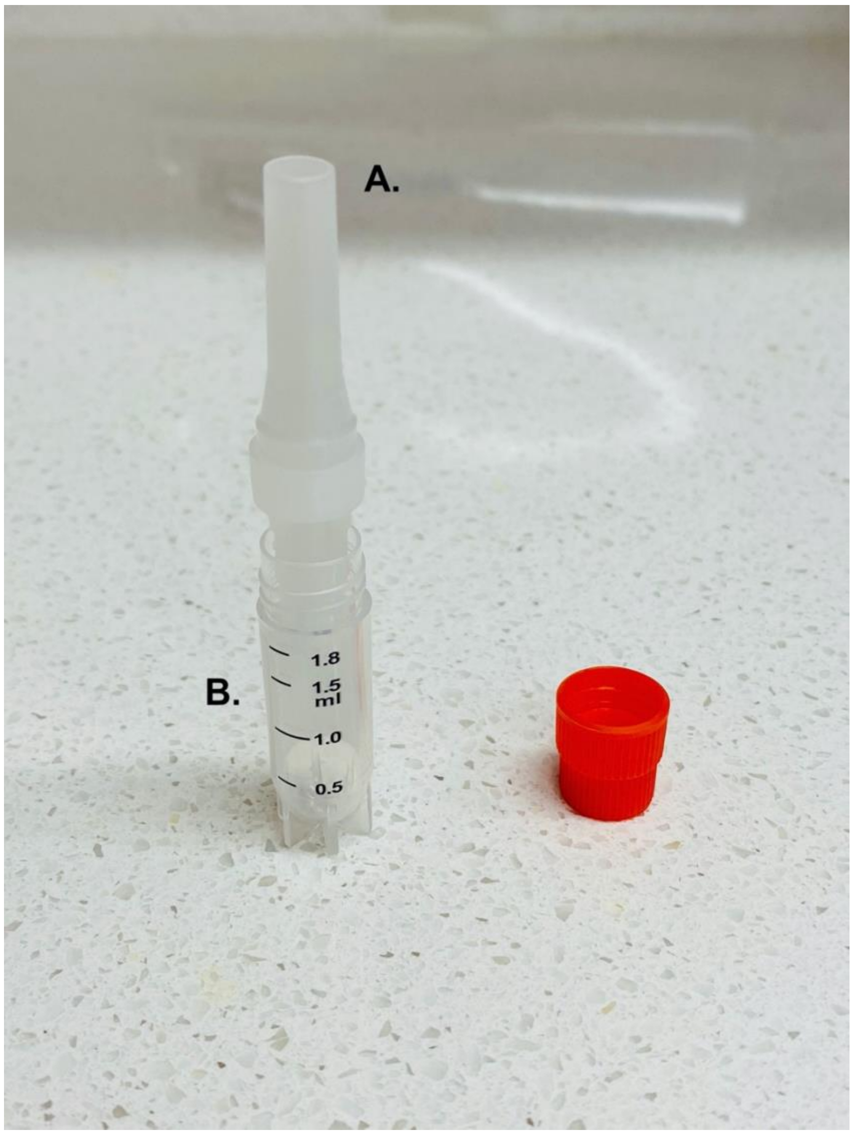
How to Reference this SalivaBio Device in Your Research (Recommended)

"Whole saliva samples were collected with SalivaBio's 2 mL cryovials and the Saliva Collection Aid (exclusively from Salimetrics, State College, PA), a collection device specifically designed to improve volume collection and increase participant compliance, and validated for use with salivary [Analytes]."

References are available online at; http://salimetrics.com/collection-system/passive-drool

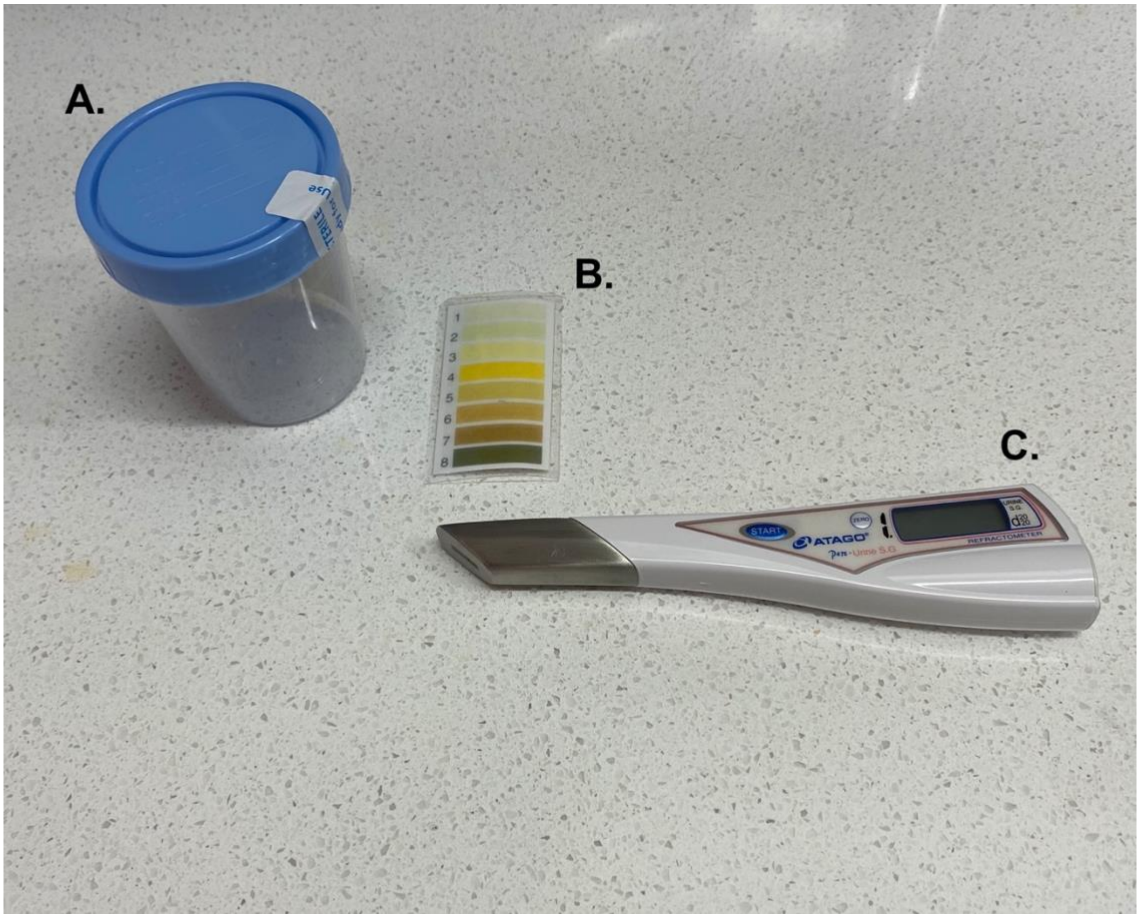
Developed in collaboration with the **Center for Interdisciplinary Salivary Bioscience Research** at the **Johns Hopkins University School of Nursing**

SALIMETRICS® | SalivaBio Exclusively from Salimetrics



Note: Passive salivary drool collection tools; A. = Saliva Collection Aid (Salimetrics, State College, PA); B. = SalivaBio's 2 mL Cryovials.

Appendix O: Hydration Assessment Tools



Note: Hydration Status Assessment tools, including: A. = Hydration sample collection cup; B. = Urine Color Chart, scaled 1-8 (McDermott et al., 2017); C. = Pen-refractometer used to measure Urine Specific Gravity (Heishman, Daub, et al., 2018).

Appendix P: Interpolated Twitch Assessment